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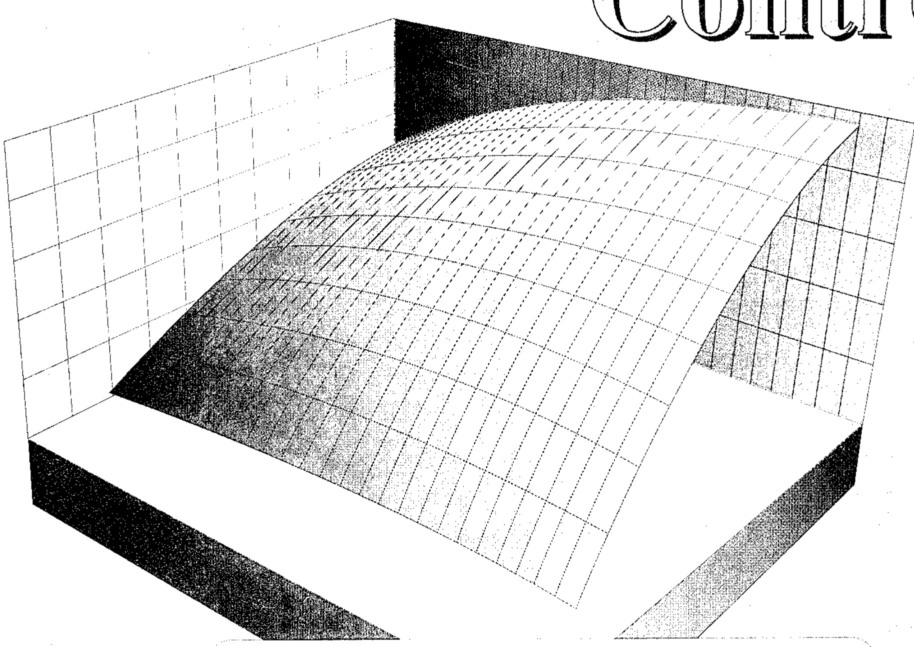
The Dollars and Sense of Command and Control



Raymond C. Bjorklund

with an introduction by General Lawrence A. Skantze, USAF (Ret.)

THE DOLLARS AND SENSE OF COMMAND AND CONTROL

To Barbara

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Raymond C. Bjorklund

NDU PRESS

National Defense University Press
Washington, DC
1995

National Defense University Press Publications

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Library of Congress Cataloging-in-Publication Data

Bjorklund, Raymond C., 1949–
The Dollars and Sense of Command and Control/Raymond C. Bjorklund.
p. cm.
Includes bibliographical references and index.
1. Command and Control Systems—Evaluation. 2. Command and Control Systems—United States—Case Studies. I. Title.
UB212.B46 1994
355.3'3'0410973—dc20 94-13963
CIP

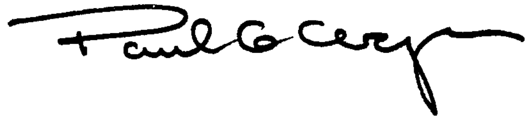
Contents

Foreword

To build a sturdy house, one must use appropriate tools and materials. Building a combat force is similar: one must select those elements which work best for the intended missions. Traditional elements such as weapons and people immediately come to mind. Force planners are less inclined, however, to rank command and control (C^2) as a basic element of force structure. In this era of defense cuts, planners are not convinced of the value of C^2, demanding proof that command and control systems do contribute to mission success.

In this study, the author attempts to measure C^2 in three ways: its role in improving mission success, its affordability, and its degree of integration into the military force structure. Using case histories of defense procurements and analyses of actual battles, he marshals convincing evidence that C^2 systems *are* effective "tools" for defense planners.

Managers will find this analysis extremely useful as they defend investments in command and control against competing demands. The new methods for measuring C^2 developed here should allow more credible and accountable decisions about command and control systems in force structure.



PAUL G. CERJAN
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Preface

Since this book was first drafted, the United States and several coalition partners successfully waged a war—Operation *Desert Storm*. Many interesting command and control challenges, ranging from the political down to the unit level, came out of *Desert Storm* and its predecessor mobilization, *Desert Shield*. Politically, effectively employing the full force potential of the coalition partners in the unified operation was challenging; many of the coalition partners had never trained together. At the unit level, distinguishing friend from foe, controlling rapidly maneuvering forces, knowing where forces were at any given time, and reacting to the tactical ballistic missile threat were some of the command and control challenges facing the unit commander.

Many anecdotes about the two operations have appeared in the popular media and in after-action critiques. At this time, however, we still do not have a definitive, in-depth assessment of what went right and what went wrong with command and control. Nevertheless, I believe that the tools in this book will help force planners decide on the appropriate mix between investments in command and control resources and investments in force elements as operational doctrine evolves to reflect the constructive lessons-learned of *Desert Storm* and the increasingly constrained Defense budget. On a grander scale, I believe that these tools will also aid the United States in adjusting and reformulating its national strategy as the power of the former Soviet bloc continues to wane.

Acknowledgments

My thanks to the faculty of the Industrial College of the Armed Forces for helping me improve the framework for understanding the many complexities of national security decisionmaking, which allowed me to grasp the larger context for analyzing the issues surrounding the politics of command and control resources in the US Defense establishment.

Martin van Creveld's nontechnical analysis of command and control in his book *Command in War* was particularly valuable to me. Avoiding the high technology often associated with command and control systems and the detailed quantitative analyses of command and control processes, van Creveld breathes fresh air into the understanding of the vital importance of command and control to success in peace and war.

Several others have helped me focus my thoughts. Dr. Cindy Williams of The MITRE Corporation provided a very comprehensive critique, based on her extensive experience in command and control analysis and defense system advocacy. Dr. Tom Julian of the National Defense University's Command and Control Research Program thoughtfully commented on the manuscript and opened many doors for me. Dr. Tony Oettinger, Chairman of Harvard University's Program on Information Resources Policy gave me both insights and enthusiastic encouragement. Frank Snyder, Professor of Command and Control at the Naval War College, socratically challenged my notions and improved my philosophy of thought on this topic. Colonel John Rothrock, NDU Senior Fellow, advanced my thinking about the operational art through his critical analysis of attrition-oriented theories of warfare. Two of my colleagues, Lieutenant Colonels Tom Hopkins and Frank LaBelle, provided detailed analyses of the content. The directors and editors of the NDU Press endured my technical questions and gave me many useful suggestions for improving the manuscript. A special thanks to General Skantze for so graciously providing the

introduction. And finally I have treasured my loving wife's forbearance and support during the many hours I spent wrestling with the concepts and numbers to produce this book.

To all these people, my thanks for constructive help. However, the final responsibility for effectively communicating with the reader is mine.

Introduction

This volume includes a timely and instructive treatment of the fundamental elements of command and control and its historical usage; a solid description of command and control in operational warfare applications; and a practical approach to analyzing its contribution to creating the right balance in combining fighting elements and command and control elements into a combat force structure.

Trading off investments in "shooters" versus "radios" rarely works in favor of radios, especially with a declining budget. On the other hand, as a result of *Desert Storm*, in the future contingencies will be the most likely scenarios, rather than global nuclear war. Joint and combined operations are now the standard for US warfighting. Clearly, the lessons of how much combat leverage was provided by command and control systems are self-evident. The Airborne Warning and Control System, Joint Surveillance and Target Attack Radar System, Airborne Battlefield Command and Control Center, and Rivet Joint strategic reconnaissance aircraft are prime examples of leveraging combat capability. Fortunately, the buildup time to *Desert Storm* provided the breathing room to introduce and integrate a powerful set of command and control systems to conduct a sustained, complex air campaign with a single Air Tasking Order for all the US air components as well as the coalition air forces. The ground war didn't last long enough to test the Combined Air Land Command and Control System. Nevertheless, the lessons are there to be learned and this lucid analysis of the command and control function ought to be required reading for all service operators as well as the Joint Force Commanders and their staffs who will have to plan for future contingency operations with a much reduced warfighting force structure.

General Lawrence A. Skantze, USAF (Ret.)

The Dollars and Sense of Command and Control

Overview

Leaner military budgets are compelling Defense planners to look for sources of savings beyond the traditional elements of the military force structure: the airplanes, tanks, ships, missiles, and combat units. Looking beyond these traditional elements usually means drastic spending reductions for other vital defense assets, including command and control.

While force planners sense there is some force-effectiveness benefit attributable to command and control resources, these planners—who make the tough investment decisions—are distracted by a dilemma. On the one hand, they want better information processing and communications for command and control users. On the other, the same force planners want more forces, often sacrificing plans for existing or additional command and control resources.

The US Defense establishment is gradually integrating command and control systems into the military force structure. Contributing to the force planner's dilemma is the difficulty of placing a value on those command and control systems, on what those systems contribute to mission success. This book was thus written because defense planners need rational methods to adjust (decrease or increase) funding for command and control systems in that force structure context. And to that end, the focus is on three key issues: Are command and control systems effective in improving mission success? Can we measure the effectiveness of command and control systems? Can we successfully integrate command and control systems within the military force structure? The answer to all three is yes.

The reader may wonder how "command and control" is defined. It is difficult to perceive command and control, therefore definitions are left to the reader, because force planning decisions are mainly based on connotations held by decisionmakers about command and control and other military functions. While it is hoped that perspectives of decisionmakers about the contributions of command and control resources will be broadened, in the final analysis decisions will be based on each commander's own understanding of the issues. The methods proposed are meant to help capture the decisionmakers' understanding of command and control in a force structure context.

In the best of shared perceptions, command and control is an ill-defined process of modern (and ancient) conflict, a pervasive process used across the continuum of warfare in both warfighting and peacekeeping. Command and control resources—the computers, display equipment, communications, trained people, and interoperable standards for information exchange—have become so sophisticated and intertwined with the operations, intelligence, and logistics realms of the Defense establishment that they are often the object of high-level force planning attention.

History shows time and again that technologists don't do a very good job of relating command and control resources to force effectiveness, especially within the context of the military force structure. Much of the current research plunges directly into the engineered aspects of command and control systems and their internal processes. Until technologists offer senior decisionmakers a broader understanding of how command and control contribute to mission success, we cannot expect senior decisionmakers to account accurately for its value.

This book instructs on how to measure the effectiveness of command and control at a level higher than those engineered aspects. In the spirit of a "return-to-the-basics" philosophy, it does not evaluate how increasing the command and control system's computer processing rate to 27,000 operations per second or the system's communications rate from 1200 to 9600 baud will improve the effectiveness of the command and control process; instead, it explores force structure decisions in subjective terms, because a first-order evaluation will show how affordable command and control systems are.

Accordingly, we will examine what the consumer wants and expects—much as a business does—except in this case, the consumer is the commander of forces. As the commander has the authority and responsibility to carry out assigned missions, whether they are national war plans or readiness functions, his or her "consumer" preferences should carry the most weight in any decisionmaking process.

To capture these preferences, decisionmaking techniques and quantitative business methods were adapted that allow understanding and measurement of the relative "value-added" from command and control. The resulting interdisciplinary method is also evaluated in several scenarios below the level of Armageddon that span the continuum of conflict and several aspects of warfare. These scenarios also cross service boundaries. On the basis of this measure of the subjective value of command and control resources, defense force planners can translate available dollars into what force structure—force elements and command and control systems—should be bought for those dollars.

However, the reader should not expect crystal-clear answers to the difficult dilemma of choosing between command and control resources on the one hand and force elements on the other. Mathematics and judgmental analysis notwithstanding, what is offered is a new way of thinking about command and control resources in a force structure context so the dilemma's solution can be approached on a known course.

An instructive approach was used in writing this book, because senior leaders, decisionmakers, and advocates need realistic tools to improve—but not replace—decisionmaking and auditing for tough problems. This book is directed at an audience of national security decisionmakers and military leaders. Besides the members of the Defense establishment who make day-to-day "what-if" decisions about the force structure, this audience also includes members of Congress and their professional staffs and auditors. The book is also written for the operational managers and technologists who are continually called upon to defend investments in command and control. Finally, information technology and telecommunications advocates in the private sector may also find something of use in these methods. By including all the force planning participants in a systematic, accountable way, these new methods can rebuild the credibility of our efforts to enhance the command and control process with better decision support resources and communications. Over the coming decades, we need to apply such methods for making rational, auditable decisions about command and control systems.

As command and control (C^2) resources increasingly influence the force structure, we need to understand how to account for their contribution to national security strategy. To this end, three issues are explored in this book:

- Are C^2 systems effective in improving chances for mission success?
- Can we measure the effectiveness of C^2 systems?
- Can we successfully integrate C^2 systems within the military force structure?

The remainder of this book explains how military planners and decisionmakers can effectively deal with these C^2 issues. A reader looking for a pragmatic method may go directly to chapter 7. For the reasoning leading to the pragmatic method, a seeker of the "whys" of these issues should read the remaining chapters:

- The first chapter removes some of the confusion surrounding C^2 and its applications to warfighting and peacekeeping.
- Chapter 2 explains a new force structure context for C^2.
- Chapter 3 identifies and categorizes the characteristics of a good C^2 system, in the context of operational warfare doctrine.
- Pinning down the elusive "force multiplier" aspect of C^2 and the contribution of C^2 to force effectiveness is the subject of chapter 4.
- Chapter 5 summarizes how hard it has been to define and understand the cost-effectiveness contributions of C^2 to mission success.
- The broader perspective of force structure decisionmaking is the theme of chapter 6, where a new approach is introduced to help integrate C^2 systems into the military force structure.

- Chapter 7 explores how C^2 preferences fit within the force structure and also shows how investments in C^2 systems are affordable within the force structure.

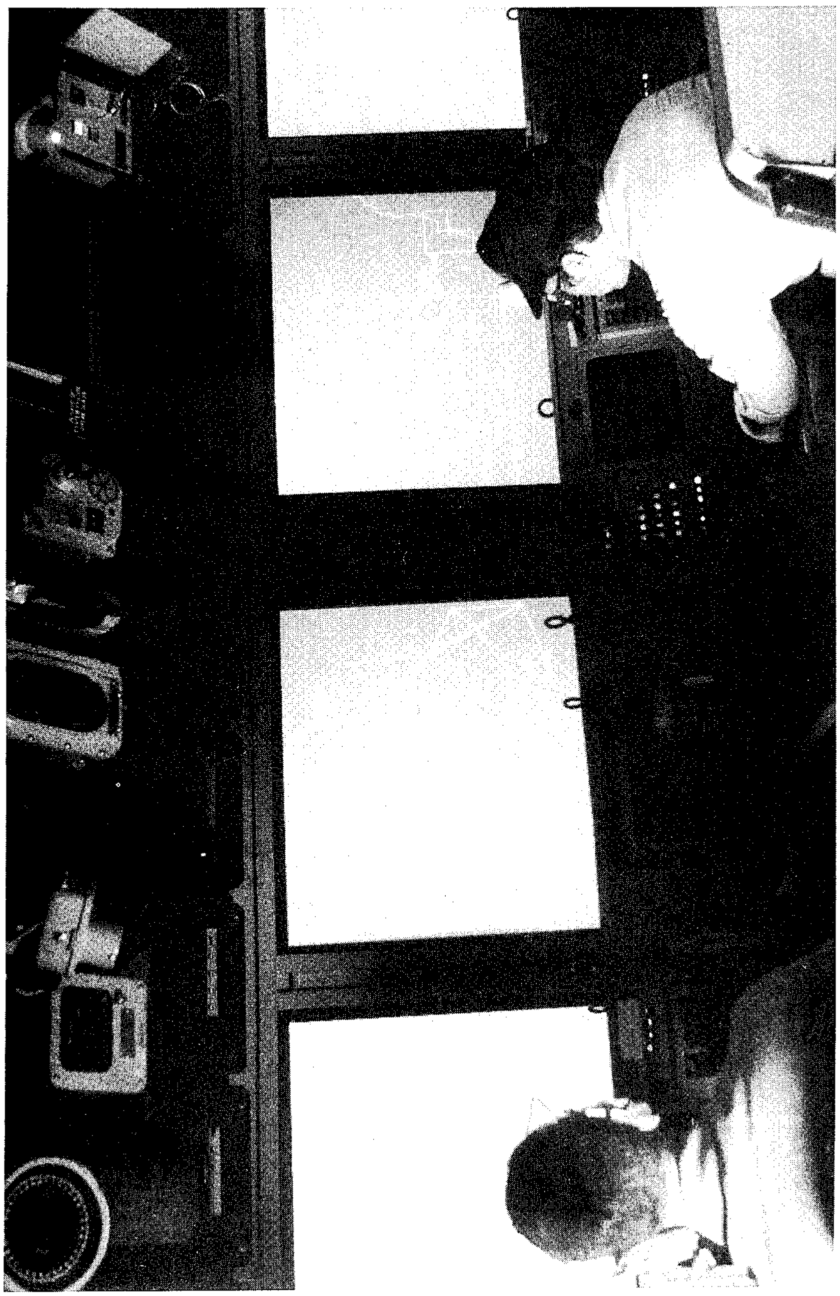
Some concluding thoughts are offered on what these proposed decisionmaking tools might mean in terms of evolving strategy and doctrine and changes in the military force planner's institutional interests.

1.
Command, Control, and Confusion

Not a cloud in the sky, and the temperature is rising with the July sun over the Straits of Hormuz. In the Combat Information Center (figure 1), it's cool. Light comes from the flickering displays and the subdued fluorescence overhead. Officers and technicians are poised at general quarters, intently watching the displays, intensely exchanging status reports and orders. The Aegis scopes of the cruiser are showing a "blip" labeled Track 4131—an unidentified, assumed hostile aircraft. Someone labels it an F-14.

> *0650Z. Bearing 025, range 32 nm. 0651Z. Bearing 025, range 30 nm, speed 350, altitude 7,000 feet. 0652Z. "Contact" observed to be descending. 0653Z. Bearing 018, range 16 nm. Speed 455 knots, descending.*

The open communications channels aboard the USS *Vincennes* are chattering with updates. Tension is mounting, and all eyes are fixed on the contact's progress across the scopes and large screen displays. The officer responsible for monitoring the air picture notifies the Joint Task Force Commander, hundreds of miles away. Radio technicians send warning signals to the F-14. Three tries—no answer. What's happening? Is our cat-and-mouse battle with the three gunboats a tactic to divert us from an air-to-surface missile attack? Has the Iranian P-3, approaching us from the west since 0647Z, been providing targeting data to the F-14?



Start firing sequence. . .

Chairman Nunn: "Your report clearly indicates that certain information about the Iranian aircraft given to Captain Rogers was inaccurate, including the IFF squawk leading to the F-14 classification, which was of course inaccurate; decreasing altitude, which you made clear was never the case, always ascending; and also that the aircraft was always inside the commercial air corridor instead of being outside the corridor.

"Now, . . . if Captain Rogers had been provided the correct information in those three aspects as well as other aspects—in other words, if the Captain had the correct information rather than the incorrect information—do you believe he would have made the decision to engage the aircraft on those three points?"

Admiral Fogarty: "Mr. Chairman, it is very difficult for me to say because that situation did not exist.

"What I can say, and putting myself in the commanding officer's position, is that the other elements that were there—the fact that it took off from a civilian/military airfield, the fact he was in combat at the time, and, as he has said and testified, he thought everything was related that day and, as you may recall, on the 18th of April when we were in combat with Iran there was a related incident where during the surface action aircraft took off from Iran and headed toward our units—that was in the back of his mind.
. . . It was also the fact that he had a P-3 off to the side of his ship at about 50 miles, in what he recognized as a typical targeting situation, giving information to a third party to target his ship. And, finally, he had no ESM, which is extraneous, of course, to the ship. . . ."[1]

What went wrong that July morning in the Straits of Hormuz? Admiral Fogarty's investigation found that some of the officers and technicians standing battle stations in the Combat Information Center misinterpreted the data given by the most sophisticated anti-air warfare electronics ever put to sea. Figure 1 shows the heart of this Aegis command and control suite where the crew of the *Vincennes* received their data. These Aegis electronics provide, every one or two seconds, a complete update of the air and surface picture—where the tracks are heading, their altitude, how far away they are. Data such as these are critical to the commanding officer and others on watch, to all participating in command and control of the battle.

What is this thing called "command and control," or C^2? Is it people; is it a configuration of equipment and processing power; is it a collection of procedures? It's all of these, woven together. Mission success depends on the contribution of these elements of C^2 as well as the quantity and quality of the forces used in the mission.

Modern weapons like smart munitions and cruise missiles enable the commander to engage precisely targets well beyond his visual horizon. Commanders depend increasingly on sophisticated C^2 equipment to detect threats beyond visual range. But while sophisticated equipment is essential, the human factor in command and control is decisive. If a unit's ability to deal with uncertain and changing situations is unknown, a commander cannot use data with optimum effect to respond promptly and correctly to looming threats.

Was the shootdown of Iranian Flight 655 a failure of C^2? Radios and computers that overload the total C^2 system with raw data can lead to mission failure. Unless the human (and non-human) components of the C^2 system can manipulate and transform the raw data into usable information reflecting the commander's perception of reality, an overload of raw data will often contribute little more than confusion to the human element of the C^2 system. Confusion was indeed a factor in command and control that July morning in the Straits of Hormuz.

C^2—A Fundamental Process

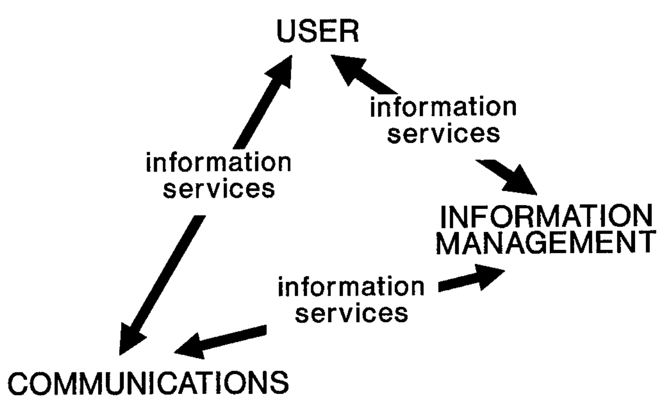
Definitions of C^2 abound, contributing to the "confusion" surrounding command and control. The term "command and control" means almost everything from radios and computers to leadership. The most authoritative (but not necessarily the clearest) definition appears in the Joint Services' dictionary: to paraphrase, command and control is the exercise of authority and direction over assigned forces by a commander in order to perform a mission. C^2 is a process of planning, directing, coordinating, and controlling forces using people (including the commander), equipment, communications, facilities, and procedures. The Joint Chiefs of Staff (JCS) defines a C^2 system as the arrangement of these five resources.[2]

But C^2 is first and foremost a process—a process implemented through several categories of tangible resources. Often forgetting that C^2 is a process, we have acquired the habit of overembellishing the term C^2 by repeatedly adding applied aspects of command and control. Several excursions from the basic C^2 term have led us all the way up to C^4I^2—command, control, communications, computers, intelligence, and interoperability, but these additional words mask the fundamental nature of C^2. Intelligence is rightfully a separate warfighting and peacekeeping discipline, but apart from a general reference to intelligence as processed and analyzed information, this book will not discuss how the intelligence cycle and intelligence systems contribute to mission success.[3] While intelligence is a separate discipline, I believe communications and computers are not. Instead, communications and computers are the main tools for getting the C^2 job done. Interoperability, in the context of C^4I^2, is a descriptor of the degree to which C^2 resources work together, of how effectively information can be exchanged in the process of command and control.[4]

C^2 is fundamentally a barebones concept describing what a leader or decisionmaker does. A leader leads by choosing objectives, understanding what information is available to him, formulating courses of action, deciding on a course of action, giving his subordinates instructions, following up to see how they are doing, and using that information to choose new objectives or modify existing ones. The resources comprising C^2 systems support the leader or commander in estimating the situation, conceptualizing the means to reach the objective, and exercising the plan. C^2 systems implement the C^2 process through command centers (usually automated), communications (usually electronic), people trained and organized for operations (often technology dependent), and accepted doctrine for performing C^2. (The parenthetical qualifiers reinforce the point that descriptions of C^2 need not dwell on the supporting computers and radios.) In sum, C^2 systems help the leader be more effective in leading.

Many elaborate models have been contrived to describe the C^2 process, and more will be said about such models in chapters 4, 5, and 6, but introduced here is one simple model useful for tying together ideas about the C^2 process and the C^2 resources supporting that process. Dr. Chris Gibson of the Royal Navy's Admiralty Research Establishment suggests a C^2 model wherein a user (commander or staff or controlled force) receives information-based services (assistance) by two different paths[5] (figure 2).

FIGURE 2. A C2 model based on flow of information services



(Source: after C. Gibson)

The user receives help or services directly from communications resources. Services may also be received directly from information management resources such as automated decision support and knowledge-based tools that help manage information. For information to flow, information management resources must in turn receive services from the communications resources.

Linking the resources in a C^2 system by information-based services leads us to an essential thesis of this book: the value a user or commander places on the contribution of information to the mission-oriented C^2 process corresponds to the value placed on the C^2 system.

As Professor Anthony Oettinger explains, information is a building block of society. Without information nothing makes sense.[6] Not only must the C^2 system produce the quantity of information the commander needs in the C^2 process to make sense of the environment, the system must also produce quality information when needed. How the commander values the contribution of C^2 information to "making sense" in the process depends then on the quantity, quality, and timeliness of the information. Situations that erode the value the commander places on information are C^2 resources that don't work or are absent, or do not afford the needed level of certainty about the situation, and information that does not arrive fast enough. Is the source of the report electronic surveillance, is it deception, or is it geese or gremlins? Are the data 3 seconds or 3 months old? How reliable is the source? In succeeding chapters, we will pursue why these questions are significant in placing a value on C^2 systems.

These questions may sound to some like intelligence issues; intelligence, many would argue, is the fuel for the C^2 engine. "Information" will be used, however, because the issues are more properly C^2 issues, as they relate to information the commander needs to make decisions. Intelligence, on the other hand, is the military descriptor for processed and analyzed information.[7] Brigadier Richard Simpkin put it in perspective in "Intelligence, Risk, and Luck," a chapter in his book, *Race to the Swift.* He relates how information, gleaned from intelligence assets, is important in achieving success or precluding failure—luck of the "good" general notwithstanding. Simpkin also adds, "Nowadays luck only stays with the good general who has a good system of command and control."[8]

The total C^2 process involves not only the transactions of information-based services among the commander, the decision-support capability, and communications resources, but also how the commander and his or her staff use the information. But no matter how much information the communications channels can pipe through and no matter how many elegant alternatives the decision support software can pump out, the responsibility for a C^2 decision is ultimately the commander's.

The accidental shootdown of Flight 655 illustrates this point. The crew of the *Vincennes* had a system of high-performance decision support computers, automated displays, and digital communications channels available to them, the crew had been thoroughly trained, and Aegis equipment performed well. But the decisionmakers aboard ship did not totally rely on Aegis. The ultimate decision to act is the decisionmaker's or commander's alone. Aegis or any other C^2 system resource is only there to support the commander with the technical means to do the job.

> *Chairman Nunn:* "When you say the technical part of the system worked fine and, using the words of the report, 'if that was the sole source of tactical information, the commanding officer might not have engaged Iran Air Flight 655,' do you believe in the broadest sense that the Aegis system human-equipment interface worked fine?"

> *Captain Gee:* "Yes sir, we believe it did. I have had command of two Aegis cruisers myself. The system does provide a great deal of information. There is a requirement to learn how to use it properly—what information is most vital to you and use it properly."[9]

The Growing Influence of C^2

How much have taxpayers spent on Aegis C^2 equipment? Costs prorated through Fiscal Year 1988 come to about $50 million a copy (in then-year dollars). With 27 Ticonderoga class cruisers purchased, the investment in shipboard Aegis equipment now totals nearly $1.5 billion.[10] After such a tragic incident, some critics question why the Department of Defense invests in systems which are so complicated that they may not work effectively. This book offers an approach to address such questions.

As prudent fiscal managers, Department of Defense (DOD) decisionmakers need to recognize that money spent on C^2 systems can be a cost-effective way to better the chances of mission success. Aegis is just one example. Aside from the Iranian airliner incident, Aegis deployment history is a reassuring success story. The US Navy originally planned to buy only 18 Ticonderoga class cruisers, but added another nine to the procurement schedule because of the platform's accuracy and completeness in finding and tracking targets in a task force operating area. The appeal of this guided missile cruiser stems from a history of operational success:[11]

- April 1986—The USS *Yorktown* and *Vincennes* provide command and control data to support the successful F-111 and A-6 raids on Libyan targets during Operation *Eldorado Canyon.*

- March 1986—USS *Yorktown* and *Vincennes* give vital support in sinking two Libyan gunboats in the Gulf of Sidra.

- October 1985—USS *Yorktown* helped Navy fighter aircraft intercept the Egyptian airliner carrying the SS *Achille Lauro* hijackers.

- 1984—Based on the quality of Aegis command and control data during USS *Ticonderoga*'s first deployment, the commanders reduce the number of combat air patrol missions.

The reduced numbers of combat air patrol missions needed to support an Aegis-capable task force suggests something else. Such reductions, attributable to C^2, can point to a more affordable force structure. Typically, each patrol mission operates as a flight of two F-14 fighters. Considering that the cost of one F-14 flying hour is several hundred dollars, the fuel savings over a 30-day war would be substantial.[12] Facts like these need to be brought into the force planning process, but the value of C^2 systems with respect to mission success is rarely considered by force planners. Roger Beaumont writes that the tradeoffs between cost and effect have not been resolved even after decades of rigorous quantitative analysis. "While the loss of an infantry division's signal battalion could be more serious than the loss of any one of its infantry battalions, the exact or even approximate relative values in such tradeoffs remained elusive."[13]

Because the defense establishment has long treated C^2 as part of the military infrastructure and not as part of the force structure, it is difficult to pin down how much we spend on C^2. Market analyst Theodore Smith estimates that DOD spent nearly $13.6 billion on command, control, communications, and intelligence (C^3I) in fiscal year 1989.[14] Because Smith includes intelligence programs, this number is probably high for C^2 alone. On the other hand, the estimate is low because it reflects only big-ticket items and expenditures for classified C^2 programs and smaller, bread-and-butter programs for communications, computers, and other mission support equipment. Moreover, it addresses only the Procurement and Research, Development, Test, and Evaluation appropriations, not Operations and Maintenance, Military Personnel, or Military Construction. According to Smith, C^3I is approximately 16.5 percent of DOD's RDT&E budget and only 9.5 percent of the Procurement budget.

What is the significance of these numbers? To put these expenditures in perspective, $13.6 billion equates to 0.26 percent of the US GNP; over 388,000 Defense-related civilian jobs (at $35,000 per job annually); four Nimitz class aircraft carriers plus some spare change ($3.2 billion each copy); 76 B-1 bombers ($178 million each copy); or 4,533 M-1 Abrams main battle tanks ($3 million each copy).

How did this increasing significance of C^2 come about? Detailed histories are available elsewhere,[15] but a brief background review will set the stage for our investigation into the interdependence among C^2 systems and the elements of the force structure they support. Because of lessons learned in World War II and the Korean war about the positive contributions of C^2, the advancing polarization among international alliances, and increasingly available electronic technology, more sophisticated C^2 systems came into their own in the early 1960s. With pressing national concerns about the looming possibility of a World War III, DOD invested in C^2 systems to provide early warning of missile and bomber attacks on North America. Besides the Distant Early Warning line along the Arctic Circle, these investments included some of the first large-scale digital computer C^2 projects ever attempted—the "four-story" computers called Semi-Automatic Ground Environment (SAGE) and the Back-Up Interceptor Control (BUIC).

In the early days, C^2 systems were definitely part of the infrastructure and not the force structure. According to a 1965 discussion of DOD decisionmaking, the Planning, Programming, and Budgeting System encompassed only nine major force programs. At that time, the list did not even call out communications and intelligence as separate force programs as it does now. In the mid-1960s, the costs of stand-alone C^2 systems were instead part of the weapons programs and operations budgets of the military commands that sponsored them. Other communications systems between higher headquarters and unified commands as well as most intelligence systems appeared under the General Support major force program.[16]

Until the Vietnam era, the defense establishment placed little additional emphasis on the value of C^2 systems. Then Secretary McNamara saw to it that the United States invested in electronic "curtains" of sensors that could detect Viet Cong movement along the jungle trails. The government also invested in tactical computers and longer range "trunk" communications to sort out the tactical air and surface picture among the four services. With these C^2 systems, under continuous development through the 1970s, enemy aircraft and ground targets could be detected and then engaged by fighter-interceptors or the Army's air defense artillery. The big advantage of these new systems was an ability to allocate and coordinate efficiently a limited number of friendly assets to a large number of targets. These C^2 systems, capable of exchanging tactical intelligence, the air picture, operations data, and electronic warfare data, were the progenitors of modern-day tactical C^2 systems like the Aegis. Many of the C^2 system concepts also evolved into what we today call the "electronic battlefield."

In the post-Vietnam demobilization of the mid-1970s, DOD made fewer investments in C^2 systems. Among several important C^2 system efforts that did proceed, DOD upgraded the computers for the Worldwide Military Command and Control System. The Navy was beginning to develop systems like Aegis, the Army was still struggling with the Tactical Operations Support system for battle management, and the Air Force was doing some limited upgrades in strategic C^2 systems. Some rebuilding of the defense establishment then began in the late 1970s, after the Carter administration and the public became concerned about "hollow" forces. Other improvements in the C^2 capabilities for US forces started with some congressional initiatives at the turn of the decade to fix problems like false alerts in the North American Aerospace Defense Command's missile warning systems. The spurs that jabbed into the sides of the legislative horse, however, were the weapons systems (and C^2 systems) in President Reagan's strategic modernization program.[17] The horse galloped.

The Reagan defense buildup and, in particular, proclamations such as the October 1981 strategic modernization initiative and the April 1983 Scowcroft Report on strategic forces, provided the momentum and means for rebuilding a viable strategic force structure that could fulfill the bolder national security strategy. In an unprecedented move, the President made strategic C^2 modernization his number-one priority as he raised the funding for weapons systems. Then in 1983, the President tasked the Scowcroft Commission to check the progress of the modernization program for survivability and flexibility. Over all other modernization initiatives, the bipartisan Commission urged that programs permitting the National Command Authorities to have surviving and enduring command and control of nuclear forces continue to have the highest priority.[18]

The defense buildup also began to close the perceived "window of vulnerability" ascribed to conventional and unconventional warfare forces, a window partly opened by the 444-day hostage crisis precipitated by Iran in 1979. Congress and the American people were willing to support heavy expenditures to close the window. This momentum for strategic and conventional C^2 peaked in the mid-1980s as the Congress supported almost all funding requests for C^2 and even legislated a new Assistant Secretary of Defense for C^3I.[19] From this new political position, the ASD(C^3I) led in an area where no one armed service had a monopoly. Although the growing realm of C^2 crossed interservice boundaries and interfered with many service-specific force structure interests, this new centralized management was able to capture the lead because the institutional interests of the Services in C^2 issues had not become thoroughly entrenched.

But as Alan Campen observed during that time, "We gained visibility over the cost of C^3I systems and lost it over their worth." C^2 advocates could often describe their program in exhaustive detail but could rarely explain what the program contributed to force effectiveness. With centralized management of C^2 at the Assistant Secretary of Defense level, it was difficult to relate the C^2 programs to the service-managed forces they supported.[20] For the most part, service institutional interests in ships, tanks, and airplanes held sway over the DOD sponsorship of major C^2 programs.

A Tightening Budget Belt, A Leaner Force Structure

On target or misplaced, public and Congressional pressure on the Executive Branch to control defense spending increased in the late 1980s and will continue to inspire budget-cutting for years to come.

Reduced superpower tensions and advancing preoccupation with domestic issues are deflating the perceived need for large standing military forces as an element of national security policy. This cycle has happened before, especially after major wars in this century, but in the period since World War II, we have reached a new notch in belt-tightening.

White House and DOD leadership responses to these pressures have been frequent requests for defense services and agencies to cut and trim. DOD leaders distribute cost-reduction targets among service secretaries and agency directors. Ideally, budget cuts should be mapped from the top down—beginning with changes in national security strategy and ending with a specific choice of forces to fulfill the strategy, but senior decisionmakers in each service and agency simultaneously grapple with how to balance the forces needed to meet the threat and to meet the "bogey" as well. Beginning with Defense Secretary Cheney's administration, the pressure has been intense to cut specific programs: Few slowdowns, stretchouts, or bailouts, mainly cuts.

In the halcyon years of the buildup, C^2 system advocates were able to shoo away the budget trimmers with quotes from the Office of the President, such as "program of the highest national priority" and critical program priority designations like "BRICKBAT" and "Force Activity Designator I." It was like wearing a garlic necklace to ward off bloodthirsty vampires.

Questions of affordability are now legion. Can we afford more than one type of long-range bomber? Can we continue to afford a 600-ship Navy? Can we afford to keep troops overseas and build a new main battle tank for them? These questions come from senior DOD leaders as well as from the appropriations and oversight committees of the Congress. Innovative budgetary strategies now encourage force planners to accept a "measured" risk, to decrease their force requirements consistent with a changing world situation and fiscal limitations. As international tensions continue to loosen and nuclear superpowers continue to show reluctance to use nuclear weapons, slight increases in spending for quality conventional forces at the expense of nuclear deterrent forces becomes one suitable tradeoff. As the overall number of force elements decreases, integrating more C^2 systems into the force structure—to exploit the leverage stemming from C^2 information services—may be another part of the solution. Making force structure decisions such as these, consistent with our perception of the risk environment, is a way of accepting the "measured" risk.

But in meeting the fiscal challenges of constrained Defense spending, C^2 advocates are also faced with frequent questions as to whether we can afford C^2 systems. What's the payoff of a multi-million dollar investment that doesn't fly, shoot, or steam? You want to spend all that money on one radio? The questions are understandable. Compared to the purchase price of some C^2 systems, the unit flyaway cost for a jet fighter and the unit roll-out price for a main battle tank seem insignificant. Spending money on C^2 systems, however, can make economic sense in the context of how the United States organizes its forces. Senior decisionmakers need new ways to accept the tradeoff of other systems for C^2—ways that are rational and accurate and do not compromise national strategy.

§ § §

Notes

1. Congress, Senate, Committee on Armed Services, *Investigation into the Downing of an Iranian Airliner by the USS "Vincennes"* 100th

Congress, 2d sess., 1988. Facts of the engagement extracted from pages 10-13; questions and testimony extracted from pages 19-20. Rear Admiral Fogarty, Director of Policy and Plans, US Central Command, was Head of the Department of Defense's Investigation Team. IFF stands for "identification, friend or foe," an electronic means of beaming an element's unique identity code. ESM are electronic warfare support measures which provide electronics intelligence to the commander. The new name for the Combat Information Center is the Combat Direction Center.

2. *Department of Defense Dictionary of Military and Associated Terms Joint* Pub 1-02 (Washington, DC: The Joint Chiefs of Staff, 1 December 1989). Many definitions of C2 systems do not include the resources used in scouting, surveillance, and other forms of reconnaissance. Mine generally does, especially when the reconnaissance element is continuously linked with the commander for decisionmaking. Airborne forward-looking infrared radar for protecting the flank of a night heliborne assault would not fit my definition. A radar integrated with an airborne warning and control system, such as the E-3 AWACS, would.

3. I believe that quantitatively measuring intelligence's contribution to mission success is fertile ground for research. Similar work is already being done to assess how logistics contributes to warfare. See, for example, logistics aspects in Donald E. Emerson, *TSAR: A Large-Scale Simulation for Assessing Force Generation and Logistics Support in a Combat Environment* RAND P-6647 (Santa Monica, CA: The RAND Corporation, October 1981) and Glenn A. Glotz, *Modeling the Contribution of Maintenance Manpower to Readiness and Sustainability* RAND R-3200-FMP (Santa Monica, CA: The RAND Corporation, January 1986).

4. *Defense Electronics* editor Floyd Painter laments the "alphabet soup" defense writers and others have cooked up over the last three decades to deal with the several communities and professional disciplines involved in this business. He recounts the growth from command or "C" to "C^3I" and the recent introduction of a fourth "C" for computers. Painter explains that: "Command and control are necessary functions that are exercised through the use of communications. Computers are just tools that allow us to do a lot of things, including C2. The importance of data processing in the military needs to be recognized, and the services are doing just that. But there is no need to include computers in the title of an important warfare dis-

cipline that may be misnamed as it is. . . ." *Defense Electronics,* April 1989, 7. Assistant *Parameters* editor Greg Todd, with tongue in cheek, suggested that some day we will be talking about $C^{27}E$ to cover calculators, canoes, and so on. In his "C" term, the "E" stands for "etc." Greg Todd, "C1 Catharsis," *Army* 36, no. 2 (February 1986): 14.

5. Chris Gibson, presentation at the Admiralty Research Establishment (Portsdown), Portsdown, England, 9 May 1990.

6. Anthony G. Oettinger, *The Information Revolution: Building Blocks and Bursting Bundles* (Cambridge, MA: Harvard University Information Resources Policy Program, 1989), 7-9. Professor Oettinger is the Chairman of the Information Resources Policy Program.

7. The Joint Services define information to be "unevaluated material" or, in a broader sense, "meaning that a human assigns to data by means of known conventions used in their representation." Intelligence is the "product resulting from collecting, processing, integrating, analyzing, evaluating, and interpreting available information concerning foreign countries or areas." *Department of Defense Dictionary of Military and Associated Terms* Joint Pub 1-02 (Washington, DC: The Joint Chiefs of Staff, 1 December 1989).

8. Brigadier Richard E. Simpkin, UK (Ret.), *Race to the Swift* (Washington, DC: Brassey's Defence Publishers, 1985), 204-205.

9. US, Congress, Senate, Committee on Armed Services, *Investigation into the Downing of an Iranian Airliner by the USS "Vincennes"* 100th Congress, 2d sess., 1988. Captain Gee was Director, Surface Combat Systems Division, Office of the Chief of Naval Operations.

10. Defense Marketing Service, "CG-47 Ticonderoga Class," DMS Market Intelligence Reports: *Warships* (Newtown, CT: Forecast International, 1989), 4-5. Investment costs estimated from a list of Aegis-related contracts awarded since 1978.

11. Captain Richard Sharpe, RN, ed., *Jane's Fighting Ships* (London: Jane's Defence Data, 1989), 722.

12. The US Air Force is now emphasizing the broader logistics costs for aircraft. Realistically accounting for the cost of repairable parts,

the cost of a flying hour may now be calculated to be six times as great as yesterday's cost based on fuel alone.

13. Roger Beaumont, The Nerves of War: *Emerging Issues in and References to Command and Control* (Washington, DC: AFCEA International Press, 1986), 23.

14. Theodore H. Smith, "C³I Budget Summary," *The C³I Handbook* 3rd ed. (Palo Alto, CA: EW Communications, Inc., 1988), 198.

15. See especially Martin L. van Creveld, *Command in War* (Cambridge, MA: Harvard University Press, 1985) for historical aspects of C2 in land warfare and Captain Wayne P. Hughes, Jr., USN (Ret.), *Fleet Tactics: Theory and Practice* (Annapolis, MD: Naval Institute Press, 1986) for the history of naval warfare C2. See also Roger Beaumont, *The Nerves of War: Emerging Issues in and Reference to Command and Control* (Washington, DC: AFCEA International Press, 1986) and Major George E. Orr, USAF, *Combat Operations C³I: Fundamentals and Interactions* (Maxwell Air Force Base, AL: Air University Press, July 1983).

16. Based on descriptions by Charles J. Hitch, *Decision-Making for Defense* (Berkeley: University of California Press, 1965), 34, 36. In 1990, Major Force Programs numbered eleven.

17. Congress, Senate, Committee on Armed Services, *Department of Defense Authorization Act of 1982,* S.Report 97-58, 142-143.

18. Reagan speech cited in United States, Congress, Senate, Committee on Armed Services, Subcommittee on Strategic and Theater Nuclear Forces, *Strategic Force Modernization Program* hearings, 26-30 October and 3-13 November 1981. The full text of President Reagan's 2 October 1981 remarks on defense policy may be found in "Remarks and a Question-and-Answer Session with Reporters on the Announcement of the United States Strategic Weapons Program," US President, *Public Papers of the Presidents of the United States,* (Washington, DC: Office of the *Federal Register,* National Archives and Records Service, 1982), Ronald Reagan, 1981, 878-880. For the follow-on analysis, see United States, President's Commission on Strategic Forces, *Report of the President's Commission on Strategic Forces* ([Washington, DC]: The Commission, 6 April 1983), 10, 20. General Brent Scowcroft chaired this commission. In a 1988 report, another senior panel reached the same conclusion about con-

tinuing the highest budget priority for C3I. Department of Defense, Commission on Integrated Long-Term Strategy, Offense-Defense Working Group, *The Future of Containment: America's Options for Defending Its Interests on the Soviet Periphery* (Washington, DC: GPO, October 1988), 7, 72-79. Dr. Ikle and Professor Wohlstetter co-chaired this commission.

19. Congress, *Department of Defense Authorization Act, 1984,* P.L. 98-94, Sec. 1212, 24 September 1983. Congress later approved Donald Latham to hold this position.

20. Colonel Alan Campen, USAF (Ret.), "Forces and Force Control—In Pursuit of Balance," originally in the March 1986 issue of *Signal, in Principles of Command and Control,* Jon L. Boyes and Stephen J. Andriole, eds., AFCEA/*Signal Magazine* C^3I Series 6 (Washington, DC: AFCEA International Press, 1987), 403. Campen was Vice President of C3 and Information Systems at the BDM Corporation when he wrote the article.

2.
A New Context for Command and Control

C^2 systems are edging toward full membership in the military force structure. Defense specialists are increasingly recognizing the pervasive contributions of C^2 resources to everyday operations, and this recognition is helping to find a formal home—a new context—for C^2 in the force structure. Acceptance of this transition, however, from association with the infrastructure to full membership in the force structure is uncomfortable for many force planners. In congressional testimony, one information resources expert defined "infrastructure" in a way that reveals this discomfort: "Much of what gets labeled as infrastructure in the public policy arena is stuff that some people want, but are unwilling to pay for directly."[1] Full membership in the force structure will compel the force planners to figure a way to pay for the C^2 systems, in balance with the other important elements of the force structure.

With this transition to full membership, force planning questions put to C^2 advocates are now much more challenging than in the past. If, for example, decisionmakers slash in half a program to purchase tactical C^2 equipment (and the overall budget neither increases nor decreases), how must the force structure change? How much would this new force mix hurt or help the US defense posture? Defense decisionmakers are posing questions such as these to try to come to grips with paring down C^2 in view of the changing needs of national security. In the fast-paced world of Defense budgeting, answers to these questions include "I don't know," "We'll need more airplanes to do the same job," "We'll lose our qualitative edge," and so on. These answers are not satisfactory.

This chapter describes how C^2 systems have reached the clubhouse door of the military force structure and explain some of what's wrong with force structure planning—what stumbling blocks stand in the way of full force structure membership for C^2 systems. Also included are descriptions of some mechanisms for reflecting the role of C^2 in the force structures; spending money on C^2 systems can make military and economic sense in light of national security needs. The supporting reasoning will show why C^2 resources are entitled not only to membership, but also to full tenure in the force structure.

New Directions

Before we talk about integrating C^2 systems into the force structure, it will be useful to first define "traditional" force structure. A good way to understand the concept of a force structure is to refer to it by its colloquial term: force mix. A force structure is a devised mix of the several categories of force elements or weapons systems, the size of each category chosen to best fulfill the national military strategy.[2] The "traditional" force structure does not expressly recognize C^2 resources as a fundamental category in the mix.

Force structure is one of the four "pillars" of military capability. Along with modernization to meet new threats and improve performance, readiness to keep people trained and equipment maintained and ready to go, and sustainability to keep the war going once forces are deployed to action, force structure has been an area of deliberate, measured focus among Defense decisionmakers and resource managers.

In generic terms, the traditional military force structure includes strategic bombers and strategic defensive fighter-interceptors, ICBMs, fleet ballistic missiles, combat divisions and brigades, tactical fighter and attack aircraft, combatant ships, airlift aircraft, sealift resources, and tanker aircraft. These categories have been the meat and potatoes of warfighting for decades. Force structure planning is then deciding how many submarines, carrier task forces, Army divisions, bomber wings, ballistic missiles, Marine and Air Force tactical fighter wings, and so forth the United States needs to meet its national military strategy objectives.[3]

During the Reagan defense buildup, the administration willingly offered funds to the services to bolster their respective traditional force structure programs. Many development programs enjoyed increased robustness, and the principal categories of the military force structure grew. Table 1 shows the Fiscal Year 1990 force structure estimates and how the resource categories grew in the mid-1980s.[4] But during this buildup, decisionmakers only sporadically deliberated over how the force structure was growing in relationship to the national military strategy.

Defense leaders also found themselves with additional funds and White House support to improve the warfighting infrastructure. To remedy a "hollow warfighting capability," DOD added money for flying hours, steaming days, battalion training days, ammunition, spare parts, prepositioned supplies, medical care, military construction, and C^2 systems. As explained in chapter 1, the administration also assigned the highest national priority to certain strategic C^2 programs. The list of politically protected systems even included a few C^2 programs such as the Joint Tactical Information Distribution System, upgrades for tactical warning and attack assessment systems in Cheyenne Mountain, and the Milstar Satellite Communications System.

A 1988 book by Colonel Robert Haffa thoroughly reviews how we do force structure planning today and how we got here and recounts how force planning methods have evolved in three major types of military forces: strategic nuclear, general purpose, and contingency (or rapid deployment). Haffa emphasizes how the force planners have to learn to integrate it all together rationally and prudently. But in analyzing the state of the art in planning, he also reflects the traditionalist's view. He explicitly covers C^2 as an aspect of the force structure only once and then as an attribute of strategic nuclear force planning.[5]

This is not a new deficiency. The chroniclers of force planning methods in the 1960s, Alain Enthoven and Wayne Smith, recognized that the defense planners of their day had no useful methods for determining communications and intelligence needs. Enthoven and Smith asked for more effort in understanding how the large sums being spent in those areas con-

TABLE 1. US military force structure

	FY 1984	FY 1986	FY 1988	FY 1990 (estimate)
Strategic				
Strategic offense				
Land-based ICBMs	1032	1007	1000	1000
Strategic bombers	241	259	324	263
Fleet ballistic launchers	456	464	528	608
Strategic defense interceptors				
Squadrons	15	15	14	13
General purpose				
Land forces				
Army divisions	24	28	28	28
Marine Corps divisions	4	4	4	4
Army separate brigades	31	27	28	28
Army Special Forces groups	8	8	8	9
Army Ranger regiment	0	1	1	1
Tactical air forces				
Air Force attack/fighter squadron	120	121	122	121
Navy attack/fighter squadrons	72	75	77	76
Marine Corps attack/fighter squa	32	33	33	33
Naval forces				
Deployable battle force ships	524	555	565	574
Other ships	33	28	26	24
Airlift and sealift				
Intertheater airlift				
Aircraft	329	353	389	401
Intratheater airlift				
Aircraft	605	592	613	526
Sealift				
Ships	157	186	205	226

Source: *Defense '89 Sept/Oct*

tributed to national security. To understand the total (quantitative and qualitative) force balance among adversaries, they argued that Defense planners must pay more attention to the "unglamorous essentials necessary for an effective fighting force"[6]—and C² systems are among the unglamorous essentials. The highly regarded defense analyst Jacques Gansler also notes this deficiency and observes that a service will assign a low priority—and therefore low funding—to missions the service perceives are inconsistent with its institutional role. In addition to listing strategic mobility, close air support, and special operations, Gansler includes C² resources.[7] When a C² program crosses interservice boundaries, the problem gets worse because the lead service is probably reluctant to spend money to satisfy another service's requirements. The deficiency of not including C^2 resources in the force structure is most evident in the respected annual, *The Military Balance.* The annual's editors do not expressly list C^2 systems in any of the forces of military nations.[8]

To help understand the theme of succeeding chapters in this book, a few words about the state-of-the-art in force planning are in order. In some areas, such as strategic nuclear forces, force planners often rely on precise measures of effectiveness to decide how big the force structure should be. For these strategic force elements—which put firepower directly on the target—force planners use kill probabilities to directly evaluate the "value-added" by investing in less or more force elements. While kill probabilities are precise numbers, some critics argue whether such measures are accurate—or even realistic. Often systems analysts recommend numbers of strategic nuclear force elements (bombers, missiles, and submarines) based on modeling. If the model is crude or fragile, the value of the recommendation is obviously subject to question.[9] C^2 systems, in contrast, do not have such force effectiveness measures and thus are largely subjected to qualitative measures for evaluation

To add an economic dimension, analysts sometimes measure force effectiveness in dollars per kill, but this tends to become a meaningless measure when the size of the adversary's force is orders-of-magnitude greater in numbers than your own.[10] With this economic dimension, the life cycle cost of a new main battle tank may identify it as a less-expensive way to deliver firepower than several infantry fighting vehicles. But if the enemy has three times as many tanks as your own forces, the "dollars per kill" measure has not helped to build a rational force structure. It may be prudent then to look to other force solutions (such as anti-tank measures) to improve your chances of mission success. Few analysts have ever tried to quantify the usefulness of C^2 systems in "dollars per kill."

In conventional warfare areas, force planning methods sometimes include scoring techniques that account for persons and the types of weapons that comprise a force. These methods attempt to predict the outcome of battles and the corresponding level of attrition or casualties. Usually these methods don't account for important, intangible factors (such as training, leadership, and morale) that might contribute to a unit's chances of mission success.[11] Some senior force planners even make decisions by "rule of thumb." Their logic contends that if Defense leaders want to reduce the budget by *X* million, then the force structure should be cut by *Y* percent, distributed somehow among the various appropriation accounts. This kind of subjective force planning usually results in disproportionately lower priorities and funding for C^2 systems.

What's wrong with state-of-the-art force planning? A panel of 12 retired flag officers and civilians, distinguished by their former roles in high NATO, Pentagon, and major command positions, met in 1985 to discuss how the United States should configure its conventional forces for the next century. They evaluated how budget reductions would lead to cutting military support to US foreign policy in various parts of the world.[12]

> Although none of the . . . conclusions were unexpected, it is interesting that all participants concluded that the traditional manner of accommodating budget reductions—decrementing proportionately across the services and reducing sustainability and readiness—impaired US conventional force posture the most. In an exercise where differing views often flourished, the extent of agreement on this point was noteworthy. It underlies the need to consider alternate ways of adapting US conventional structure to reduced rates of defense growth, should these occur.
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> . . . .
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> Second, the participants generally agree that a ready force, sustainable and mobile in conflict, was preferable to a larger, hollow force if resources forced these difficult tradeoffs. Few, if any, participants felt comfortable with the assumed level of resources in the study and strongly recommended more. In that regard, sustainability, mobility, training, and improved command, control, communications, and intelligence were all viewed as critical force multipliers. Indeed, many argued that the greatest leverage for US forces rests in the C^3I area.

Force planning is now far more budget driven than it was in the early days of the Reagan defense buildup. Leaner military budgets encourage defense planners to look beyond the traditional, protected elements of the force structure for sources of funding offsets. Looking beyond these traditional elements usually means cutting vital components of the force structure, like C^2 systems.

But right now C^2 systems are "square pegs" in the "round holes" of the force structure—holes rounded out by decades of institutional strategic and tactical force planning. Because force planners cannot directly measure the contribution of C^2 systems by bombs on the target and cannot count the "force level" of C^2 systems like they count ships and warheads, C^2 systems do not fit the planning concepts understood by traditional force planners.

There's no question that C^2 resources are very difficult to "count"; some C^2 resources are stand-alone and others are embedded. Stand-alone systems rarely occur in large numbers. Usually they are one-of-a-kind systems like the missile warning system in Cheyenne Mountain or a few-of-a-kind system like the Marine Corps Tactical Air Operations Center.[13] Embedded C^2 systems, on the other hand, are not very visible. An example is the embedded Aegis C^2 system on a cruiser platform. Some C^2 systems are simple: a commander and staff with a complement of paper and stubby pencils. Some are so "transparent" to the commander or user, their presence is not noticed.[2] Because many C^2 are transparent to users, finding operational (in addition to technical) advocates for them is a problem.[14] While this is testimony to the quality of the delivered C^2 system, it makes it difficult to bring C^2 into the force structure because operational advocates have the greater influence over the composition of the force structure.

Some of the strongest evidence of the 1980s emphasis on centralized C^2 management shows up in the "C^2 architectures." By taking many different slices among the physical and functional interconnections among C^2 systems, the architects are able to record C^2 system relationships, identify C^2 deficiencies, and propose evolutionary solutions to fix any problems. These architectures have been an important first step toward integrating C^2 systems into the military force structure. They include architectures depicting a single C^2 system or "a system of systems," mission area functions, the C^2 needs of a subordinate or component command, theater-level C^2 requirements, and the specific configuration of the National Military Command Structure.

Because of the interdependency between C^2 systems and the several categories of forces they serve, force planners need rational models to understand the interrelationship between C^2 and the rest of the force structure. These models, built on how the perceived value of information changes from one level of measured risk to another, can account for how C^2 contributes to mission success.

C^2 systems have, of course, always been around. But C^2 systems have become more significant with respect to the force structure for four reasons: definition traps, increasing costs of C^2 systems, congressional "line item" interest, and the process of assigning forces to combatant commanders.

The first reason is found in definition traps. In the late 1960s and the 1970s, it became increasingly time-consuming to acquire specialized computer resources for weapons systems, especially those adjunct computer resources used in developing, testing, and supporting weapons systems. These difficulties stemmed from enactment of the Brooks bill, which consolidated much of the acquisition management and approval authority for computer systems.[15] While the Brooks bill and its corresponding procedures have saved a great deal of money, they have also interjected additional layers of bureaucracy which impeded procurement. Decisionmakers often presumed C^2 systems, which do not directly put firepower onto targets, to be subject to Brooks bill procedures.

By the mid-1970s, the DOD had firmly established its position that mission critical computer resources (MCCR) were exempt from the Brooks bill provisions, that many "supporting" systems such as those used in C^2 fell under the rubric "weapons system." The Warner-Nunn Amendment, recognizing the Brooks bill impediments and responding to problems such as the 1980 NORAD false alerts, streamlined MCCR acquisition. C^2 systems and many systems that performed functions closely related to C^2 became "weapons systems."[16] As more of the traditional force planners accepted the idea that C^2 systems are weapons systems, they began to look for a home for C^2. If a C^2 system is a weapons system, then logically it must compete with other weapons systems for its share of the defense dollar. And where are weapons systems and other force balanced? The force structure. The definition trap snaps shut.

Our second reason is the increasing cost of C^2 systems. Increasingly sophisticated C^2 technology is driving system prices higher. C^2 systems have grown from simple, hand-cranked field telephones requiring human switchboard operators to worldwide, instantaneous, fully-automated hotlines. Advances in technology have reduced the size of behemoth computers used in C^2, like the SAGE and BUIC computers, to the size of desktop personal computers. At the same time, prices have skyrocketed-not the price of the electronics which is generally going down, but the price of integrating the communications and computers with software and embedded knowledge.

High-technology weapons also influence C^2 prices. The commander's increasing dependence on high-technology weapons leads to a greater dependence on sophisticated communications and computers to manage and control them. High-technology adversaries (or the enigmatic adversaries of unconventional conflict) are forcing an increased interdependence between the C^2 process and the supported forces. Prices of these high-technology systems, expressed in unit procurement cost or even "dollars per pound," often highlight them in Congressional deliberations. Records of the annual DOD authorization bill hearings reflect these discussions. And because familiarity breeds contempt, public familiarity with the electronics technology used in C^2 (the personal computers, facsimile machines, and "intelligent" telephones) now makes it easier for critics to debate C^2 issues.

Through the 1980s, congressional oversight of defense and other national matters increased substantially. A product of this increased oversight—and our third factor—is the enhanced level of detail in the lists of Congressionally-authorized weapons systems and system upgrades. A sampling of legislative histories for defense authorization bills in the 1980s will clearly illustrate how the authorization line-item detail is increasing. Designating programs as congressional "items of interest" has brought many weapons systems (including C^2 systems) into the limelight. As a prime example, the high dollar value of military satellites has made those C^2 system programs an attractive target for oversight—and budget cuts. Other examples include national warning system computer upgrades and jam-resistant combat radios. Besides the dollar value of programs, the Congress has also been deeply interested in interoperability among the services. This interest also glows in the C^2 limelight because many of the more costly C^2 programs deal with interservice communications.

Our fourth reason is found in the politics of assigning forces to combatant commanders (that is, to the CINCs). For a combatant commander to be viable—to be able to carry out the orders of the National Command Authorities—he needs to have forces assigned to him. As forces are principally under the administrative control of the respective service, formal force assignment is essential to a combatant commander's unity of command and his ability to exercise his statutory authority.[17] Without unity of command, the combatant commander's chain of command can be interrupted in "skip-echelon" fashion by higher organizations or by Service components. USCINCEUR must have Army combat divisions and other categories of forces assigned to him so he can maintain the US deterrent posture on European soil. USCINCLANT and USCINCPAC need combatant ships assigned to them to carry out US maritime strategy in the Atlantic and Pacific Oceans. USCINCSTRAT must have strategic bombers, ICBMs, and fleet ballistic missile submarines assigned under his control so he will be able to execute strategic nuclear policy.

When the Congress authorized the formation of the US Space Command (USSPACECOM) in 1985, the assignment of forces took a curious twist. Much of the space launch and tracking facilities then operated by the Air Force Systems Command were assigned to USCINCSPACE, as were the tactical warning and attack assessment systems of the North American Aerospace Defense Command (NORAD).[18] But with the exception of NORAD fighter-interceptor squadrons, USCINCSPACE has few "traditional" elements of the military force structure assigned to him. Instead, the Joint Chiefs of Staff have assigned him mostly C^2 systems.

Former Vice Chairman of the JCS General Herres explained that the C^2 resources managed by USCINCSPACE are integral components of the national C^2 system. But from the perspective of USCINCSPACE, ". . . these sensors are not command and control system elements, but rather the *basic components of his force structure. . . .*"[19] General Herres also identified budgeting for over-the-horizon radars as another force structure issue. "They're big and expensive and nobody's in love with them since they take away from force structure in other areas. But the CINCs need them, and we're going to have a shootout here before long; the services are probably going to want to cut back on their deployment."[20]

These efforts over the years to make C^2 systems part of the traditional force structure, both deliberate and inadvertent, mean that major C^2 systems now must compete for weapons systems dollars within the context of the military force structure.[21] C^2 system competition for tenured membership in the force structure is a novel idea—not only novel, but a difficult idea for the "traditional" force structure planner to accept.

Swords and Stumbling Blocks

C^2 membership in the force structure club is a two-edged sword. Budget fluctuations activate the sword. Swung in one direction, the sword challenges the rest of the force structure for territory. Swung in the other, the sword slices at the low-seniority C^2 newcomer. Until C^2 is awarded a tenured position in the force structure, this sword-swinging will continue to happen.

Why has it been difficult for traditional force planners to accept C^2 for tenured membership? A large part of this reluctance stems from the institutional interests or culture of the service force planners. This is our first stumbling block. Senior RAND Corporation researcher Carl Builder investigates these institutional interests. Drawing on his findings will explain how these interests relate to the membership of C^2 in the force structure.[22] C^2 systems, as explained earlier in this chapter, are hard to "count." However, "counting" is a principle of traditional force structure planning. Builder found that the services' idea of self-measurement is counting numbers—numbers of carriers, air wings, combat divisions, and so forth. A service which perceives it does not have adequate numbers to fulfill its mission feels it has been less than successful in competition with other services. Consequently, traditional force planners are preoccupied with numbers. For example, the Navy has used its maritime strategy as an institutional defense when the naval force structure (that is, the number of capital ships) is threatened. Builder is not passing judgment. He says the services are doing what institutions often do in a competitive environment where they perceive they are being rewarded for how well they compete for resources.

These institutional measures are so deeply entrenched and enduring, particularly in the Air Force and the Navy that C^2 systems or resources are a hard thing for the traditionalist to accept. As Enthoven and Smith commented 20 years earlier, one who grows up in military bombers will continue to advocate more bombers. If the bomber advocate needs to compromise with the aircraft carrier advocate because of a shift to a more intense maritime strategy, Enthoven and Smith claimed that the force planners will build a force structure which promotes more bombers and more carriers.[23] As users of C^2 systems, operational leaders should, but are often unwilling to, advocate C^2 systems. Operational advocates perceive that reducing or realigning the traditional force structure—whether or not it means incorporating more C^2 systems—limits the perpetuation of the long line of force elements.

Our second stumbling block, budget fears, harkens back to the two-edged sword. When proposed budget cuts are very serious, there are questions about whether we have to "reach down" to the highly esteemed traditional force structure. It's as if you were to take not only "a pound of flesh" but a piece of bone from the skeleton—compromising the integrity of the service itself. Everything not the traditional force structure skeleton is flesh. Logistics, medical support, ammunition, fuels, C^2 systems, and the like are flesh. As the 1985 Senior Steering Group on conventional force planning declared, investments in mobility, training, and improved C^2 are preferable to a larger, hollow force whose worth is based on numbers alone.[24]

Builder found that the budget-driven tradeoffs among force structure categories are "forbidden ground." The idea that forces can be traded off implies that one force category can be traded or substituted for a different one.[25] It also implies that, because task forces of multiple categories perform well, the composite forces are interdependent. The idea of interdependence flies in the face of a service's concept of independent forces with unique roles and missions.[26]

The realm of C^2 resources frequently crosses interservice boundaries. This is our third and final stumbling block. As Gansler contends, resources used by many and not part of anyone's primary mission are rarely championed by one.

How can we push aside these stumbling blocks? We know these institutional cultures will not change quickly and, for the sake of stability, probably should not. We can only plead for more balance in force structure planning—to rationally include C^2 systems and other supporting resources. As C^2 systems seek tenured membership in the force structure, we should learn how to decide on the proper mix of C^2 systems with respect to the rest of the forces, within a constrained budget.

Forces for Unified and Specified Commands

A JCS document, "Forces for Unified and Specified Commands," enumerates how military forces are assigned to the unified and specified CINCs.[27] This document, commonly referred to as the "Forces for," is the heart of force structure planning and debate. The "Forces for" deals only with existing forces in the force structure, not systems on the drawing board. It is the ideal instrument for reflecting how to integrate C^2 into the force structure.

While the "Forces for" has been around since the 1960s, it wasn't until the DOD Reorganization Act of 1986 that the document grew some teeth. Congress passed the Goldwater-Nichols Reorganization Act in part to ensure that combatant commanders have the authority and the assigned resources to fulfill their respective theater missions. In other words, Congress wanted to ensure the CINCs could enjoy unity of command, an important principle of command and control.[28] To encourage more efficient use of defense resources, the House and Senate agreed that the military departments must explicitly assign all forces (except those for recruiting, organizing, training, or supplying armed forces) to the combatant commands in a way that is consistent with the national military strategy.[29] Combatant commanders are therefore going to play a greater role in force planning and budgeting. Consequently, force planners need to work out a rational scheme for systematically reflecting CINC interests in the context of national security strategy. The "Forces for" will be the principal tool for assigning forces.

In a 1989 report on DOD's progress in implementing the Goldwater-Nichols Act, the General Accounting Office (GAO) analyzed the "Forces for" document[30] and found that although the assignments are for peacetime only, they coincide closely with the CINCs' wartime missions. When combatant commands are established or disestablished, when combatant command missions are changed, or when CINCs' geographical areas of responsibility are changed, the JCS opens the "Forces for" document for proposed changes and comment. Once the force structure changes in the document are jointly agreed upon, the JCS sends the "Forces for" to the Secretary of Defense for approval. In the latter part of the 1980s, the JCS opened the "Forces for" several times.

One such opening of the "Forces for" in the 1980s was the springboard for the entry of C^2 systems into the traditional force structure. The event was the establishment of USSPACECOM. In forming this new combatant command, the JCS had to identify forces USCINCSPACE could use for carrying out his new missions. This evolving trend to include C^2 systems in the force structure began with high-dollar-value "forces," including military satellites for communications, tactical warning, navigation, and meteorological support.

The representative types of forces assigned to the CINCs through the "Forces for" include: strategic offensive forces, strategic defensive interceptors, general purpose land forces, general purpose tactical air forces, general purpose naval forces, intertheater airlift, intratheater airflift, sealift ships, and command and control resources. This last includes national command systems, command and control headquarters for CINCs, airborne command posts, surveillance and warning systems, strategic defensive control systems, missile and space warning systems, and space operations systems. Note that, in addition to the traditional elements of the force structure, the list now includes space systems and national warning and attack assessment systems—C^2 systems.

With the trend toward tenured membership for C^2 in the force structure, it is possible that by the end of the 1990s "Forces for" will also include other military communications satellites and the larger terrestrial satellite communications terminals,[31] the C^2 system for the US Transportation Command, larger nodes of tactical communications network equipment which are used by all land and air forces, and maybe some elements of national missile defense battle management.[32]

Each one is properly called a C^2 system; many are designated as weapons systems; all have high price tags. The contribution of each of these evolving C^2 systems to mission success will have to be measured so force planners can decide how much C^2 to buy, in balance with force elements, within the new context for command and control.

§ § §

Notes

1. Statement of John F. McLaughlin to the Communications Subcommittee, Committee on Commerce, Science, and Transportation, US Senate, 4 April 1990. McLaughlin is Executive Director of Harvard University's Program on Information Resources Policy.

2. Joint Pub 1-02 defines force structure under the heading "military capability" as "Numbers, size, and composition of units that comprise our Defense forces; e.g., divisions, ships, air wings." *Department of Defense Dictionary of Military and Associated Terms* (Washington, DC: The Joint Chiefs of Staff, 1 December 1989).

3. Any force structure, whether or not it expressly includes C2, must be chosen to fulfill the aims of the national military strategy.

4. Department of Defense, *Defense 89* September/October 1989, (Washington, DC: GPO, 1989), 40-41.

5. Colonel Robert P. Haffa, Jr., USAF, *Rational Methods, Prudent Choices: Planning US Forces* (Washington, DC: NDU Press, 1988), 15.

6. Alain C. Enthoven and K. Wayne Smith, *How Much is Enough?* (New York: Harper and Row, 1971); reprint ed. (Millwood, NY: Kraus Reprint, 1980), 162, 324.

7. Jacques S. Gansler, *Affording Defense* (Cambridge, MA: MIT Press, 1989), 136, 139-140. Gansler calls for even more centralized force planning and programming by the Organization of the Joint Chiefs of Staff to address such deficiencies.

8. International Institute for Strategic Studies, *The Military Balance 1988-1989* (London: IISS, 1988).

9. Colonel Robert P. Haffa, Jr., USAF, *Rational Methods, Prudent Choices: Planning US Forces* (Washington, DC: NDU Press, 1988), 16-24.

10. Francis P. Hoeber, *Military Applications of Modeling: Selected Case Studies* Military Operations Research, vol. 1 (New York: Gordon and Breach, Science Publishers, Inc., 1981), 21.

11. See Haffa, 47-52, for a general explanation of these methods. Later chapters of this book will discuss these techniques in more detail. For an intricate way of predicting land warfare outcomes based on historical battle data, see Trevor N. Dupuy, *Numbers, Predictions, and War* (Fairfax, VA: HERO Books, 1985).

12. Harlan K. Ullman and others, *US Conventional Force Structure at a Crossroads* (Washington, DC: Georgetown University Center for Strategic and International Studies, 1985), 8, 42, 44. Participants included LtGen Kelly Burke, USAF (Ret.); Adm Thomas B. Hayward, USN (Ret.); RAdm Robert Hilton, Sr., USN (Ret.); LTG James Hollingworth, USA (Ret.); Robert Komer; Gen Bill Minter, USAF (Ret.); Robert Pirie; LTG Philip Shutler, USMC (Ret.); Gen William Y. Smith, USAF (Ret.); and Adm Harry D. Train II, USN (Ret.).

13. Resources like tactical radios are abundant, but a stand-alone radio isn't usually counted as a C^2 system.

14. Lt General Clarence E. McKnight, Jr., USA (Ret.), "A Nation in Transition: The Role of C3I Systems," *Signal* 42, no. 8 (April 1988), 55.

15. Congress, "Automatic Data Processing Equipment," Amendment to Title I of Federal Property and Administrative Services Act of 1949 (Sec. 111), P.L. 89-306, 30 October 1965.

16. Lieutenant Colonel Israel I. Caro, USAF, and others, *Mission Critical Computer Resources Management Guide* (Fort Belvoir, VA:

Defense Systems Management College, September 1988), 2-2 defines mission critical computer resources (MCCR) as "Any computer resource that is an integral part of a weapons system or an operational system and required by that system for proper operation." Embedded computer resources are a subset of MCCR. The Warner-Nunn Amendment exempts five areas of MCCR from Brooks legislation: (a) those involving intelligence activities; (b) those involving cryptoanalytic activities related to national security; (c) those involving command and control of military forces; (d) those involving equipment that is an integral part of a weapons system; or (e) those critical to direct fulfillment of military or intelligence missions. See Caro and others, 3-1 to 3-4, for the chronology leading to the Warner-Nunn Amendment. For reasoning behind the amendment, see Senate, *Department of Defense Authorization for Appropriation for Fiscal Year 1982* S.Report No. 97-58, 97th Congress, 1st sess., 1981, 142-143. Professor Wilbur Jones of the Defense Systems Management College defines weapons systems as those system used by armed forces to "warfight." They include all equipment and systems used by a combatant command, that is, trucks, trailers, radios, and so forth, as well as ordnance, guns and the like to perform a specified function or meet a mission need. See Wilbur D. Jones, Jr., *Introduction to Defense Acquisition Management* (Fort Belvoir, VA: Defense Systems Management College, March 1989), 1. The DOD-NATO definition for weapons system is not as clear: a combination of weapons required for self-sufficiency with related equipment, materials, services, people, and means of delivery and deployment. *Department of Defense Dictionary of Military and Associated Terms* Joint Pub 1-02 (Washington, DC: The Joint Chiefs of Staff, 1 December 1989).

17. For a force commander's perspective on what it was like to have responsibility for implementing C2 in the pre-Goldwater-Nichols era, and little wherewithal to do it, see Lt. General John H. Cushman, USA (Ret.), *Command and Control of Theater Forces: Adequacy* (Washington, DC: AFCEA International Press, 1985), 73-78, 83-105, 153-164.

18. USCINCSPACE is dual-hatted as CINCNORAD.

19. General Robert T. Herres, USAF, "Equipment, Personnel and Procedures—Foundations for Future C2 Architecture," in *Principles of Command and Control,* Jon L. Boyes and Stephen J. Andriole, eds, AFCEA/Signal Magazine C^3I Series 6 (Washington, DC: AFCEA International Press, 1987), 420-421. Emphasis in the original. General Herres was the first commander of USSPACECOM.

20. General Robert T. Herres, USAF, "Strengthening the Chairman of the Joint Chiefs of Staff," in *Seminar on Command, Control, Communications, and Intelligence* Guest Presentations, Spring 1988; Incidental Paper I-89-1 (Cambridge, MA: Harvard University Program on Information Resources Policy, 1989), 80.

21. Of course, many "minor" C2 systems are embedded in the weapons systems they support, and there are also many C2 systems used by the "peacetime" commanders (such as the Commander, Air Combat Command) to "organize, train, and equip" the forces. These, too, compete for Defense dollars.

22. Carl H. Builder, *The Masks of War,* A RAND Corporation Research Study (Baltimore, MD: The Johns Hopkins University Press, 1989), 20-22, 65. An underlying theme of Builder's book is how the US Army should do force planning. The book is largely based on his 1986 study, *The Army in the Strategic Planning Process: Who Shall Bell the Cat?*

23. Enthoven and Smith, 5-6.

24. Ullman and others, 44.

25. In later chapters, we will explore how C2 systems as a force category can be traded for other types of forces.

26. Builder, 160.

27. Comptroller General, "Defense Reorganization—Progress and Concern at JCS and Combatant Commands," Report No. NSIAD-89-83 (Washington, DC: US GAO, 1 March 1989), 43-44, 56.

28. It would be reasonable to suggest that the Goldwater-Nichols DOD Reorganization Act of 1986 is a C2 tool because it improves unity of command for the combatant commanders.

29. See especially Congress, *Goldwater-Nichols Department of Defense Reorganization Act of 1986,* P.L. 99-433, Sec. 211 and 214, 1 October 1986. See also H.Report 99-824, 12 September 1986. The DOD Reorganization Act of 1986 also permits CINCs to have small budgets and encourages continued CINC participation in Pentagon force planning. As the Act also permits eventual growth of CINC budgets, CINCs will be much more budget driven. Most of their small

budgets are now dedicated to C2 efforts under the CINC Initiatives program. For a history of how the CINC Initiatives program evolved, see Cushman, 204-207, 210-211.

30. Comptroller General, 43-44, 56.

31. Some of the satellite communications resources, namely satellite capacity and the larger earth communications terminals, are already managed by corporate decisionmaking among the Joint Staff and the services.

32. Those C2 systems which are intimately integrated into a Service-unique platform probably will never make the "Forces for" list. By this, I mean C2 systems specifically tailored to one (maybe two) Service's way of doing business, even though the system may be linked with other Services through interoperable communications. For example, the Aegis C2 system is tailored to the Navy's doctrine for monitoring and controlling anti-air and anti-surface warfare. But the Aegis can also be linked to the E-3 Airborne Warning and Control System and other parts of the Air Force's Theater Air Control System, USMC Tactical Air Operations Centers, Army air defense systems, and corollary NATO systems.

3.
Command and Control in Operational Warfare

Now that we have characterized how significant C^2 is to warfighting and peacekeeping and how traditional force structure planning is undergoing a major—and permanent—change to encompass C^2 systems, we need to develop a suitable technique for understanding how to fit C^2 systems into the national military strategy. The suitability of any technique will be found in how well it measures what C^2 contributes to the success of military missions. With an acceptable model as a foundation for analyzing the impact of C^2 systems, we will be able to explore ways to integrate C^2 successfully into the military force structure. We can then evaluate whether investing in C^2 systems brings about an "economy of force."[1]

What C^2 systems contribute to mission success is the pithy essence of the difficult questions posed to C^2 advocates and specialists nearly every day. Some years back the C^2 world turned its focus to an emphasis on technology rather than on contributions to mission success. Questions, particularly in the Navy and the Air Force, centered around whether new C^2 technology was affordable enough to replace old C^2 technology. This focus on the technical aspects of C^2 mirrored the technology focus in the rest of the force structure, a focus on better tanks, better ships, better airplanes.[2] Consequently, the present US military force structure is unfortunately organized within the framework of technology rather than within the framework of the missions to be performed by military forces. The fact that we tend to "count" force elements in a force structure categorized by force types bears this out. Despite the statutory definition of roles and missions of the military departments along task lines to "organize, train, and equip," the military departments often measure their self-worth by the degree of improvement in the technology of the weapons systems they have been authorized to acquire rather than the estimated effectiveness within their assigned missions.

With a lower defense budget, the United States can no longer afford to rely on technology as the cornucopia of opportunities for populating the force structure. The United States must instead return to common-sense precepts of Defense decisionmaking wherein military mission requirements drive technological solutions, not vice versa.[3] The possibilities for returning to the basic precepts are manifest in two areas: first, in the newly defined decisionmaking powers given to the unified and specified combatant commanders for force planning; second, in the revitalization of the operational art.

The Renaissance of Operational Level Doctrine

As the US military becomes less preoccupied with technology and more concerned with the mission in deciding how to spend its budget, the operational level of warfare is coming back into focus. Before embarking on a review of how C^2 systems contribute to contemporary warfighting and peacekeeping, a review of the operational level of war is in order, because operational warfare will strongly influence how the United States invests in command and control. Major Paul Hughes is one of the first to address C^3I in light of operational warfare doctrine. He maintains that the "renaissance" of the operational level of war in land warfare doctrine dictates radical changes in the way the military configures C^2 systems to give leverage to "meager resources" of a leaner force structure.[4] In other words, different C^2 equipment and procedures are needed to exercise operational level doctrine than to support a doctrine of attrition warfare. Rather than amassing overwhelming forces to ensure mission success—a measure the US military can no longer afford—commanders need to manage fewer, higher quality forces with finesse. Rather than amassing information relating to the conflict, the commander and the staff need to manage information for results selectively.[5]

The reintroduction of the operational level of war has often confused the US military establishment, because many middle managers and senior military leaders have not been exposed to its various meanings in their professional schooling. One way to look at how the operational level of war fits between the strategic and tactical levels of war is to view it in the analogy of a game of chess.[6] When two opponents face each other over a chessboard, each contemplates a strategy, to include not only objectives, but also mental instructions about what "path" to travel to get there. Should I attack vigorously and vindictively, sacrificing any piece to reach checkmate quickly? Should I sustain a defensive posture and conserve my forces? What are my opponent's options and how many of his next moves can I anticipate? The competent player is also aware of and drilled in the available tactics—how the rules permit each playing piece to move across the board. The king can move only one square at a time in any direction, while bishops can tactically move on diagonal paths, knights jump in three-square patterns, and so forth. How to apply this set of chess rules represents the "standard doctrine," the principles and policies by which the player can tactically employ his forces.

In this analogy, the operational level of war is represented by a player skillfully combining the various tactics available within the set of rules and "standard doctrine" to fulfill the intent of his game strategy. The skilled player, armed with a mission-oriented order, builds a concept of operations which is consistent with standard doctrine. He must be innovative to seize the initiative, think "three steps ahead," quickly gain the tactical advantage, and continuously and intelligently adapt to the changing situation. Is it better to make short-distance moves on my side of the board to deceive the opponent and set an enveloping trap? Or is it better to rapidly combine tactical moves to provide a forward screen my opponent can't penetrate? What's the opponent's culminating point? Extrapolating this analogy back to the operational level of war, we see how the commander, inspired by doctrine, artfully combines practiced tactical moves into an operation (or operations) that satisfies the mission objective and fulfills the overall strategy.

Chess opponents enjoy one luxury US military commanders rarely have: they begin their conflict with quantitatively equal forces. US military commanders, usually poised for conventional warfare conflict against numerically superior forces (as on the Korean peninsula) need to practice the operational art to gain the qualitative advantage and improve their chances for mission success. Instead of trying to annihilate opposing forces, the commander is obliged to use his limited forces to neutralize the threat—to deny the enemy the ability to perform those functions that most threaten friendly security.[7] Apportioning a few sorties to crater airfield runways may, for example, be a more effective use of munitions in gaining air superiority than sortie after sortie to lure enemy air forces into dogfighting. Deep ditches at chokepoints along armor advance routes may be more effective than antitank munitions. We have to think smarter to gain and sustain the qualitative advantage. In addition to better weapons technology, we need better C^2.

We can extend this overarching concept of denying functions to all forms of warfare. However, the subelements of operational art do not relate well to all warfare categories. While maneuver theory is an important component of operational level doctrine for land and tactical air warfare, it is almost diametrically opposed to the attrition theory prevalent in other warfare categories.

In his foreword to Simpkin's 1985 on the maneuver-oriented future of land warfare, General Starry even contends that attrition warfare is outmoded for Western powers because we will continue to be at a quantitative disadvantage relative to our most threatening adversaries.[8] While General Starry's rationale holds much merit for operational level doctrine in land and tactical air warfare, classic applications of maneuver theory are inconsistent with strategic warfare and naval warfare. Strategic nuclear war planning can include many preplanned options for strikes that would disrupt or deny enemy functions, such as C^2. But intercontinental bombers and missiles, once ordered to specific flight paths and trajectories, perform few operational-level maneuvers to deny enemy functions.[9] The physically superior force, if commanded into battle, usually has the advantage. Attrition theory is even more important in naval warfare. In the domain of the sea, operational-level (apart from tactical-level) maneuver is desirable but difficult because the force commander cannot always artfully execute operations with "finesse" in open water. First, there is no terrain or vegetation advantage. Second, there is rarely any compelling logic for keeping reserve forces or a defensive posture at sea.[10] Nevertheless, trends in US military doctrine are putting less emphasis on attrition and more on maneuver. In the end, denying the enemy from performing his most threatening functions—by applying attrition, maneuver, or any other doctrinal theory—should be the most important goal in operational art.

This larger realm of operational warfare, infrequently visited by the US military establishment since World War II, is drawing new attention to ways of effectively employing increasingly limited forces (as Paul Hughes suggests, the "meager resources"). Rather than identifying abstract strategies at the high end and maneuvering forces and force elements by some rote application of doctrine at the tactical end, the operational level of war has expanded horizons on how to combine tactical moves in an artful way into one or more operations which contribute to the strategy. Focusing on the operational level has, however, reopened some vital dimensions of warfare relating to the quality of the operational art. Commanders are realizing there are no defined boundaries between any two of the warfare levels. A commander engaging in a campaign at the operational level may be carrying out strategic objectives; a campaign at the operational level may be one of many tactics being pursued by the strategic commanders; and so forth. So, operational art applies to the strategic and tactical levels of warfare as well as to the operational level.

What useful context can operational warfare offer for analyzing C^2? Among a handful of current descriptors of the operational art, there are three aspects that deserve attention: the shared image, the tempo of action, and the uncertainty of action.[11] These three aspects are a fertile field for growing criteria to evaluate C^2 systems. These aspects can also help the commander intelligently employ C^2 systems.[12] With our increased focus on technology for C^2, we seem to have overlooked aspects like these which embody the essence of command and control. Examining them will provide us the foundation for an improved way of thinking about C^2.

Here's how these three aspects relate to everyday life. To truly communicate, the sender and receiver of certain information must share a common understanding or image of what the sender means by relating that information. The sender bases his image on concepts he attaches to information; information is, in turn, an interpretation of raw data. To communicate intent, the commander, his or her staff, and the forces must share a common image. As private citizens, we are often uncertain about the future and have to adapt to differing rates of change in our lives. So it is also with the commander of military forces. These concepts of the operational commander sharing his image and coping with tempo and uncertainty will be this book's threads for tying together the analysis of how C^2 systems contribute to mission success.

Shared image, tempo, and uncertainty have not been as meaningful at the strategic level of war, where commanders establish major objectives and pass them to subordinate commanders as terse mission statements. Although these mission statements often identify a completion deadline and account for the broad risks in executing the strategy, they don't usually relate how the commander thinks he will orchestrate subordinate commanders' combined actions. Nor do they address how the forces must adapt to varying rates of change (tempo) in the situation, movements, strengths, and intentions. These statements rarely address the uncertainties (the probabilities of success) for the combined actions—in view of what is known and not known about the enemy threat. At the other end of the spectrum, shared image, tempo, and uncertainty are not the greatest challenges at the tactical level of war. The doctrine or methods for one ship engaging another is practiced through training and exercise; the certainty by which a mechanized infantry battalion can successfully attack a tank company under given terrain and weather conditions is generally known. Similarly, how long it takes an attack aircraft to travel from base to the locations of an enemy artillery battery and the probability of kill for the type of munitions dropped on the battery are reasonably predictable.

But when the commander forms a concept which combines these actions into a joint task force mission, the tempo at which all actions can be successfully coordinated and executed is much more a factor of anticipating how the enemy may further respond, what the commander's force morale is, how well the information available is grasped, and other speculative factors, than it is a rigid mathematical analysis of probabilities of how one force might kill or otherwise neutralize another force. Hence, actions at the operational level of war are often called the operational "art." Military professionals are recognizing the success or failure of the commander of forces in war to be a function of how well the commander practices the operational art. Martin van Creveld forthrightly describes how C^2 and uncertainty relate: the ". . . history of command in war consists essentially of an endless quest for certainty."[13] When the commander enjoys some success in this quest, what happens? At all levels of warfare, ability to cope with uncertainty and ability to cope with tempo, and the ability to build shared images are all closely related. The more certain a commander is about a situation, the greater the perception he or she can cope with the tempo or pace of battle. Certainty on the part of the commander also enhances his ability to use available information to build a shared image. But we should also recognize absolute certainty cannot be achieved, because of continually expanding information and information warfare (such as deception) among opponents.[14]

Looking at C^2 from a different viewpoint, the objective of increasing the tempo of the conflict is to increase the enemy's uncertainty and to jeopardize the enemy ability to form "shared images" with his forces. Increasing tempo to a level where the enemy cannot cope with it is the essence of an "artful" counter-C^2 effort. George Orr advances the ideas that creating uncertainty for the enemy can totally perplex him because some ". . . are so intolerant to ambiguity that the mere presence of ambiguity is perceived as a threat."[15] Accordingly, the application of C^2 countermeasures has become an important branch of operational warfare doctrine because commanders recognize that the contribution of C^2 systems to mission success is crucial. On the one hand, commanders strive to protect their C^2 assets; on the other, they attempt to target the enemy's C^2 assets.

Simpkin, in describing some advantages of maneuver theory over attrition theory, stresses the importance of velocity over mass in achieving the momentum to defeat the enemy. Velocity, he explains, can be increased or decreased much more readily than the mass (force level) of the organization.[16] Managing velocity is one of the technical skills in practicing the operational art. The importance of velocity relates, in turn, to the importance of tempo.[17] the enemy assaults with a high-velocity component such as heliborne forces, the operational tempo of the engagement is far greater than if he had assaulted with light infantry. The heightened tempo puts more stress on the friendly C^2 process. In fact, Simpkin considers C^2 timing to be one of the several elements comprising tempo and that "paucity or inaccuracy of information" in the C^2 process is one of the several factors which can slow momentum.[18]

Taking what we know about these three aspects of operational art, the objective of a commander's C^2 effort is then to reduce the time to decide, coordinate, and execute military actions; reduce any murkiness clouding the image of his intent; and reduce the uncertainty about his side's ability to act. His corollary objective is to increase these things on his opponent's side. If there is a fixed amount of information about the situation available to both sides, then the C^2 efforts become a pull-and-tug between the two sides to exploit that limited information. It's much the same in the game of chess. With what we now know about these three aspects of operational art, it's time to consider what constitutes a C^2 system good enough to contribute to exercising operational art.

Desirable C^2 System Features

What are the characteristics describing a good C^2 system? There are many different sets of desirable attributes for a C^2 system; any two groups of experts probably could not decide on a common set. The following paragraphs therefore catalogue as many desirable C^2 system factors as practicable, in the context of operational art. The emphasis is on subjective factors because, at the higher levels of military problem solving and decisionmaking, issues are not clear cut and cannot be easily quantified.[19] This "brainstorming" serves to identify all subjective factors which may have some bearing in deciding what C^2 contributes to mission success. In chapter 7, we will sort out which factors are the most relevant in evaluating what a C^2 system contributes to mission success. Because these attributes portray a successful C^2 system, the better a system adheres to these attributes, the better the chances of mission success.

Other searches for these factors have not been fruitless, but neither have they been coherent. For a 1987 symposium, Ricki Sweet attempted to build a catalog of suitable measures of merit for C^2 and looked into the pros and cons of having a single catalog. She reviewed several efforts from 1973 to 1987, variously sponsored by the military services, to derive a generic set of measures. Sweet concluded that we have barely started to catalog the measures of merit. Of the 60 measures she encountered, only 16 were used by more than one analyst—and then typically by only two analysts. Even then definitions for the shared-use parameters were rarely consistent. Sweet concludes that until a more common set is developed, the best consistency we can hope for falls within a C^2 system supporting a specific military mission in a specific armed service.[20]

Before we begin to build our own set of measures, it's important that we review what a C^2 system is for. The mission of a C^2 system is not to "command and control" but to satisfy the needs of the commander and his staff in allocating and managing forces to execute assigned missions. Therefore, the objective of a C^2 system is the success of the military mission—whether a force functions more effectively and more quickly than its enemy. In a larger sense, mission success will largely depend on the ability of commanders to effectively manage their forces in response to a changing threat or other environmental situation. Success will also depend on the ability of the commander to keep a fast-moving situation from crossing a threshold into a higher level of conflict (if that's what the mission is).

Characteristics that yield a simple descriptive framework for C^2 should be neither technology dependent nor technology driven, because C^2 is a fundamental process for which technology is an "enhancer." In other words, command and control can be as simple as the senses, mind, and will of the leader with no communications or computational support—except the ability to recognize the situation, decide on a course of action, and verbally communicate the decision and his intent to the forces. Or the C^2 system can be as simple as organizing a trusted, competent staff that supports the operational command relationships the commander has with senior and subordinate commanders. We must remember that the commander and his or her staff are part of the C^2 system, and the set of C^2 system descriptors should reflect that.

One of van Creveld's books, *Command in War*, demonstrates his deep insight into the history and characteristics of C^2. His list of nine attributes, incorporated in the list to follow, produces a good starting place for desirable C^2 system characteristics. Because they have a historical basis reaching back to what he calls "The Stone Age of Command," his attributes should apply to any C^2 system, from the most non-automated to the most automated, from the crudest of communications to the most sophisticated. Van Creveld's analysis is particularly well suited to the decision support aspects of C^2 systems.[21]

For those characteristics that relate more to the flow of data and information in the C^2 process, we will turn to a comprehensive paper written by Lieutenant Colonel Fincke at the Army's School of Advanced Military Studies. To complement the evolution of the US Army's and US Air Force's AirLand Battle doctrine, Fincke postulated a series of characteristics that relate more to communications systems than to the decision support aspects of the C^2 process. In describing a "technology-independent" C^2 system, however, we must be careful about Fincke's descriptors. His are firmly oriented toward electronic solutions, but are nevertheless useful in analyzing information exchange.[22]

Major General Welch set out his criteria for a "perfect C^3I system" in a 1977 lecture, and General Bohannon explained his in a 1984 speech. Captain Hughes also dispensed some insight for desirable system characteristics in naval warfare C^2. Through the looking glasses of these two senior soldiers and a senior sailor, we get the important perspective of the operational commander.[23]

In short, a good C^2 system should be dispersed, invulnerable, mobile, responsive, and timely. The following bullets explain these categories, in terms of what a C^2 system should and should not do for the commander and his/her staff.[24] The categories and subcategories are listed in alphabetical order. The way the characteristics are categorized generally follows the intent of the authors.

A. Dispersion to support decentralized operations

Aa. **Decentralization** to maintain C^2 during fluid and lethal conflict

- Support the decentralized operations typical in modern warfare, brought about by geographically separated forces, combat which is fluid in time and space, and increasingly lethal long-range weapons.
- Help the commander effectively control widespread and distant forces pursuing limited, politically complex objectives such as resolving a crisis (Bohannon, 182). Ensure shared image among separated forces is accurate.
- Provide assets with universal characteristics (interoperability and compatibility) so assets will be useful to commander regardless of location, but not cause the C^2 system to become overcomplex or weakened.
- Satisfy the commander's desire to stay close to the battle and be able to feel the way it is going; to judge environment and force status for himself; to judge intentions of the enemy; and to seize initiative Bohannon, 179-180; Fincke, 43-44).

Ab. **Flexibility** to support maneuver of forces

- Be agile and flexible enough to support the maneuver of forces-whether the forces physically maneuver or whether the roles and functions of the forces are changed by the commander. Permit the commander to use whatever force is needed to gain advantage over the enemy, at the time and place of the commander's choosing (Welch, 4-6).

- Provide ease of use by a commander and his staff-adapting to changes in organizational structure, providing aids to decisionmaking, and communicating information with clarity, directness, and freedom from the complications of plans, orders, and the operation itself. Support the commander but do not "dictate" to him (Bohannon, 183).

- Enable a commander to exercise autonomous command from anywhere on the battlefield, allowing him to move about the battle area undetected or at least unidentified as a high-value target (Bohannon, 182).

Ac. **Independence** to operate in stand-alone mode

- Effectively operate in a stand-alone mode if required, maintaining current information when communications are interrupted (Fincke, 45).

B. Invulnerability against active and passive attack

Ba. **Indeterminacy** to make information vague to adversaries

- Keep elements of the C^2 system from becoming the force's center of gravity (Fincke, 27-28, 30).

- Frustrate enemy targeting and countermeasures by creating a perception of random variability and proliferated nodes within the force's C^2 signature throughout the conflict area (airspace, land, or sea).[25]

- If the location of forces cannot be otherwise disguised, create a perception that the C^2 system is continuously "on" so that the enemy can neither identify the specific user nor figure out the content or frequency of information transfer (Fincke, 52).

Bb. **Information security (INFOSEC)** to keep adversaries from exploiting friendly information

- Provide enough communications security to prevent an enemy from exploiting C^2 signals but not inhibit the commander's use of the C^2 system.
- Exchange information in a way which minimizes signal degradations and errors and permits simpler signal encryption and routing.
- Protect information against computer viruses and other forms of data manipulation.

Bc. **Survivability** against loss or degradation of information

- Protect C^2 system against unacceptable loss, interruption, or degradation of information; continue to produce the information needed by the commander and staff. Keep information flowing, consistent with how long the commander can afford to be uncertain about the conflict situation, can issue orders and directives with confidence they will be received and understood, and can forego the ability to synchronize combat actions consistent with battle tempo (Fincke, 15, 56).

C. Mobility to support the tempo of conflict

Ca. **Modularity** to effectively interconnect C^2 system parts

- Provide system modules with common features so that parts of the C^2 system may be effectively combined with others without causing operational problems. Accordingly, support a degree of standardization, flexibility, and ease in reconfiguring the components (Fincke, 25).
- Provide standard procedures, data definitions, and formats to support information exchange, especially for interservice communications.
- Contribute a degree of standardization to the staff so that staff units may perform different primary functions as operations pass through a sequence of phases.

Cb. **Redundancy** to ensure access to information

- Support C^2 communications with multiple information paths and extra equipment and human processing resources to ensure that the commander, staff, and forces will always be able to receive and send needed information.

Cc. **Self-repairability** to correct C^2 failures

- Find, diagnose, contain, and repair C^2 system failures so information paths will not be severed for long (Fincke, 20). Furnish a range of support, from computer self-diagnosis and repair to a command structure realizing its organization is ineffective and doing something about it.

Cd. **Good technical design** for supportability and interoperability

- Accommodate human factors to reduce special expertise and training needed to operate, maintain, and manage the C^2 system and achieve safe and effective performance by operators and maintainers (Fincke, 63).

- Contribute to the commander's leadership quality, continuity, and performance in controlling forces in combat, minimizing uncertainty and sustaining the tempo (Fincke, 61-62).

Ce. **Homogeneity** among means to acquire and transfer information

- Provide uniform ways and means to acquire and transfer C^2 information, to help synchronize the capabilities of the forces consistent with the tempo of the campaign (Fincke, 25).

D. <u>Responsiveness</u> to needs of commander and staff

Da. **Adaptability** to contingencies and unforeseen needs

- Preserve order and cohesiveness among a commander's forces (Welch, 4-6) to adapt to the uncertainty and fluid tempo of chaotic events.

- Furnish means for people and equipment in different functions and echelons to readily exchange information across the same network, in ways which are transparent to the user and provide speedy re-routing, reconstitution, and reorganization as needed within the network (Fincke, 19).

- To accommodate commanders and staff when they move, provide for system elasticity to expand, contract, or change as the situation evolves—without moving the entire C^2 network (Fincke, 39, 41).

Db. **Data transformation** to manipulate raw data into information for decisionmaking

- Collect raw data and transform it into information a human can accurately apply in decisionmaking; transform data quickly enough to yield information useful to decisionmaking. Comprehensively treat all data sources equally and in equal depth (van Creveld, 8).
- Maintain current data; keep stale data away from the commander, particularly when he is being deluged with information immediately critical to mission success.[26]
- Help the commander accurately discriminate among targets and select targets which will best disrupt or neutralize the enemy's intentions.

Dc. **Connectivity** for prompt communications among users

- Improve the speed of acquiring, transferring, and distributing information (Fincke, 61-62). Immediately and automatically connect any one C^2 system user with another.
- Facilitate information exchange among commanders, staff, and forces. Provide for information to be ex-

changed at the commander's desired frequency, ranging from "realtime" to "as required."

- Supply desired communications means including (but not limited to) courier, electrical message, computer-to-computer means, facsimile, voice communication, and mail.

Dd. **Decision support** to aid commander and staff in formulating and testing viable courses of action

- Help the commander and staff select mission objectives which contribute to the overall operation or strategy. Support the decisionmaking process, by narrowing choices and identifying alternative courses of action to the commander and his staff which are suitable, desirable, feasible, and acceptable (van Creveld, 8).

- Provide information to the commander and his staff concerning how to effectively disrupt enemy actions and intentions.

- Aid the commander in envisioning and orchestrating the combined tactical actions of forces at the operational level, at arms-length. Be able to deal with the tactical context of operations (or details of the conflict) if tactical employment doctrine is not well defined (W. Hughes, 188).

- Contribute to stabilizing crisis situations and prevent the conflict intensity from accidentally or spasmodically crossing escalation thresholds. Aid in hostility termination by providing accurate force status and damage assessment and providing the means for the leadership of one adversary to talk with another.

- Provide adequate capacity, but do not overload the commander and his staff with too much information.

- Provide the commander access to raw data which may stimulate his instincts and lead to innovative solutions (Bohannon, 183).

De. **Direction/monitoring** to help commander and staff issue orders and monitor implementation

- Help a commander and staff form and issue orders and instructions which are clear and unambiguous, but do not tell subordinates more than they need to know (van Creveld, 8). Serve a commander by projecting his personality and meaningful orders down chain of command.
- Avoid tactical complexity in planning if it will put control of forces at risk (W. Hughes, 190-191).
- Help the commander and his staff closely monitor the changing situation and how subordinates are complying with orders and instructions, but not so close as to undermine a subordinate's authority or initiative (van Creveld, 8).
- Adhere to the essence of the commander's final decision on a course of action, but account for new circumstances as appropriate (van Creveld, 8).

Df. **Knowledge maintenance** to maintain adequate knowledge base about mode of operations

- Display information (or selected data) clearly and comprehensively (van Creveld, 8).
- Maintain an adequate shared knowledge base so that information can be analyzed as if it had been analyzed individually or collectively by the commander and his staff to produce an estimate of the situation.[27]
- Enhance communications so that the commander, his staff, and forces share a common image of the operational concept.

- Maintain memorized data and "expert" rules from the commander and collective staff which are meaningful, realistic, and current (van Creveld, 8).

Dg. **Relevancy** to identify and exploit the most useful information

- Reliably distinguish which information is true, relevant, and significant enough to bear on the decision (van Creveld, 8).
- Selectively process information. Remove noise and clutter and look at specific areas. Ignore enemy attempts at deception and other manipulation.

E. Timeliness to provide sufficient early warning and execution time

Ea. **Early warning** to sufficiently forewarn commander

- Provide enough warning time for commander to make unrushed decisions on courses of action.

Eb. **Execution time** to provide sufficient time for commander to make the best decision

- Provide enough execution time to issue orders and instructions and synchronize operations.
- Reduce the enemy commander's available time for making decisions and issuing orders.
- Improve the quality of decisions by enabling the commander to delay difficult decisions to the "last possible

moment," but leaving time enough to communicate and implement the decision (Bohannon, 182).

Ec. **Reliability** in providing high-quality, complete information

- Collect and transform data continuously (van Creveld, 8); reliably generate high-quality, complete information sharing among the commander, his staff, and his forces under all threat and environmental conditions (Fincke, 17).[28]

- Preclude errors in judgment that would prevent the commander from engaging the enemy at the time and place of his own choosing and, once engaged, to control the tempo of the engagement (Welch, 4-6). Preclude judgmental errors by helping the commander, staff, and forces share the same image about operational concepts. Support the commander by reducing uncertainty in conducting friendly operations and increasing uncertainty on the part of the enemy commander.

The preceding several pages of characteristics may seem overwhelming, but we must leave no stone unturned in our quest to understand how C^2 resources contribute to mission success. Chapter 7 explains how we can systematically use this list in force structure decisionmaking.

§ § §

Notes

1. Use of this term refers to one of the fundamental principles of war as well as to applied economic analysis and accounting. This will become evident in later chapters.

2. Roger Beaumont, *The Nerves of War: Emerging Issues in and Reference to Command and Control* (Washington, DC: AFCEA Inter-

national Press, 1986), 24, commented that DOD's intense, revisionist review of C^2 systems in the late 1970s perceived problems in a way "closer to engineering than art. . . ." Focus on technology tends to be more prevalent in the Navy and the Air Force than in the Marines and the Army. In a 1986 report, RAND Corporation staff specialist Carl Builder attributed this focus to a Navy and Air Force tendency to revere their respective Services' institutional roles in national security, which are founded on the continued use of naval and aerospace technology. See Carl H. Builder, *The Army in the Strategic Planning Process: Who Shall Bell the Cat?* (Bethesda, MD: US Army Concepts Analysis Agency, 1986), 60ff. Builder updated his analysis in his 1989 book, *The Masks of War* (Baltimore, MD: The Johns Hopkins University Press, 1989).

3. I acknowledge that technological advancements sometimes open new vistas for employing force, and advanced technology sometimes interjects new threats that must be countered. In these cases, technology inspires new *validated requirements*, which in turn sanction technological solutions.

4. Major Paul D. Hughes, *Mercury's Dilemma: C^3I and the Operational Level of War* (Fort Leavenworth, KS: School of Advanced Military Studies, 1988), 4-5. Military theorists generally recognize the Army as the leader in defining operational warfare doctrine.

5. One of the key tenets in current operational doctrine is maneuver. As a result, the academic focus here is on land and amphibious warfare, together with tactical air warfare, as they support force employment ideas in the air-land battle. Strategic warfare (offensive bombers and ballistic missiles and warning and intercept systems) and naval warfare do not expressly subscribe to maneuver warfare. Nevertheless there are elements of operational warfare that can definitely influence strategic and naval warfare.

6. Some tacticians would oppose this analogy and suggest better analogies are found in backgammon or the Asian game of go, where strategic maneuvers and blocking are more essential to success of the game play. Critics also point out that, in any such board game, the opponents can see force status and order of battle across the entire "battlefield," an opportunity rarely found in real warfare. Captain Wayne P. Hughes, Jr., USN (Ret.), *Fleet Tactics: Theory and Practice* (Annapolis, MD: Naval Institute Press, 1986), 168-169, suggests the best analogy for naval warfare is chess in three planes: surface, subsurface, and air.

7. This concept of "functions denied" comes from General Otis, who, as commander of NATO's Central Army Group, was more concerned with preempting Warsaw Pact artillery from firing its weapons just long enough to maneuver his forces rather than consuming a lot of munitions to destroy the artillery pieces. Interview with General Glenn K. Otis, USA (Ret.), 24 October 1989. Brigadier Simpkin's precise expression for "functions denied" is "rendering the enemy force operationally irrelevant." Brigadier Richard E. Simpkin, UK (Ret.), *Race to the Swift* (Washington, DC: Brassey's Defence Publishers, 1985), 139.

8. General Donn A. Starry, USA (Ret.), Foreword to Simpkin, x.

9. Colonel John E. Rothrock, National Defense University Senior Fellow, relates a Vietnam experience which substantiates this tenet at the operational level of warfare. Interrogating enemy forces during that conflict, he learned that the B-52 interdiction strikes against strategic targets had little specific effect in halting North Vietnamese military actions. What deterrent effect the bomber strikes did have was in limiting the size of enemy military actions. Consequently, North Vietnamese and guerilla commanders were instructed to limit the size of their operations; above a certain size, the staging and preparations for operations drew too much attention and led to more strikes. If US commanders had been able to apply more flexibility and adaptability in employing the B-52s to exploit this ability to deny enemy functions (rather than pursuing attrition targets specified by the NCA), there is strong evidence the strikes could have been far more effective.

10. See Wayne P. Hughes, 27, 143-146, and other locations in his book for these important distinctions between attrition and maneuver theories in naval warfare. While Hughes contends that the commander at sea can't be "constantly clever," he doesn't totally put aside the idea of operational maneuver at sea. His examples of littoral operations rely on some concept of maneuver, often to exploit a terrain advantage and to deploy naval tactical air assets. See his Chapter 10 on "Modern Fleet Tactics." Operational level maneuver was also a useful ploy in the 1973 war between Israel and Egypt. Egyptian anti-ship missiles outranged Israeli naval forces, but Israel maneuvered, compelling Egypt to fire ineffectively and enabling Israel to close in and successfully engage the Egyptian task force (Hughes, 79).

11. Frank M. Snyder, in *Command and Control: Readings and Commentary* (Cambridge, MA: Harvard University Program on Information

Resources Policy, April 1989), 15-17, introduced me to the idea of focusing on the aspects of uncertainty and tempo. Frank Snyder, Raymond S. Spruance Professor of C^2 at the Naval War College, refers to reducing uncertainty and increasing available reaction time as goals of the C^2 process. The object of increasing available reaction time is to avoid making half-baked decisions. I chose "tempo" rather than "time," since tempo also connotes dynamic changes in the pace of activity rather than discrete clock periods. Also, tempo is one of the factors usually considered in warfare planning. See also Frank M. Snyder, "Command and Control and Uncertainty," *Naval War College Review* 32 no. 2 (March-April 1979): 109-113 and Frank M. Snyder, "Command and Control and Decision Making," in *Principles of Command and Control,* Jon L. Boyes and Stephen J. Andriole, eds., (Washington, DC: AFCEA International Press, 1987), 17-21, for earlier discussions of uncertainty and time in a C^2 context. The concept of "the shared image" may seem somewhat self-evident, but analysts have only infrequently written about it in the context of C^2. I adopted the term "shared image" from a noteworthy RAND Corporation study about C^2 at echelons-above-brigade level. See James P. Kahan, D. Robert Worley, and Cathleen Stasz, *Understanding Commander's Information Needs* RAND R-3761-A (Santa Monica, CA: The RAND Corporation, 1989), sections 2 and 3. In his seminal paper on C^2, Professor Jacobs explained the same idea as the ability for C^2 participants to "communicate concepts surrounding data." John F. Jacobs, *Design Approach for Command and Control* MITRE SR-102 (Bedford, MA: The MITRE Corporation, January 1964). See also Martin L. van Creveld, *Command in War* (Cambridge, MA: Harvard University Press, 1985), for his ideas about "sharing a common knowledge base."

12. According to Rothrock, employment of C^2 resources also often neglects the operational level of warfare because it doesn't recognize linkages between the C^2 system and the forces being controlled. Just like the operational level calls for the artful employment of forces, it also calls for the artful employment of C^2 resources. He believes commanders need comprehensive education about the intelligent employment of C^2 resources to supplement their education about how to artfully employ forces.

13. van Creveld, 264-268.

14. Major George E. Orr, *Combat Operations C^3I: Fundamentals and Interactions* (Maxwell Air Force Base, AL: Air University Press, 1983),

85-87. Major Orr's book examines the breadth of C^2 theory known at that time.

15. Ibid., 74-76.

16. Simpkin, 93-115.

17. A related principle of war here is the element of surprise. Simpkin contends that the "addicts of attrition theory" plan their warfare deliberately and pragmatically—even announce it ahead of time. Simpkin, 181. In the realm of operational art, where limited forces cannot afford to pursue wholesale attrition, commanders often need to achieve surprise and so must deal with uncertainty.

18. Ibid., 106, 113.

19. While these characteristics address how well the C^2 system works, they do not directly address the quantitative supportability (reliability, maintainability, and related factors) of the system. Although extremely important in evaluating the usefulness of the system, such criteria do not relate directly to C^2 functions.

20. Ricki Sweet, "The MCES and the Search for Generic Measures," in Stuart E. Johnson and Alexander H. Levis, *Science of Command and Control: Coping with Complexity* AIP Information Series Vol. 1 (Washington, DC: AFCEA International Press, 1988), 109, 116.

21. van Creveld, 8.

22. Lieutenant Colonel Dale E. Fincke, USA, *Principles of Military Communications for C^3I* (Fort Leavenworth, KS: School of Advanced Military Studies, 1986), 10-64.

23. Major General Jasper A. Welch, Jr., USAF (Ret.), "C^3I Systems: The Efficiency Connection," paper written from speech given at 39th Military Operations Research Society Symposium, US Naval Academy, Annapolis, MD, 29 June 1977, published in *Selected Analytical Concepts in Command and Control,* John Hwang, Daniel Schutzer, Kenneth Shere, and Peter Vena, eds., (New York: Gordon and Breach, Science Publishers, 1982), 4-6. In spite of the paper's title, Welch downplays optimizing resources for efficiency, since the quest for efficiency is an unlikely wartime activity. General Anthony G. Bohannon, former senior British Army officer, "C^3I in Support of the

Land Commander," paper written from speech given at Fifth AFCEA European Symposium and Exposition, Brussels, Belgium, 24-26 October 1984, published in *Principles of Command and Control,* Jon L. Boyes and Stephen J. Andriole, eds., AFCEA/*Signal Magazine* C^3I Series 6 (Washington, DC: AFCEA International Press, 1987), pp. 182-185. For the perspective of naval warfare C^2, see Wayne P. Hughes, 185-195.

24. Because van Creveld, Fincke, Welch, Bohannon, and Wayne Hughes often state these attributes concisely, many of their word choices are used and references to their respective works are cited in parentheses.

25. The signature, with its image, data, and procedural dimensions, is the intelligence by which the type of force, its size, and its intentions can be deduced. A signature may be visual, aural, photographic, thermal, electromagnetic, or some combination.

26. Interview with Major General Doyle Larson, USAF (Ret.), 7 November 1989.

27. *See The Joint Staff Officer's Guide* Armed Forces Staff College Pub 1 (Washington, DC: GPO, 1988), 150-151 for a tutorial on the classic "Commander's Estimate of the Situation," a tool commonly used by ground forces to evaluate the environment and the threat and to formulate and test courses of action.

28. This characteristic is not the engineer's measure of reliability, but how well the available information can increase the commander's confidence in pursuing the courses of action.

4.
Stalking the Elusive Force Multiplier

What do C^2 systems contribute to this renaissance of operational warfare doctrine? We have established that C^2 systems help the commander in "commanding and controlling" assigned forces. Since assigned forces typically have less capability than the commander desires, C^2 systems generally help the commander communicate a shared image and cope with uncertainty and tempo in the conflict. But exactly how much do C^2 systems contribute to success in all levels of warfare, including the operational level? Some C^2 enthusiasts believe that C^2 systems increase the effectiveness of forces to the point where the forces can execute their mission as if the forces were greater in strength than they actually are. In other words, C^2 resources have "multiplied" the strength of the original force. Critics believe the idea of "force multiplication" is bunk.

The term "force multiplier" has often been used in electronic warfare, C^2, and other aspects of the military environment. While there is not enough evidence to establish precisely when the term "force multiplier" first came to be applied to C^2 systems, a former government official (using the pen name Cassandra) claims that force multiplication became a "prominent and recurring theme" applied to C^2 in the late 1960s. During Vietnam demobilization, rising costs and reduced forces compelled the military to look for ways to manage and control limited force resources more effectively. Cassandra comments that while the argument about whether a force is "multiplied" may not be necessarily provable, it sounds attractive during austere fiscal times."[1] This lack of common meaning is the principal problem with the term "force multiplier."

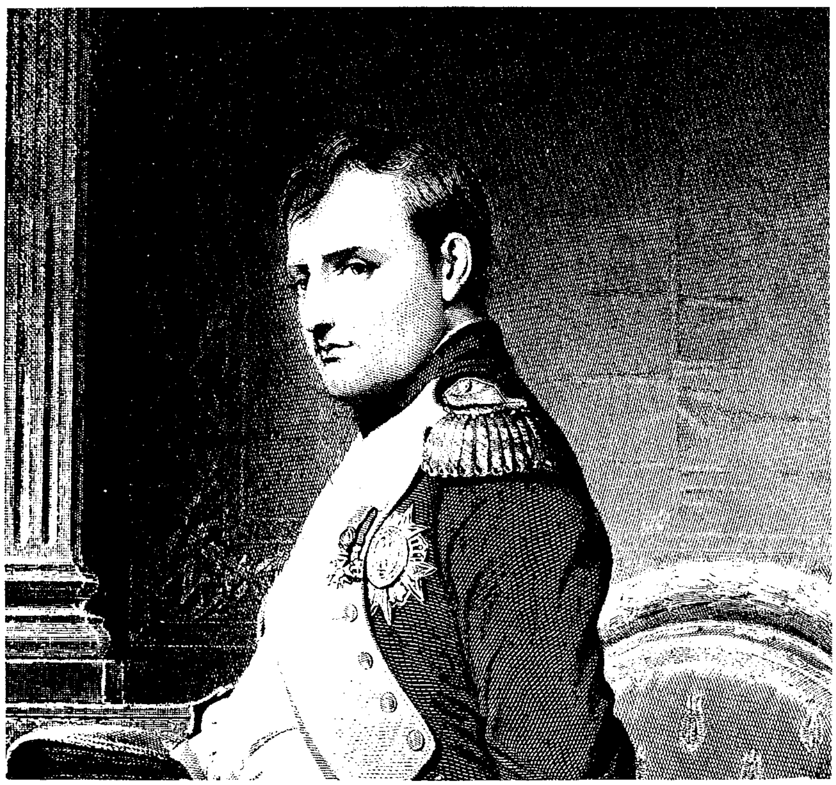
Since the late 1960s, C^2 operators and advocates have applied the term to C^2 systems, but after nearly three decades of using and misusing the term, we are no closer to quantifying the magnitude of the multiplier—is it 2, 1.2, 3.7, or 0.73 times? Indeed, the term has been so misused, it means little anymore and seems to be falling into disuse.[2] "Force multiplier" is no longer suitable rhetoric to answer Pentagon force structure questions. During periods of constrained defense budgets, the only thing that really counts is the bottom line, measured in dollars (we will get to the question of affordability later).

Can we measure the force multiplier effect? Do we need to? In the decades since this term has been applied to C^2, few have ever attempted to design a satisfactory means of determining whether C^2 resources are a multiplier or a divisor and—more important—how to quantify the effect. But if we are going to do "more with less" as a lower budget demands, we must establish what C^2 resources can contribute to mission success. And if they don't contribute anything to doing "more with less," then enhancing C^2 resources is not worth the investment.[3] In this chapter, we will study practical examples of "force multiplication," as well as some of the warfare theories which try to capture the essence of the term in C^2.

Force Multiplication in Operational Warfare

As explained in chapter 1, the C^2 system, whether replete with technology or consisting only of the commander and his staff, depends on the commander because the commander is an integral part of the C^2 system. Martin van Creveld suggests, in a Napoleon anecdote, that the presence of a charismatic, competent leader with talent to "command and control" effectively could be a force multiplier. Interestingly, the Duke of Wellington quantified the multiplier effect (figure 3).

The Battle of Britain (1940 to 1941) was Hitler's attempt to soften up the British Isles, as a precursor to a massive German invasion known as Operation *Sea Lion.* British defensive air forces, greatly outnumbered, depended on a terrestrial net-



Napoleon, a commander as a "force multiplier"

work of coastal radars, operations centers, and communications lines to operating bases to get scramble orders against each Luftwaffe attack. At that time, both the Germans and the British had radar. But in 1940, radar was a defensive device, not practical for airborne use. Consequently, Britain's radar-based C^2 network gave it the home advantage. In the words of a Luftwaffe attack leader,

> In battle we had to rely on our own human eyes. The British fighter pilots could depend on the radar eye, which was far more reliable and had a longer range. When we made contact with the enemy our briefings were already three hours old, the British only as many seconds old—the time it took to assess the latest position by means of radar to the transmission of attacking orders from Fighter Control to the already airborne force.[4]

Using this information advantage from C^2, the British prevailed over every attack with relatively minimal losses, against significant air superiority odds of about 1.4-to-1.[5]

Cassandra and others have credited the United Kingdom's successful homeland defense to the force multiplication from these C^2 resources.[6] The United Kingdom adapted to the tempo of action, launching and redirecting defensive air forces as needed, and the electronic surveillance reduced the uncertainty in the magnitude and intentions of the air threat. Improved communications and progressive doctrine (evolved from combat experimentation) enhanced the "shared image" among the geographically separated air squadrons. The well-accepted success of this "force multiplication" resulted in priority funding for the North American air defense network after the war, according to Cassandra. Although Cassandra claims the multiplication effect was well-accepted, he did not claim that it was possible to measure the degree of effectiveness attributable to the introduction of the British air defense system.[7] A half-century later, our ability to quantify the multiplication effect is not any better.

One of the most often discussed reasons for the US Pacific Fleet's victory over the Japanese in the Battle of Midway (1942) is the good intelligence Admirals King and Nimitz held about Admiral Yamamoto's war plans. Far from their bases and densely concentrated in the mid-Pacific, the Japanese had, but never held, the tactical advantage over the United States. US naval forces established and sustained the tempo of the conflict, exercising operational flexibility to capitalize on Japanese tactical errors. With the knowledge the United States had after breaking the Japanese communications codes, the United States had minimized its uncertainty about Japanese deceptions and courses of action and was able to use its C^2 system to exploit that information. At Midway, the Pacific Fleet had an overall force advantage of 25-to-20 capital ships. But more important—because most of the action depended on naval airpower—the United States had only three aircraft carriers to Japan's four. At the end of the battle, the Japanese had lost all four carriers, one cruiser, 250 aircraft, and 3,500 lives, while the United States lost only one carrier, one destroyer, 150 aircraft, and 307 lives.[8] What advantage did the information give to US forces? While there were many factors leading to the US victory, we could say the United States used its information advantage to overcome a force disadvantage in aircraft carriers of 4-to-3, or 1.33-to-1. It would not be unrealistic to say the force multiplication due to C^2 was 1.33-to-1.[9]

Apart from these "field" examples, there are also examples of force multiplication from the more controlled environment of the "laboratory." C^2 researcher Philip Feld documented the learning curve of a headquarters staff over a 5-day exercise. His factor, understanding the enemy, would be inversely proportional to "uncertainty." As the staff learns to work together, the "understanding" improves. As understanding increases, the "shared image" improves. When the four daily improvements are multiplied together, the composite "force multiplier" is 1.41.[10]

In 1988, the Army assembled a data base of 260 selected air-land battles from 1937 to 1987 to evaluate the credibility and plausibility of wargames and wargame scenarios.[11] This data base consists largely of force-on-force characteristics: unit size, numbers of people, tanks, close air support sortie rates, artillery tubes, and so forth. Robert McQuie, the principal investigator, found many of the data were skewed, or far outside the usual parameters. As the data base expressly rules out intangible variables such as "success," "morale," and "training," we wonder what is the source of the skewing. Embedded in these intangibles, is there any element of success, morale, or training that can be attributed to the commander's and staff's skills and leadership in exercising C^2 over forces? In other words, is the skewedness related to the force multiplier effect of C^2?

Intuitively, many of us would like to believe that C^2 systems are "force multipliers," but some planners and decisionmakers find it difficult to grasp the concept of C^2 as a force multiplier, when compared to other weapons systems that destroy targets and have a performance directly measurable in terms of target casualties. Indeed, some lessons learned suggest that C^2 systems are divisors and not multipliers.[12] An example that comes to mind is General Haig's micromanagement of his British forces in the Battle of the Somme (1916). Because he was too intertwined with the limited technology of the field telephone, he would not relinquish initiative to his maneuvering forces as they attacked the German trenches on the Western Front. Consequently, his subordinate commanders had no flexibility to seize the initiative and adapt to the tempo. As a result, the British forces were stymied in their slavish execution of orders and suffered many casualties.

Martin van Creveld reveals the curious twist: "Within a mere four days, the Germans recaptured ground that the British has fought over for four months—and did so, moreover, in the face of defenses considerably stronger than they themselves had been able to muster at the Somme twenty-one months before." Van Creveld attributes the German success partly to some new tactics and tactical weapons, but mainly to a highly decentralized C^2 doctrine that permitted independent decisions and initiative by front line commanders and minimized interference and control from senior field headquarters. Thus, even though the equipment, technology, and forces were roughly equivalent, the decisive factor was the quality of the German C^2 system (here mainly the doctrinal differences).[13] Van Creveld thus shows how important the human element of C^2 can be to mission success. All the latest automation and communications equipment in the world will not transform a poor commander into a good one.

In recent times, the 1973 Arab-Israeli War was an example of using communications channels again to control action rigidly in the field—from an underground war room in Tel Aviv. In the early days of the War, the experienced commanders in the war room had reasonable continuity with the field forces but had such poor feedback and intelligence that the Israeli Defense Forces were not able to engage the Egyptian armor forces in their grasp decisively. Again, the frontline commanders were strapped and could not adapt to the tempo. While the frontline commanders were certain about the Egyptian armor threat, communications bottlenecks prevented the Tel Aviv war room from experiencing the same certainty. Here the shared image was degraded, not because the forces on the front didn't understand what Tel Aviv wanted, but because Tel Aviv could not correctly perceive the situation on the front. On the other side of the conflict, the lack of a cohesive C^2 structure among Arab forces was a detracting factor for Arab force effectiveness, contributing to the ultimate Israeli success. By a narrow margin, the Israeli C^2 system escaped being a "divisor."

In Vietnam, the United States had even more technology and a global C^2 network: a higher radio-to-soldier ratio than had ever been seen before, wideband (troposcatter) radio in the theater, and satellite communications linking Southeast Asia and Washington, DC. These direct communications again allowed the high command to micromanage forces and stifled the flexibility of those forces. Late in the war, Admiral Metcalf felt like he was on the receiving end of a long-distance "screwdriver" as he evacuated forces from Saigon in 1975. Military leaders in Washington were exercising "skip-echelon" control of Metcalf, bypassing the US Pacific Command and other levels in the chain of command.

A decade later, as commander of Joint Task Force 120, which liberated Grenada, Admiral Metcalf applied his lesson learned by sending masses of information to the National Command Authorities and the OJCS. He did this to build their confidence (certainty) in knowing what was happening in this politically risky action and to keep the Washington staffs occupied with processing situation reports. He did this, in part, to permit more time for deciding on courses of action that would adapt to the tempo as he sensed it. In a way, he corrected the lack of a "shared image" that vexed the Israeli armored forces in 1973.[14]

From Grenada to the Straits of Hormuz

In the rest of this section we will study four operations: *Urgent Fury* in which US forces rescued medical students from Grenada and restored non-tyrannical government to that nation-island, the war between the United Kingdom and Argentina over possession of the Falkland Islands in the South Atlantic, Operation *Eldorado Canyon* in which US air and naval forces conducted a retaliatory air strike against Libyan military targets, and Operation *Earnest Will,* which enforced the rights of international navigation in the Persian Gulf and assured the flow of oil for the Allies. From these and the previous examples, we can discover the characteristics of C^2 systems that contribute to or detract from mission success.[15]

During the operation on Grenada, the United States used massive airborne and marine forces to successfully rescue US citizens and liberate Grenada from Marxist rule and Cuban influence. After the first weeks of the conflict, C^2 failures, lack of communications channels, and insufficient prior coordination were publicized in the media and later investigated by Congress. Because the operation was successful, did the mass of forces outweigh shortcomings in C^2? If the opposing Grenadian and Cuban surrogate forces were more evenly matched to or larger than the US forces, would the United States have been able to synchronize the tempo of a fast-moving non-combatant evacuation operation on the tropical island-with tourist maps and uncertain intelligence about the island forces? Some analysts might conclude that *Urgent Fury* C^2 was a force divisor, overshadowed only by the mass of deployed forces.

The "pile-on" strategy used in Grenada points to one approach force planners and defense leaders take to overcome uncertainty. Uncertainty about friendly force performance, the magnitude of the threat, the scope of the scenario (tactical or strategic?), and the risk of escalating a limited war scenario to something more serious. The coping strategy is to demand more forces to guarantee a "safety margin" in the conduct of the war. In the serious profession of war, the "principle of mass" and safety margins are desirable. Lives and other valuable resources are at stake. Nevertheless, the added forces of the safety margin represent an inefficient use of resources. In a limited war campaign, this inefficiency may not be so serious, but if other limited war campaigns had been going on in addition to Grenada, forces to produce a "safety margin" may not have been available. The commander in theater *A* might have more forces than he needs, while the commander in theater *B* may not have enough.[16]

In the United Kingdom's campaign to retake the Falklands from Argentine occupying forces, streamlined command and control structures and long-haul communications were important factors contributing to success in directing combined arms actions from a headquarters 8,000 miles distant.[17] In a general description of C^2 clearly influenced by the lessons of the Falklands conflict, Captain W.T.T. Pakenham of the Royal Navy said several years later that the days are gone when the flag commander can expect to be afloat. He must now consider the possibility of operating from a protected shore location, where he will depend on C^2 systems to support his C^2 process.[18] The success of this C^2 "lash-up" permitted British leadership to share the evolving images about the operational concept in the South Atlantic. The C^2 system was a "force multiplier" for the United Kingdom forces.

In spite of the overall success of the 7-week campaign, two disturbing engagements stand out. When the British forces attempted to land at Bluff Cove on East Falkland Island during the last few days of the conflict, the landing forces were surprised by Argentine attack aircraft and suffered significant casualties. Anno and Einspahr attribute this to chinks in the unity of command (a principle of war) otherwise effectively demonstrated in Admiral Fieldhouse's remote leadership of the task force. Since the conflict had been primarily a naval war up to that time, little coordination had been necessary with air and land forces. This shortage of coordination limited the air support and air defense at Bluff Cove and put the landing force commander in an "uncertain" state. The commander almost aborted the mission. The second of these disturbing engagements was the loss of the HMS *Sheffield* to air attack by Argentine Exocet missiles. The *Sheffield* had apparently turned off her air search radar because of interference with an onboard satellite communications terminal and left herself vulnerable to air attack. Again, the commander acted in a state of uncertainty.

In contrast to the *Urgent Fury* operation and the Falklands conflict, the *Eldorado Canyon* raid against Libya used fewer forces (no ground maneuver units) and instead used forces with far higher technology—surveillance systems and attack and interdiction aircraft with smart munitions.[19] In support of the air strike, Admiral Kelso deployed a comprehensive collection of C^2 resources—airborne and shipborne air control and air defense systems as well as airborne and shipborne satellite communications.

For a precisely timed attack with specific targets, detailed C^2 coordination was essential. The lack of common radio equipment between Air Force F-111 fighter-bombers and Navy attack aircraft, however, hampered direct coordination between the two services' attacking forces and resulted in dividing the unity of effort between Tripoli (Air Force) and Benghazi (Navy) to preclude situations of uncertainty. If Libyan air defense interceptors had been launched, would the two attacking forces have been able to aid each other? After the raid, delayed coordination between the Navy and Air Force hampered search-and-rescue efforts for the missing F-111 aircraft. Since the E-3 is inherently interoperable with Air Force and Navy tactical air control systems, the United States could have used the E-3 Airborne Warning and Control System (AWACS) for coordinating the search efforts as well as the two strikes. According to Anno and Einspahr, one of the F-111 wing plans officers would, in retrospect, have used the E-3 to command and control the entire force.[20]

A speculative military theorist might ask: Would the Task Force commander have been able to synchronize his force elements in the attack with poorer C^2? If Admiral Kelso had the additional capabilities of the E-3 AWACS at his disposal, would he have been able to use "force multiplication" to successfully complete the mission with fewer bombers, attack aircraft, and refueling tankers? The additional aircraft probably gave him a "safety margin," but if the conflict had been more dynamic (two-sided), would he have had the additional reserve air forces to cover all targets in each area of operations?

In Operation *Earnest Will*, implemented to ensure freedom of navigation in the Persian Gulf during the course of the Iran-Iraq War, E-3 aircraft did provide tactical air defense information to US ships and aircraft. While the air threat was relatively uncomplicated, US forces in the area were advised to be cautious about the apparent intentions of either belligerent. When the USS *Stark* was patrolling in the Gulf on the evening of 17 May 1987, updated reports about the location, type-classification, and identity of aircraft were being sent from the orbiting E-3 to the USS *Coontz* and then being relayed to the *Stark*.[21] Among these updates was an assumed-hostile air track, type-classified as an Iraqi F-1 Mirage fighter. About 70 minutes after first learning of the Iraqi fighter's presence, the *Stark* was hit by two Exocet missiles launched from the Iraqi F-1.

In the opinion of the Navy's investigating team, the Commanding Officer and the watch team failed to recognize the Iraqi F-1 as a threat, consider appropriate options to respond to the threat in sufficient time, and exercise the permissible defensive measures. The Commanding Officer and watch team were aware of the threat from the information provided by the E-3 and the *Stark*'s on-board C^2 systems, but chose not to reduce their "uncertainty," thus missing the force multiplication advantage. When this uncertainty was jolted by the first missile ripping through the superstructure, the watch team was then unable to cope with the tempo of the evolving situation.[22]

While this lack of information led to a tragic incident on the tactical level, there is a happier story to tell about C^2 information sharing at the operational and strategic levels of *Earnest Will*. The chain of command for this politically complex operation was 7,000 miles long from the Persian Gulf to USCINCCENT General Crist in Tampa, FL. When the Iranians installed Silkworm missiles on their coast, the National Command Authorities were acutely concerned about sending convoys through the Straits of Hormuz.

Vice Admiral Tuttle, then Director of the Command, Control, and Communications Directorate of the Joint Staff (J-6), arranged to display current ship locations graphically in the Straits of Hormuz for the Secretary of Defense and the Chairman of the JCS. General Crist, the theater commander, was also able to monitor the same situation from his Florida command post.

While the first ships ran the Silkworm gauntlet and steamed out of range of the missiles, the Secretary of Defense and Chairman of the JCS watched the operation from the Pentagon. Because the Secretary and the Chairman shared the same image of the operation as the theater commander, they did not feel compelled to monitor or control the operation by "skip-echelon." Consequently, uncertainty was minimal and operational tempo was not a challenge. Admiral Tuttle claims those elements of a jury-rigged C^2 system "changed a culture." Referring to USCINCCENT's willingness to install the equipment, Tuttle declares that "General Crist had changed it all, for he intrepidly said that he did not care if his superiors had any, and all, information as long as he had the same information at the same time."[23] In a way, General Crist was using the force advantage of C^2 to preclude senior command queries that might distract the attention of his staff away from the intense Gulf operations.

Theories about Information in Conflict

"The more people share information, the more its importance will increase. Information which nobody uses diminishes its value." So writes Paul Strassmann, referring to the automation of business functions.[24] His words also ring true for the flow of information among C^2 resources. Effectively sharing information with his superiors, his staff, and his forces, the commander can cope with uncertainty and tempo in conflict. Without sharing an image or concept of what is desired and how to achieve it, the value of command information diminishes, taking with it chances for success in conflict.

In the early 1980s, then Deputy Assistant Secretary of Defense for C^3I Harry Van Trees challenged the defense systems analysis community to find meaningful ways to evaluate C^2 systems quantitatively. He accused the analysts of being far too comfortable with measurable parameters, such as bits per second and decibels of signal gain. He asked that they start thinking hard about how to relate C^2 technology to conflict.[25]

As we begin the 1990s, the systems analysis community still has not conclusively measured how C^2 contributes to mission success, but the prodding of senior defense leaders like Van Trees have put them on a course toward that end.

Brian Conolly and John Pierce, in the preface to their 1988 book, summarized the lack of consensus on how to approach the problem and the less-than-complete adequacy and fidelity of the mathematical approaches in the fledgling, decade-old science of military C^2. They listed the four prevailing schools of thought on characterizing how C^2 contributes to mission success: control theory, information theory, fuzzy set theory, and catastrophe theory.[26] Control theory and information theory hold the greatest promise, by virtue of their widespread acceptance and use. Because of the similarity of the C^2 processes of direction and feedback to those functions seen in control systems, control theory is a favored approach, although it is too mechanical to accommodate the human component of C^2 and focuses too much on internal, closed loops and not mission effectiveness, which is external to the control loop. It thus appears that information theory is the best of the four approaches. Information, pervasive throughout all C^2 functions, is the "lifeblood" of C^2; when information is old, corrupted, or inadequate, the C^2 process is likely to lose effectiveness. The other two categories, fuzzy set theory and catastrophe theory, are not widely accepted. Conolly and Pierce explain that proponents of fuzzy set theory believe the imprecision of the C^2 process can be reliably represented by fuzzy sets, or mathematical approximations of the flow of data between steps in the C^2 process. Adherents to the catastrophe school of thought believe that chaotic breakdowns in the C^2 process and sudden changes in the warfare environment can be represented as catastrophes.[27] Because these last two approaches are least understood, I agree that they are not yet useful.

This section concentrates on only one of the four theory categories, information theory. We will explore certain theories about C^2 information[28] and what they can tell us concerning the force multiplier effect. First, we will examine David Alberts' early 1980s methods for estimating what "value-added" can be attributed to C^2 systems. We will then backtrack to World War I, to briefly cover Frederick Lanchester's mathematical theories about how to improve force effectiveness through concentrated, aimed fire. Armed with the fundamentals of Lanchester's theories, we will look at how Fred Ricci and Daniel Schutzer related Lanchester's theories to information thresholds, optimum time windows, and battle dynamics between opponents. Then we will briefly look at J.C. Emery's classic paper on cost-benefit analysis, which will provide additional insight into the time value of information. Following this, we will study at length Donald Gaver's mathematical analysis of force advantage gained through coordinated fire. Finally, we will review Daniel Schutzer's ideas about measuring force effectiveness by comparing relative force strength, before and after an engagement. We will also review his concepts about timing in the C^2 decision cycle.

In the early 1980s, MITRE researcher David Alberts offered an approach to quantifying effectiveness, using a "value-added" technique. Alberts' estimates of "value-added"—both subjective and quantitative—illustrate the operational leverage imparted to the commander by using C^2 resources. In one example, he modeled the time to close the weapons assignment loop, both with and without a new automated C^2 system. This "loop" is the sequence of actions taken by operations planners first to decide to strike a target and then to provide the instructions to a weapons system (such as a fighter aircraft) to seek and engage the target. Without the new C^2 system, closing the loop took 6 minutes; with it, only 3 minutes.

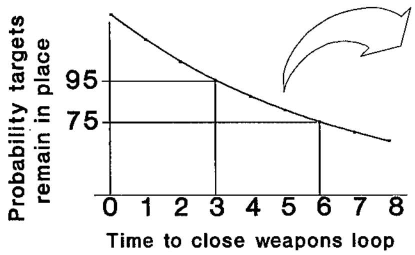
Similarly, Alberts estimated the probability of the weapons system closing with the target, once assigned and before the target moved. The suggested C^2 system would help in tracking relocatable targets—without the new C^2 system, there is a 75 percent probability of closing with the target; with it, 95 percent. If we put these two estimates in the context of what we have been discussing as the operational art, the new C^2 system would improve the commander's ability to cope with the tempo of weapons assignment by a factor of two (6 minutes over 3 minutes). And the new system would improve the commander's ability to cope with the uncertainty in striking targets by a factor of 1.27 (95 percent over 75 percent). The top half of figure 4 depicts this relationship.

In another example, Alberts showed how improving the probability of a communications system to receive nuclear force direction messages correctly could result in improved target coverage. His estimated increase in the commander's certainty of directing nuclear forces would result in a force multiplier effect of 1.17 for bomber forces, 1.00 for land-based missiles, and 1.32 for submarine-launched missiles.[29] The lower half of table 3 shows this example. With the improved assurances that force elements are receiving their instructions, the strategic commander needs fewer force elements to strike the same number of targets.

The methods David Alberts explored start to provide insight about how to integrate C^2 into the force structure. If the C^2 system provides force leverage, the commander may be able to succeed with fewer force elements. If the C^2 system

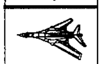
FIGURE 4. Examples of C2 improvements

- Improving flow of targeting data



System	Time	Probability targets remain in place
Without C2 capability	6 min	75
With C2 capability	3 min	95

- Improving probability of correctly receiving messages

Weapon	PCMR	Improved PCMR	SSPK	Improved SSPK	Number required	Reduced number	Force multiplier
	.8	.9	.08	.09	28	24	1.17
	1.0	1.0	.3	.3	6.5	6.5	1.00
	.6	.8	.06	.08	37	28	1.32

(Source: Alberts 1980)

PCMR = Probability of correct message receipt
SSPK = Single shot probability of kill

is less expensive than the price tag of the corresponding force reduction, adding the C² system creates an equally effective, but more affordable force structure.

Next we look at some approaches to mathematically modeling C² in combat. Probably the most famous (or infamous) group of equations reflecting warfare are Lanchester's equations. Inspired by the new school of scientific management and motivated by the relatively static conditions of trench warfare, Frederick W. Lanchester postulated the basis for the equations during World War I to model force effectiveness (attrition) warfare between two relatively homogenous opponents during an engagement. Lanchester's two families of equations distinguish between what he called "ancient warfare" and "modern warfare."[30]

Over the years, these equations have been very useful to operations researchers in mathematically representing military engagements. They have also been subject to much criticism, especially when analysts attempt to use Lanchester's theories in modeling C^2. In a 1988 article, John Dockery and Robert Santoro reviewed the current issues. Applications of Lanchester's theories often portray warfare as rigid, deterministic attrition exchanges between forces. These attrition exchanges, with their tendency to promote annihilation doctrine, overlook the dynamics of present-day warfare. Among the "dynamics" not accounted for are maneuver theory and, maybe more importantly, Simpkin's function of "rendering the enemy force operationally irrelevant." Moreover, when Lanchester's theories are used to characterize C^2 in warfare, the analysts often unrealistically assume that the C^2 process always has access to "perfect" information. Lanchester's equations can be adjusted for the effect of some warfare factors. However, as Dockery and Santoro admit, fixing Lanchester applications to account for C^2 will take intensive numerical processing.[31] Now let's look at some applications of Lanchester's theories and what they have to offer for C^2.

In what Lanchester would have called "ancient warfare," BLUE can't effectively locate specific RED targets so he can fire on them. Here, BLUE's attack tends to be more in the category of area fire (such as "shooting in the dark") rather than aimed fire. Far less effective than "modern warfare," the ability of BLUE's ancient warfare to destroy the adversary force is proportional to the density of RED targets in the area. If RED's forces are dispersed, BLUE's area fire must continue for a longer period to destroy RED targets. In contrast, "modern warfare" exemplifies aimed (or directed) fire. Modern technology (as machine guns were in World War I) makes it possible for BLUE to destroy RED forces at a rate which is proportional to BLUE's effective rate of fire—typically achieving mission success more quickly.[32]

Lanchester's assumptions for his second (square law) equation of modern warfare suggest several means to evaluate how C^2 contributes to mission success. First, RED's concentration of fire may counterbalance BLUE's advantage in weapons performance. *Without* concentrated fire (that is, under the linear law), engagement success is directly proportional to the performance of BLUE's weapon type. *With* concentrated fire (under the square law), RED's numerical superiority could outdo BLUE's weapons performance.[33] For BLUE to overcome RED's advantage in concentrated fire, he needs improved force effectiveness—over and above to his improved weapons—which could come from additional C^2 resources. Second, if weapons technology can improve BLUE's force effectiveness by permitting a more selective engagement of RED targets, then why can't improvements in C^2 technology (instead of improved weapons technology) also permit a more selective engagement of RED targets? BLUE could be more selective in engagements because C^2 technology could allow sharing an image with force commanders, which would permit them to act with more initiative and still satisfy the BLUE commander's intent. They could act with more certainty, according to the battle tempo. A number of researchers in the late 1980s began to recognize these potential correlations.[34]

Fred Ricci and Daniel Schutzer, in their book *US Military Communications: A C^3I Force Multiplier*, do not attempt to directly quantify the force multiplier effect (title notwithstanding). They do, however, provide an extensive shopping list of advanced technology. In subjective terms, they explain how communications and automation contribute to force effectiveness. Ricci and Schutzer also relate several information warfare concepts which indirectly suggest the idea of force multiplier.

Their information warfare concepts, based in part on Lanchester's equations, include thresholds, time windows, and battle dynamics. By operation of Lanchester's equations, Ricci and Schutzer show that the information advantage accrued to one side (BLUE) in the conflict has to build to a certain threshold to ensure mission success. Information advantage relates to having enough or more than enough information to be successful in conflict, all other factors considered. Once BLUE reaches an advantageous position or threshold—in terms of force size relative to RED, information, and the choice of firing tactics (direct fire or area fire)—additional increases in information advantage have no effect on the outcome of the conflict. In essence, there appears to be a "law of diminishing returns" for BLUE's information advantage.

In treating time windows, Ricci and Schutzer suggest that when RED's information advantage has reached an "ideal" level, RED should take this optimum time to attack BLUE and should be successful in the conflict. If RED has the advantage of tactics but not the information advantage over BLUE, then the optimum time window for attack may never come. RED may eventually prevail in the conflict but with a prohibitive number of casualties. An experienced field commander is well familiar with this idea of a "time window," even if by other names. A commander who jumps into conflict with poor knowledge of his opponent and the situation, without an effective C^2 system to develop and share that information with staff and forces, is entering a conflict where the chances of success will be minimal. A commander who hesitates entering the conflict, even after having acquired sufficient information, may become the victim of an opponent who has meanwhile gained the information advantage.

The third idea, called "battle dynamics" by Ricci and Schutzer, suggests that the information state (or advantage) will not remain static throughout the course of the conflict. Unless replenished, the information advantage of an opponent will degrade exponentially with time.

To illustrate these aspects of information warfare, using information to advantage in an engagement, Ricci and Schutzer modify Lanchester's equations for the effect of information entropy. Entropy, in this case, characterizes the extent of disorder inherent in the C^2 process due to lack of useful information. A commander relies on the influx of new information to keep his image of the situation current. Without information updates, he cannot adapt to the changing situation and his C^2 process becomes ineffective. If these negative aspects of information entropy are reversible (with information updates), the degree of entropy will remain constant but will not decrease with changes in the information base. The commander would be able to "hold his own" because the amount of information (not necessarily the content) would remain roughly the same. If the commander cannot get adequate information to keep the image of the situation updated, the effect of entropy cannot be reversed and the degree of entropy worsens. Ricci and Schutzer build on the work of James G. Taylor[35] and others, by showing how uncertainty (entropy or inability to collect and maintain useful information about the situation) and tempo (time periods in this case) can influence force effectiveness and mission success.

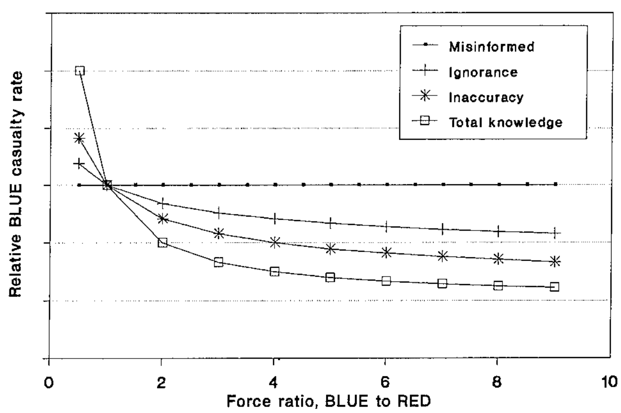
The first part of figure 5 shows how information entropy can affect BLUE's mission effectiveness in attacking RED. Mission effectiveness is measured here in terms of relative BLUE casualties per unit of time, for varying force ratio levels and different assessments of BLUE's information quality. We can say this information quality encompasses the BLUE force's knowledge level and understanding of the situation, embodied in the BLUE force's shared image. It logically follows that as BLUE's force size increases with respect to RED's (force ratio on the *x*-axis), the chances for BLUE's mission success increase (BLUE's relative casualty rate decreases). As the quality of BLUE's information also increases, the casualty rate drops even more rapidly with an increase in BLUE-to-RED force ratio. Note that when BLUE is totally misinformed, BLUE has slightly lower casualty rates at a force ratio level less than one; we can attribute this stage to "dumb luck," a haphazardly led campaign. But also note that this state of knowledge, left unimproved, results in increased total (absolute number of) casualties along with increasing force ratio levels. BLUE's commander is sending his forces into slaughter. An effective C^2 system to collect and maintain a better knowledge base could prevent that unfortunate result.

The second part of figure 5 illustrates how BLUE's relative casualties (casualty rate per unit of time) changes when he is attacked by RED. When BLUE has total knowledge of the situation, he can hold his casualty rate steady. But if BLUE has less than total knowledge of the situation, his casualty rate goes up dramatically. BLUE is unable to properly defend his position and safeguard his forces.

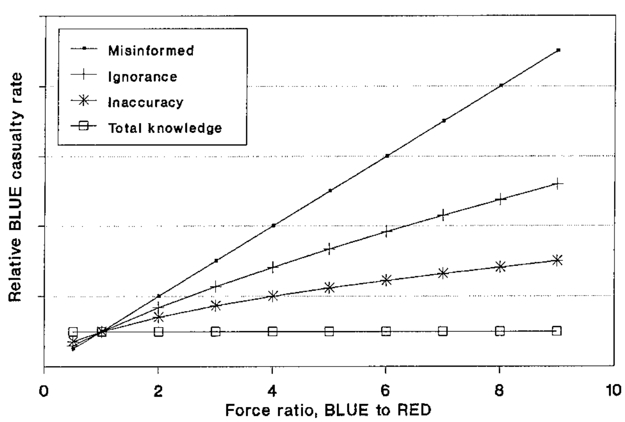
What can we learn from Ricci and Schutzer to help us in measuring the effectiveness of C^2 systems and integrating C^2 into the force structure? We can deploy C^2 systems to improve BLUE's ability to continuously collect and transform data into information and then share a common understanding of that information among staff and forces. With the improved information base, BLUE will be able to fight a war with fewer casual-

FIGURE 5. Effect of BLUE information on attrition

(BLUE attacks and RED defends)



(BLUE defends and RED attacks)



(Source: Ricci and Schutzer, 1986)

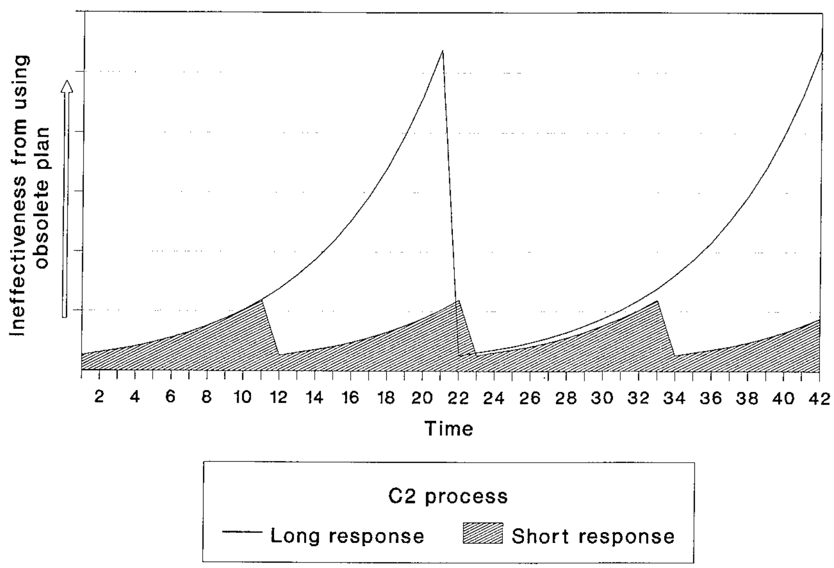
ties, even against larger forces. Casualties include neutralized weapons systems as well as people; both are part of the force structure. If losses can be avoided with better C^2 information, an improved C^2 system is a positive contribution to force effectiveness.

J.C. Emery, in his classic description of how to approach cost-benefit analysis for management information systems, provided a similarly useful model for demonstrating the time value of information.[36] Like Ricci and Schutzer, Emery provides insight into the nature of information in conflict. BLUE prepares his war plan, based on available information. As everyone knows, unexpected events can always be expected. When BLUE begins to execute the war plan, information relating to why the BLUE commander chose a course of action changes. The plan tends to become obsolete. Adhering to an obsolete plan reduces BLUE's ability to cope with uncertainty and tempo, and will continue to do so, until the plan can be "replanned." The value of the new plan, based on the newly available information, increases again. This model is useful for illustrating how a C^2 system delay in updating information can make a plan ineffective and execution increasingly difficult (figure 6). The lesson learned here: the better the C^2 system, the shorter the response time. Shorter response times help the commander by quickly letting him know if there's any new information which would change his image of the situation. Shorter response times within the C^2 cycle also help the commander expedite plan updates, to incorporate new information. If feedback comes quickly enough through the C^2 system, and the C^2 system aids in replanning, then BLUE's chances of mission success improve.

Closing in on the Hunted

Professor Donald Gaver of the Naval Postgraduate School took a slightly different tack. While he didn't start out using Lanchester's equations, he suggested other equations that model the probability of attrition and help to measure the value of information in C^2. Exploring Gaver's work in greater detail than the others will be useful because his mathematical approach illustrates each of the three important aspects of

FIGURE 6. Information decay



(Source: Emery 1971)

the operational art: maintaining the shared image, coping with uncertainty, and coping with tempo.

Gaver investigated scenarios in which one or both opponents use "coordinated" fires to engage the other. If there is any similarity to Lanchester's two models of warfare, coordinated fire is similar to aimed fire or modern warfare. His research mainly reflects "one-on-one" engagements (such as two naval battle groups, two squadrons of dogfighters, or two infantry brigades) versus one-on-many. Looking at a scenario wherein BLUE and RED forces are relatively large and assuming a 1.0 probability of kill and 1.0 rate of fire for both sides, Gaver derived a set of equations that reveals the advantage of coordination among RED forces. Improved C^2 resources are the basis for this advantage of coordination. Here, the RED commander has enough information to be able to direct each RED force element to fire on a specific BLUE target.

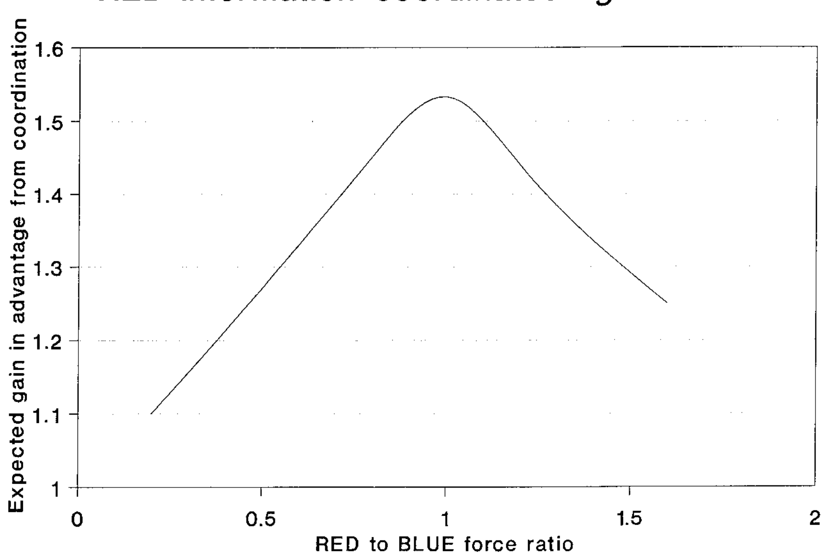
The results of this simple (and admittedly imperfect) model clearly show how RED, when information-coordinated against

BLUE, can sustain an engagement advantage (force multiplication) over BLUE even when RED is outnumbered 5-to-1 (a RED-to-BLUE force ratio of 0.2) (figure 7). In addition, Gaver's formula suggests another interesting point. As RED's numerical superiority rises (RED-to-BLUE force ratio increases), the extra force multiplication attributable to the C^2 could mean that RED now has superfluous force elements that could be employed elsewhere.[37]

In retrospect, Operation *Urgent Fury* may have comprised just such an overcommitment of forces. Experiencing a "rough start" in terms of coordinated operational information, the operation eventually gained steam and was fully coordinated by the operational commander. As the *Urgent Fury* C^2 system (command structure, decision support, and communications) matured and stabilized in the early part of the conflict, the "information advantage" in tactical intelligence and order-of-battle data leaned more toward the United States. As the dissimilar US forces learned to work with each other, they were able to build a "shared image" about what had to be done to complete the mission. Uncertainty about the tactical situation and Cuba's strategic intentions was reduced and Admiral Metcalf was able to cope with the tempo of the operation. If Gaver's simple information advantage model had been applied, however, the "extra" force elements diverted from Lebanon could have been sent to stabilize the peacekeeping force crisis created days earlier when the Beirut Marine barracks were bombed.

Gaver expands his accounting of coordination and the contribution of C^2. Applying more realistic conditions, he reduces RED's probability of destroying any one BLUE target to less than 1.0 and considers the length of engagement time. Still, Gaver finds that there is an advantage in coordinating what targets are selected by RED (C^2 resources reducing RED's uncertainty about the situation), but suggests that the same C^2 may also adversely impact how the engagement turns out. Figuring on the time consumed in the C^2 activity, then RED's rate of fire would decrease and the engagement would be longer or have a less predictable outcome. Therefore, a less-than-fully-responsive C^2 system may inhibit RED's ability to cope with battle tempo.[38]

FIGURE 7. Effect of info coordination - RED information-coordinated against BLUE



(Source: Gaver 1980)

Then Professor Gaver modeled the effect of RED coordinating against BLUE in a Lanchester-like context using discrete-time, deterministic equations to build his case for modeling dynamic warfare,[39] with interesting results (figures 8-13).[40] Assuming a certain probability of kill for both BLUE and RED, a one-salvo rate-of-fire from each side during the time interval, and RED with the C^2 advantage in its battle with BLUE, the series of cases in the figure shows the number of force elements remaining after each engagement interval. (In the examples, RED has the coordination advantage over BLUE because it has an advanced C^2 capability.)

What are the engagement results? As shown in Case A, where BLUE and RED start off with equal forces, the C^2 capability permits RED to prevail in the conflict. In Case B, the coordination (C^2) activity gives RED a notable advantage even when RED's forces are outnumbered. Only when BLUE has three more force elements in the beginning than RED does BLUE have the advantage of numerical superiority (Case C), but the collateral effect is to draw out the conflict to six intervals and destroy nearly all force elements on both sides, nominally a "lose-lose" situation. By increasing his numerical advantage to 25 force elements versus RED's 20 elements in Case D, however, BLUE is able to shorten the conflict and prevail with a higher margin of remaining force elements.

Using this simple model, we can estimate the force multiplier effect. The C^2 activity of coordination permits RED to prevail even when outnumbered by two force elements in Case B. The force multiplier is then 22 force elements to 20 force elements, or 1.10. Putting Case C in a time dimension, RED's C^2 activity extended the conflict three engagement intervals, twice as long as Case B. When considering the possibility of RED replacing his lost force elements by bringing in reserve forces (a process made easier by a C^2 advantage), the C^2 activity has given the RED commander additional force options. RED may, if the casualty rate has been tolerable, extend the conflict to the point where he can muster enough additional forces to again use the C^2 activity as a force multiplier.

In Cases E through G, Gaver reduces the probability of kill to a more realistic 0.2, while maintaining the same rate of fire for each engagement interval. In these cases, the force multiplier advantage is not as pronounced. When BLUE and RED begin with equal forces as in Case E, RED prevails by neutralizing all of BLUE's 20 force elements, while losing only six of his. In Case G, BLUE needs two more force elements than RED's 20 to persevere in the battle. The force multiplier effect is somewhere between 1.05 and 1.10. But what is really significant is how RED's C^2 advantage can prolong the conflict when RED and BLUE weapons system have lower probabilities of kill. Case F, on the other hand, seems to end in a stalemate. But consider that RED's C^2 advantage extends the time dimension four time intervals, while BLUE's one-force-element advantage doesn't help him. Also consider what might happen if an initially outnumbered RED uses this earned time to bring in other force elements to help out in the battle.

Case H represents another concept. In it, RED and BLUE start off with the same number of forces but BLUE has a

FIGURE 8. Number of force elements remaining after each engagement: RED coordinated against BLUE

For engagements where RED has the C2 advantage

$$RED(t+1) = RED(t)\left[1-\left(\frac{1}{RED(t)}\right)\left[1-(1-pRED:BLUE)^{rateBLUE}\right]\right]^{BLUE(t)}$$

If $RED(t) \leq BLUE(t)$, *then*

$$BLUE(t+1) = BLUE(t) - RED(t)\left[1-(1-pBLUE:RED)^{rateRED}\right]$$

If $RED(t) > BLUE(t)$, *then*

$$BLUE(t+1) = BLUE(t)\left[(1-pBLUE:RED)^{rateRED}\right]^{RED(t)}$$

where
RED(t) is the number of RED force elements at engagement time interval (t)
BLUE(t) is the number of BLUE force elements at engagement time interval (t)
pX:Y is the probability of X being killed during an exchange
rateX is X's rate of fire

(Source: Gaver 1980)

CASE A. Equal forces
(pK=0.5, rate=1.0)

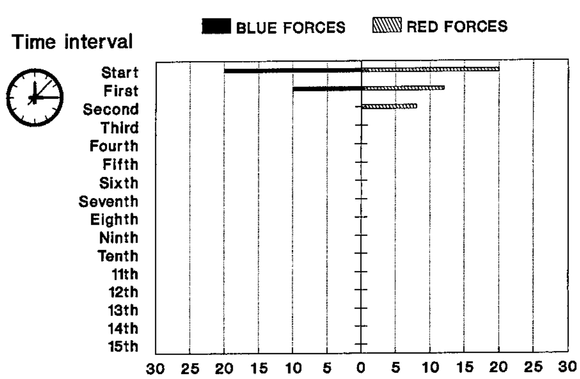
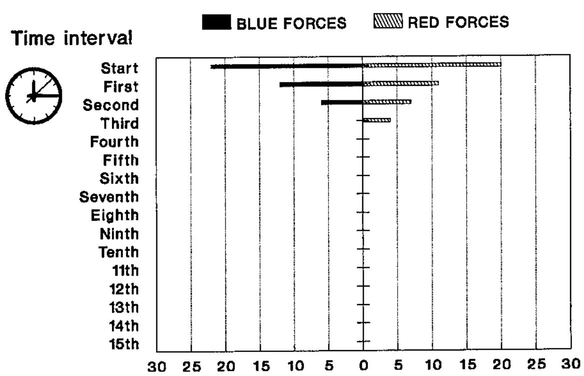
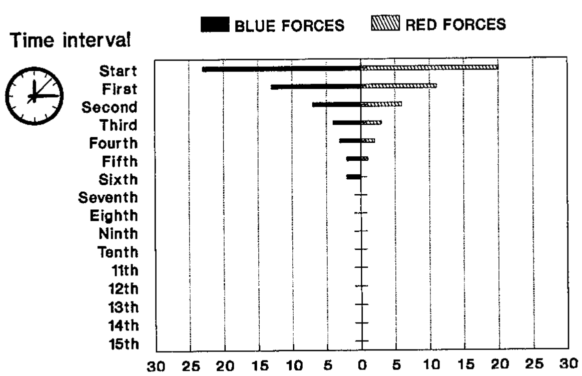


FIGURE 9. Number of force elements remaining after each engagement: RED coordinated against BLUE

CASE B. Slight force advantage to BLUE
(pK=0.5, rate=1.0)



CASE C. Medium force advantage to BLUE
(pK=0.5, rate=1.0)



weapons system with a 1.15 rate of fire. The engagement results suggest that even a "15 percent" improvement in weapons firing rate is barely sufficient for prevailing in a conflict where the opposing side (RED) has the C^2 advantage. BLUE does prevail, but after extending the conflict to 13 intervals and losing nearly all his force elements. Case I is similar. The probability of BLUE neutralizing RED in any one engagement increases from 0.2 to 0.3. It takes this significant increase to again prevail over RED, but the conflict does not last as long as in Case H.

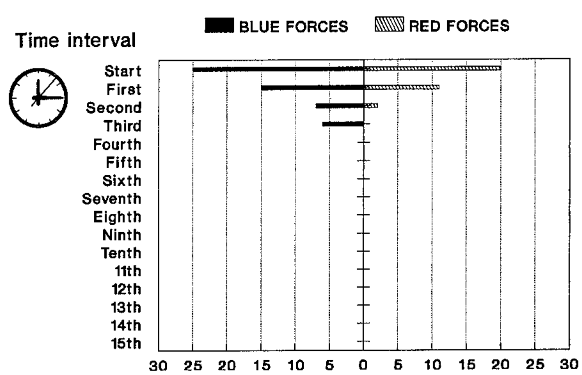
The conflicts illustrated in Cases J and K start with BLUE having a 23-to-20 or 1.15-to-1 force advantage over RED. In Case J, BLUE eventually prevails. But in Case K, RED takes advantage of the reduced tempo to bring up four force elements between the fourth and fifth time intervals to replenish his forces. This opportunity to cope with the tempo permits RED to prevail in the conflict.

In understanding how to cope with uncertainty, one might conclude that the C^2 activity enabled RED to aim or direct his fire and precisely assign each of his force elements to specific targets. BLUE, always uncoordinated, was committed to the more ineffective area fire. In terms of coping with the tempo of the conflict, we found that the C^2 activity buys time for RED to call up replacements. These notions of tempo become all the more significant when one considers the pace of modern conventional warfare. It would seem then that C^2 plays a vital role in coping with tempo and uncertainty.

Wayne Hughes contends that modern naval firepower—especially using the antiship missile—is highly effective in dispersing naval forces. When naval forces are concentrated or lack a C^2 advantage, they are at greater risk to anti-ship missiles being fired by a fully-coordinated enemy. The Falklands conflict and Operation *Earnest Will* bear this out.[41] From his air-land warfare perspective, Richard Simpkin would agree with Wayne Hughes. According to Simpkin, the opposition's firepower disperses force elements, dynamically shifts mass, and unifies mobility requirements. But as Simpkin sagely concludes, it's not about firepower but about information. "For it is really the acquisition, processing, and dissemination of information that lies at the root of the speed and accuracy with which fire can now be applied."[42]

FIGURE 10. Number of force elements remaining after each engagement: RED coordinated against BLUE

CASE D. Strong force advantage to BLUE
(pK=0.5, rate=1.0)



CASE E. Equal forces, lower pK
(pK=0.2, rate=1.0)

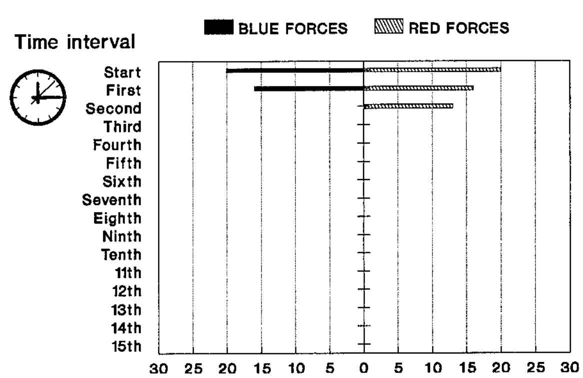
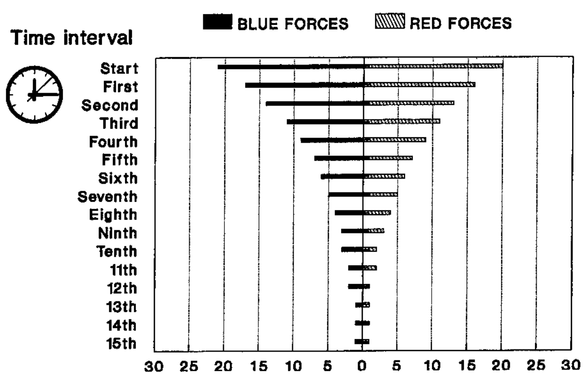


FIGURE 11. Number of force elements remaining after each engagement: RED coordinated against BLUE

CASE F. Slight force advantage to BLUE
(pK=0.2, rate=1.0)



CASE G. Medium force advantage to BLUE
(pK=0.2, rate=1.0)

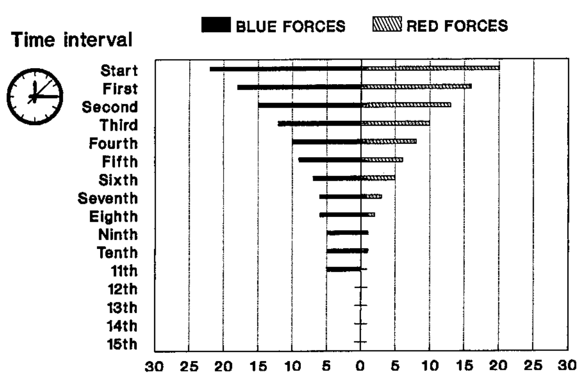
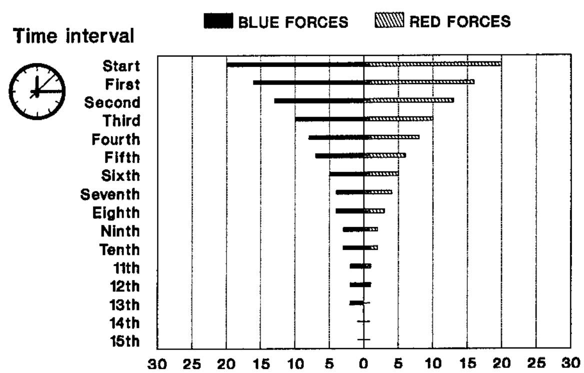


FIGURE 12. Number of force elements remaining after each engagement: RED coordinated against BLUE

CASE H. Equal forces, higher rBLUE
(pK=0.2, rBLUE=1.15)



CASE I. Equal forces, higher pRED:BLUE
(pRED:BLUE=0.3, rate=1.0)

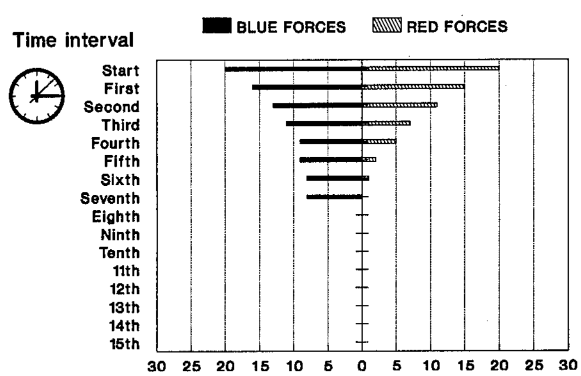
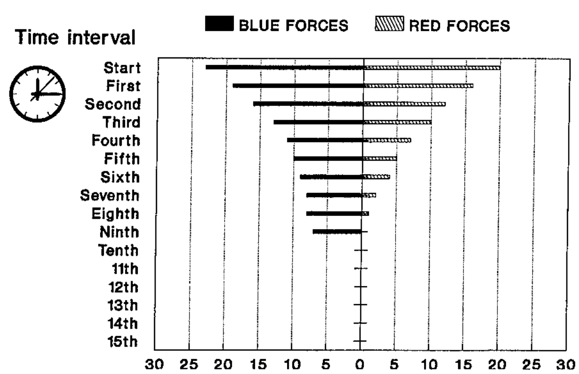


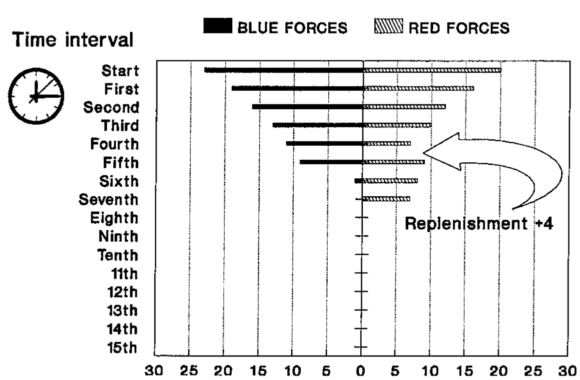
Figure 12—Full Page

FIGURE 13. Number of force elements remaining after each engagement: RED coordinated against BLUE

CASE J. Med BLUE Advantage, no replen
(pK=0.2, rate=1.0)



CASE K. Med BLUE advantage, RED replen
(pK=0.2, rate=1.0)



How does Professor Gaver's research help us in integrating C^2 systems into the force structure?[43] To find out, we will select some examples from Cases A through K and put them in economic terms. In Case B, RED is down two force elements but prevails because he has a better C^2 system. If we assume RED's information advantage came from an Aegis system and the force elements are guided missile frigates, his \$50 million C^2 purchase was a better investment than BLUE's two additional frigates at \$324 million for each copy.[44]

In Case F, RED and BLUE weapons system have lower probabilities of kill. RED's \$50 million Aegis C^2 advantage prolongs the conflict to a stalemate, while BLUE's extra \$324 million frigate advantage doesn't help him. RED and BLUE start off with the same number of forces in Case H, but BLUE's 76 mm guns on each of his frigates have a "15 percent" improvement in their rate of fire. If BLUE spent, say, \$15 million to upgrade each of his 20 frigates, his \$300 million investment in improved guns barely helped him win against RED and his \$50 million Aegis system. And the idea that the conflict dragged on means RED could have called in additional ships to achieve the quantitative edge to win the battle.

Another operations researcher, Daniel Schutzer, uses a different measure of force effectiveness: the ratio of relative force strength before and after the engagement.[45] He computes the force multiplier as the ratio of BLUE assets for a given measure of effectiveness in two cases, holding RED assets constant. Using Lanchester-based modeling, Schutzer evaluates how C^2 systems contribute to mission success by exploring factors which impact effectiveness in managing forces: the command platform's probability of survival, how well the command platform can allocate forces to targets, and the BLUE-RED exchange ratio.[46]

How well a commander can allocate forces to oncoming and in-depth targets goes hand-in-hand with reducing uncertainty. According to Schutzer's model, all things equal between RED and BLUE force capabilities, increasing force allocation effectiveness from 0.5 (random) to 0.75 results in a force multiplication factor of greater than 1.5. If we introduce a C^2 capability to improve how the BLUE commander and his staff characterize RED targets and then improve how they decide to allocate or assign forces to specific targets, we achieve a perceived BLUE-to-RED force ratio of 3-to-2. In other words, if BLUE's tanks perform the same as RED's on the other side of the river, a C^2 advantage on BLUE's side will enable BLUE to put up two tank battalions successfully against RED's three.

Schutzer also deals with another aspect relating to uncertainty in conflict: the survival of the command platform. In the above example of RED and BLUE tank forces, the platform's probability of survival without C^2 is high (0.9) and the individual exchange ratio without C^2 is decisively in favor of BLUE ($X_0=\frac{1}{2}$). When the command platform's probability of survival without the C^2 capability is much lower (0.3), then inaugurating the C^2 capability is also likely to enhance the platform's probability of survival. If survivability increases to 0.9, the effectiveness of allocating forces is 0.75, and the exchange ratio is unchanged, Schutzer calculates that introducing the C^2 capability boosts the force multiplier effect to greater than 4.5.

If the probability of survival and exchange ratio are both low (0.3 and 1.0, respectively), initiating the C^2 capability is likely to improve all three parameters: survival from 0.3 to 0.9, allocation effectiveness from 0.5 to 0.75, and exchange ratio from 1.0 to 0.5. Under this combination of enhancements, Schutzer finds the force multiplier is then greater than 6.36.[47]

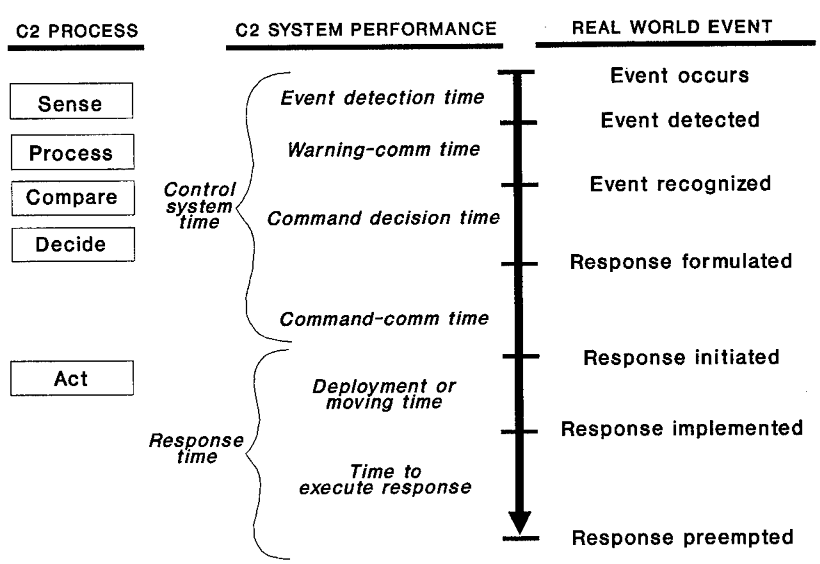
Schutzer approaches the tempo issue as "timeliness" in the C^2 process (figure 14). He illustrates how, when BLUE's and RED's force effectiveness (not necessarily force strength) are roughly the same, BLUE's C^2 resources can be used to sustain any engagement equilibrium or to keep timeliness on BLUE's side. BLUE's inability or ineffectiveness in reacting to an event may end in "response preempted" if BLUE can't keep up with the conflict's tempo. This inability or ineffectiveness may stem from incompetency, lack of technology, lack of decision support, an ineffectual command structure, or other C^2 shortcoming. In a broader sense, a lack of C^2 resources (human and nonhuman) prevents the C^2 system from sharing a high-fidelity image of the situation and the commander's intentions.

A scout element of BLUE's advancing light infantry brigade spots a two-battalion concentration of RED's armor column (event de-

tected) and the scout leader radios the posture, composition, and location of the potential target back to brigade headquarters (event recognized). The commander of BLUE brigade requests battlefield air interdiction from BLUE air forces (response formulated, response initiated). BLUE air force diverts two combat air patrol sorties, instructing them to strike the RED tank battalions. The tank battalions close up with six batteries of RED's air defense artillery before the BLUE sorties can get to BLUE's advance position (response preempted).

In a modern air-land battle scenario, a slow C^2 system may—from time to time—negate an otherwise effective capability to neutralize targets. In the tempo of modern naval warfare, a slow C^2 system may preclude the skipper of a destroyer from evading a high-speed surface missile.[48] In explaining how countermeasures against RED aids BLUE in scouting or in controlling, Wayne Hughes concludes that "jamming a scouting system buys *range*, jamming a controlling system buys *time*."[49] We can infer a reciprocal theorem: your C^2 or controlling system is *time* leverage if you can defend it.

FIGURE 14. C2 timelines



(Source: Schutzer 1982)

Intuitively, BLUE's situation becomes increasingly worse as the tempo of the conflict increases. Schutzer mathematically derives a way to demonstrate how the effectiveness of a C^2 system is proportional to available reaction times, namely, the available response time and the time for forces to move into position for engagement. According to Schutzer, effectiveness is proportional to the sum of the two time intervals to the fourth power. It is also proportional to the C^2 information's mean square error to the second power.[50]

Therefore, the commander's lesson is:

- Keep timelines shorter in sensing, processing, and deciding.
- Establish an accurate information base.
- Communicate reliably to the forces quickly enough for them to act.

This lesson is important because the commander can rapidly fall behind in his decisionmaking process and his time for effective reaction diminishes exponentially.

Do these theories about information really answer the question about force multiplication? We can't be sure until there is an meaningful way to test such theories in actual warfare, or even in crisis situations. Lanchester's attrition theories have occasionally been compared to empirical data, ex post facto. The highly regarded military historian Trevor Dupuy reported on two efforts undertaken by Daniel Willard and Janice Fain. Willard analyzed Bodart's *Kriegs-Lexicon* (1908), which cover battles from 1618 to 1905, but could not establish meaningful correlation between Lanchester's theories and the data. Fain followed Willard's approach, but used Dupuy's 60-engagement data base of World War II battles in Italy. Even this "more modern" warfare did not correlate well with Lanchester, until she incorporated some combat variables suggested by Dupuy. The correlations were consequently close.[51] Robert Helmbold had more success in comparing Battle of Britain data to Lanchester's theory.[52] Although Lanchester's theory may not fit very well and is very difficult to represent in view of historical complexities, it does provide a qualitative insight into the value of information in warfare. What we can say, from the theories and the historical examples already discussed, is that measuring the "force multiplier" effect is less than straightforward and often less than persuasive.

The central theme of these several models and historical examples is attrition, and it was in 20th-century warfare that attrition models came to the forefront. World War I was largely a war of attrition, in which men, materiel, and other resources were continuously sent to the front for consumption at the static, opposing trenches. Lanchester modeled this attrition with mathematical equations that have become the central basis for many warfare studies. In the strategic bombing surveys summarized toward the end of the World War II,[53] the measure of merit for forces was also attrition. The rite of passage for the new field of military operations research was again an emphasis on things that can be counted, quantified. Finally, during the Vietnam conflict, daily reports from Southeast Asia gave the Washington decisionmakers "body counts" as a measure of force effectiveness.

Today, despite continuing discussions about qualitative measures to offset quantitative supremacy, the US military and its civilian enthusiasts still measure force "parity" by counting the numbers of warheads, airplanes, ships, tanks, and combat divisions. This is the traditional approach to force structure planning. Clearly, the number of forces available for conflict is vital in a "force equation." Forces and their artful employment often are directed toward selective attrition in order to achieve political aims. The downside of this preoccupation with attrition-oriented warfare is that it does not account for the situations that more typically engage the US military: peacekeeping operations and other touchy predicaments that can easily escalate into more demanding crises. Moreover, this preoccupation with attrition-oriented warfare does not mesh well with the directions of US military doctrine toward operational warfare with the three key dimensions of operational art we have been examining: maintaining the shared image, coping with uncertainty, and coping with tempo-dimensions addressed by command and control.

Perhaps efforts to quantify "force multiplication" should be debunked, but they nevertheless give us insight about what C^2 systems contribute to mission success.

§ § §

Notes

1. I. Cassandra, "C^3 as a Force Multiplier—Rhetoric or Reality?" *Armed Forces Journal International* 115 no. 5 (January 1978): 16. Cassandra credits former DOD C^3 chief and later Secretary of the Air Force Thomas C. Reed with popularizing the expression "force multiplication through C^3." For a more recent reference to the question of force multiplication, see General John A. Wickham, Jr., USA (Ret.), "C^3I as a Force Multiplier," *Signal* 42, no. 8 (April 1988), 21-22. Wickham comments that while DOD may readily enhance the lethality of an attack aircraft to further increase its weapons effectiveness, the DOD may on the other hand be reluctant to improve C^3I and defensive systems because the force multiplier effect is not understood. See also Roger Beaumont, *The Nerves of War: Emerging Issues in and Reference to Command and Control* (Washington, DC: AFCEA International Press, 1986), 22-24 for political concerns raised about the value of C^2 as a force multiplier: disillusionment with the "electronic battlefield," opportunity for "skip-echelon" control of forces, and a lack of a unified C^2 architecture.

2. In a very different but logical approach, Professor Snyder thinks the problem with the idea of force multiplication is that the listener subconsciously believes the physically impossible—that the commander's forces increase in number. What Snyder contends, instead, is that the force multiplier is always less than one (unity). With C^2 resources, the commander can make better use of his forces to approach "perfection;" without suitable C^2, the commander makes less effective use of forces. Interview with Frank M. Snyder, 25 January 1990. I could counter Snyder's argument. Raising the effectiveness of forces without a good C^2 system (at an effectiveness level of, say, 0.6) to a higher level of effectiveness (say, 0.9) by employing a good C^2 system raises the force's effectiveness by a multiplicative factor of 1.5. However, the overall effectiveness of the force is still less than 1.0.

3. Another question about the usefulness of C^2 systems suggests a potential for diminishing returns from the investment. Can too much computerization and the flood of information from communications channels paralyze the commander's ability to act effectively?

4. Adolf Galland, *The First and the Last: The Rise and Fall of the German Fighter Forces, 1938-1945* trans. Mervyn Savill (New York: Holt, Rhinehart, and Winston, 1954), cited by Peter Fleming, *Operation Sea Lion* (New York: Simon and Schuster, 1957), 224.

5. Robert Helmbold compared the Battle of Britain (an air war) to a data base representing 92 19th-century battles (land wars) and found very good correlation of the empirical data to Lanchester's theory. In 19 engagements from August to September 1940, he found Britain's Fighter Command prevailed in 18, against a composite German-to-British force advantage of 1.41-to-1. Robert L. Helmbold, *Air Battles and Ground Battles—A Common Pattern?* RAND P-4548 (Santa Monica, CA: The RAND Corporation, January 1971).

6. An ability to read the German Enigma code was also a factor at the strategic level, but less at the operational and tactical levels of war.

7. Cassandra, 16, 17.

8. Battle statistics from David A. Howarth, *Famous Sea Battles* (Boston: Little, Brown, and Company, 1981), 152-163.

9. I acknowledge, however, that there was an important factor of chance, that US naval air happened to be in the right place at the right time.

10. Philip Feld, "Measuring Incremental Value Added: Supporting the Evolutionary Acquisition of Command and Control Systems," Defense Systems, Inc., unpublished manuscript, 1988, 8. Feld's table included absolute numbers tallied from Headquarters Effectiveness Assessment Tool (HEAT) raw scores. I converted them to ratios of one day to the last to illustrate the "force multiplication" effect.

Force multiplication due to training and experience

	Day 2	Day 3	Day 4	Day 5	
Monitor enemy ground location	1.27	0.76	0.90	1.11	
Monitor enemy ground strength	1.03	1.19	1.04	1.06	
Monitor enemy air strength	3.77	1.06	1.15	1.08	
Monitor own ground strength	3.91	1.47	0.98	1.13	
Monitor own air strength	2.50	1.48	0.92	0.47	
Overall criterion Understanding of enemy	1.28 X	1.00 X	1.25 X	0.88 =	1.41

Note: Raw scores for each day's performance have been converted to ratios comparing one day to the last to derive "force multiplier." Columns not additive.

(Source: after Feld, 1988)

11. Robert McQuie, *Historical Characteristics of Combat for Wargames (Benchmarks)* CAA RP-87-2 (Bethesda, MD: US Army Concepts Analysis Agency, July 1988). The data base was obtained, by contract, from the comprehensive source of quantitative combat data collected in the preceding 25 years by Colonel Trevor N. Dupuy, USA (Ret.), and other military historians of Data Memory Systems, Inc., Fairfax, VA.

12. I derived these examples of the Battle of the Somme, the 1973 Arab-Israeli War, and Vietnam technology from Martin L. van Creveld's *Command in War* (Cambridge, MA: Harvard University Press, 1985) .

13. Ibid., 168-170, 183-184.

14. Admiral Joseph Metcalf III, "Decision Making and the Grenada Rescue Operation," in *Ambiguity in Command*, eds. James G. March and Roger Weissinger-Baylon (Marshfield, MA: Pitman Publishing Inc., 1986), 278, 285.

15. See chapter 3 for a list of desirable characteristics.

16. As a matter of fact, forces enroute to the peacekeeping operation in Lebanon were diverted to make up the *Urgent Fury* task force. Only in retrospect, after an operation is over, can the commander determine how much of a "safety margin," if any, existed.

17. Colonel Stephen E. Anno and Lieutenant Colonel William E. Einspahr, *Command and Control and Communications Lessons Learned: Iranian Rescue, Falklands Conflict, Grenada Invasion, Libya Raid* (Maxwell Air Force Base, AL: Air University, May 1988), 23-30.

18. Captain W.T.T. Pakenham, RN, *Naval Command and Control,* Brassey's Sea Power 8 (Washington, DC: Brassey's Defence Publishers Ltd., 1989), 10.

19. Some, however, have criticized the United States for using too many aircraft in the operation. Anthony H. Cordesman, "After the Raid—The Emerging Lesson from the US Attack on Libya," *Armed Forces Journal International* 5 (August 1986), 358; cited by Anno and Einspahr, 52-55.

20. Anno and Einspahr, 61, 62.

21. The link between the AWACS and the USS *Coontz* was part of a digital information network which maintains, for network participants, a "shared image" or data base of most everything known about the tactical situation. Updates or changes to the data base are exchanged frequently and automatically. Since the USS *Stark* was not a member of this digital network, the *Coontz* had to share the information with the *Stark* by voice communications.

22. Rear Admiral Grant Sharp, *Formal Investigation into the Circumstances Surrounding the Attack on the USS Stark (FFG 31) on 17 May 1987*, vol. I : Report of Investigation, 12 June 1987 declassified version, 1-3, 8-12, 14-18, 31-33, passim. See also Congress, House, Armed Services Committee, *Report on the Staff Investigation into the Iraqi Attack on the USS Stark,* Committee Print (Washington, DC: GPO, June 1987), 1-3, 7-16.

23. Vice Admiral Jerry O. Tuttle, USN, "C^3, An Operational Perspective," in *Science of Command and Control: Coping with Uncertainty* AIP Information Series 2, eds. Stuart E. Johnson and Alexander H. Levis (Fairfax, VA: AFCEA International Press, 1989), 5. Also see Tuttle, "Tailoring C^3I Systems to Military Users," in *Seminar on Command, Control, Communications, and Intelligence* Guest Presentations, Spring 1988 (Cambridge, MA: Harvard University Program on Information Resources Policy, 1988), 93-94, 101.

24. Paul A. Strassman, *Information Payoff* (New York: The Free Press [Macmillan, Inc.], 1985), 117.

25. The MITRE Corporation, *Proceedings for Quantitative Assessment of the Utility of Command and Control Systems* (McLean, VA: The MITRE Corporation, January 1980), cited by Lieutenant General John H. Cushman, USA (Ret.), in *Command and Control of Theater Forces: Adequacy* (Washington, DC: AFCEA International Press, 1985), 237-238.

26. I do not suggest their list is all-inclusive.

27. Brian Conolly and John G. Pierce, *Information Mechanics: Transformation of Information in Management, Command, Control, and Communications* (Chichester, England: Ellis Horwood Limited, 1988), 7-8. See John T. Dockery, "Why Not Fuzzy Measures of Effectiveness?" in *Principles of Command and Control*, ed. Jon L. Boyes and Stephen J. Andriole, AFCEA/*Signal* Magazine C^3I Series (Washington, DC: AFCEA International Press, 1987), 389-396 for a positive view about fuzzy sets and how they might be used as C^2 effectiveness measures. While fuzzy sets have some potential, they do not help solve the problem of force structure tradeoff.

28. As used in this context, information theory is not the mathematical theory (Shannon's Law, for example) used for evaluating how communications channels perform. I am using it instead to represent a collection of theories about how information relates to the C^2 process and contributes to mission success.

29. David S. Alberts, *C^2 Assessment: A Proposed Methodology* MTR-80W00041 (McLean, VA: The MITRE Corporation, January 1980), 21, 24-25. Alberts used a Joint Tactical Information Distribution System (JTIDS)-like capability for the C^2 system in the first example. I converted his estimated improvements to ratios.

30. The rigorous analyst desiring a understanding of the mathematical underpinnings of Lanchester's ideas should refer to James G. Taylor, *Lanchester Models of Warfare*, volumes I and II (Monterey, CA: Naval Postgraduate School, 1983). What follows here is a cursory review of Lanchester's equations. The linear law for "ancient warfare" says that if two, sizable, homogeneous forces confront each other with the same fighting effectiveness and fight it out to the end, the casualty level for each side is directly proportional to the numbers of force elements engaged in the conflict. Ten BLUE fighter aircraft "dogfighting to the finish" with 10 RED fighters looks like 10 independent duels and results in a draw: 10 force element losses, distrib-

uted between the two sides. Ten BLUE fighters dogfighting to the finish with 8 RED fighters ends in 8 RED losses and 8 BLUE losses. Two BLUE fighters survive. Under "ancient warfare," all other things held equal, the larger force always prevails. In the following two differential equations, the rate of attrition is proportional to the density of the BLUE and RED targets together. (Other factors can be added to the right-hand side of the equations to reflect effectiveness of different types of fire, probability of kill, replenishment, and other factors of realistic combat.)

$$\frac{dBLUE}{dt} = -(BLUE)(RED)$$

$$\frac{dRED}{dt} = -(BLUE)(RED)$$

where	*dBLUE/dt*	is BLUE's attrition rate
	dRED/dt	is RED's attrition rate
	BLUE	is the force strength of BLUE at the beginning of the time interval *dt*
	RED	is the force strength of RED at the beginning of time interval *dt*

Substituting the number of fighter aircraft from our example in a simple linear equation,

$$BLUE_0 - BLUE_t = RED_0 - RED_t$$

$$10 - BLUE_t = 8 - 0$$

$$BLUE_t = 2$$

where	$BLUE_o$	is the strength of *BLUE* at the start of the battle
	$BLUE_t$	is the strength of *BLUE* at the end of the battle

and the other two terms are respective values for *RED*

In "modern warfare," the ability to direct or coordinate fire magnifies the ability of a larger force to prevail (and can sometimes enhance the overall effectiveness of a smaller force). Provided both sides have equal capability to coordinate their fire, 10 BLUE fighters battling to the finish with 8 RED fighters again results in the loss of all 8 RED fighters. But even considering RED's ability to coordinate its fire, it is only able to shoot down 4 BLUE fighters. Six BLUE fighters survive. At any time interval, as the battle progresses, the attrition rate of the BLUE force is proportional to the size of the remaining RED forces and RED's ability to inflict casualties on BLUE is proportional to BLUE's remaining force level.

$$\frac{dBLUE}{dt} = -(RED)$$

$$\frac{dRED}{dt} = -(BLUE)$$

Substituting the number of fighter aircraft from our example in a simple square law equation representing "modern warfare,"

$$(BLUE_0)^2 - (BLUE_t)^2 = (RED_0)^2 - (RED_t)^2$$

$$10^2 - (BLUE_t)^2 = 8^2 - 0^2$$

$$(BLUE_t)^2 = 36$$

$$BLUE_t = 6$$

Reflecting on these square law equations for "modern warfare," we can infer that the size of the force is very important in battle—the larger the force, the greater the attrition which can be inflicted. Some of the explanation in this note is based on Captain Wayne P. Hughes, Jr., USN (Ret.), *Fleet Tactics: Theory and Practice* (Annapolis, MD: Naval Institute Press, 1986), 35-37.

31. Dr. John T. Dockery and Robert T. Santoro, "Lanchester Revisited: Progress in Modeling C^2 in Combat," *Signal* 42, no. 1 (July 1988), 41-48.

32. Conolly and Pierce, 135-136.

33. United States, Comptroller General, "Models, Data, and War: A Critique of the Foundation for Defense Analyses," Report No. PAD-

80-21 (Washington, DC: US General Accounting Office, 12 March 1980), 68-70.

34. Conolly and Pierce, 136-164. See also Ferdinand J. Ricci and Daniel Schutzer, *US Military Communications: A C^3I Force Multiplier* (Rockville, MD: Computer Science Press, 1986), 162-166.

35. See James G. Taylor, *Lanchester Models of Warfare*, vol. II (Monterey, CA: Naval Postgraduate School, 1983), 308-310.

36. J.C. Emery, "Cost/Benefit Analysis of Information Systems," originally published by the Society for Management Information Systems 1971, *Writings of the Revolution: Selected Readings on Software Engineering*, ed. Edward Yourdon (New York: Yourdon Press, 1982), 35-37.

37. Donald P. Gaver, *Models that Reflect the Value of Information in a Command and Control Context* NPS-55-80-027 (Monterey, CA: Naval Postgraduate School, 1980), 6-7.

38. Ibid., 8-12.

39. Ibid., 15-18. Dynamic warfare models, as Professor Gaver reminds us, are usually stochastic rather than deterministic.

40. Professor Gaver's formulae were used to confirm his results for Cases A through G and to present them graphically; Cases H through K are the author's.

41. Captain Wayne P. Hughes, Jr., USN (Ret.), *Fleet Tactics: Theory and Practice* (Annapolis, MD: Naval Institute Press, 1986). See especially chapter 10, "Modern Fleet Tactics."

42. Brigadier Richard E. Simpkin, UK (Ret.), *Race to the Swift* (Washington, DC: Brassey's Defense Publishers, 1985), 169.

43. Remember that such models give us only a general idea about force structure issues; we cannot rely on such models to solve our force structure problems.

44. Cost data extracted from Defense Marketing Service, "FFG-7 Oliver H. Perry Class," DMS Market Intelligence Reports: *Warships* (Newtown, CT: Forecast International, 1989), 2-4.

45. D.M. Schutzer, "C^2 Theory and Measures of Effectiveness," *Selected Analytical Concepts in Command and Control*, eds. John Hwang, Daniel Schutzer, Kenneth Shere, and Peter Vena (New York: Gordon and Breach Science Publishers, 1982), 135-137.

46. Schutzer's mathematical derivations are too detailed to discuss here.

47. Schutzer suggests that these computations can be used in reverse for evaluating counter-C^2 measures. When C^2 efforts and counter-C^2 measures are used in unison, the complementary effects are synergistic.

48. Recall David Alberts' example of JTIDS-like C^2 capability. With the added C^2 capability, he estimated the time between "event occurs" and "response initiated" would drop from 6 minutes to 3 minutes, thereby improving the chance of implementing the response from 75 percent to 95 percent before the target moved (response preempted).

49. Hughes, 112-114.

50. Schutzer, 139-144.

51. Daniel A. Willard, *Lanchester as a Force in History: An Analysis of Land Battles of the Years 1618-1905* (Bethesda, MD: Research Analysis Corporation, November 1962), and Janice B. Fain, *The Lanchester Equations and Historical Warfare: An Analysis of Sixty World War II Land Engagements* (Arlington, VA: 1962), cited in Trevor N. Dupuy, *Numbers, Predictions, and War* (Fairfax, VA: HERO Books, 1985), 148-150.

52. Robert L. Helmbold, *Air Battles and Ground Battles—A Common Pattern?* RAND P-4548 (Santa Monica, CA: The RAND Corporation, January 1971).

53. See, for example, United States, *The United States Strategic Bombing Survey, Overall Report (European War)* (Washington, DC: GPO, 30 September 1945).

5. Searching for a Rosetta Stone

In the 1970s and 1980s, a number of C^2 conceptual gardens were seeded and nurtured by various communities of operations researchers. Each community has sought to understand the essence of C^2, each in its own way. Critical thinking and dialogue among the communities have also been nurtured. But is there a consistent framework for analysis? In a 1982 seminar, General Robert Marsh commented about the very difficult task of figuring out the effectiveness of a weapons system, and went on to assert "in the C^3I business . . . measures of merit don't exist."[1] Is there a Rosetta stone for correlating these different approaches and then understanding just what C^2 contributes to mission success? Not yet.

An ASD(C^3I)-sponsored study in the late 1980s conducted by 17 member companies of the National Security Industrial Association concluded that available detailed engineering models were useful in assessing C^2 system performance, but that there is room for improvement in modeling how C^2 contributes to force effectiveness.[2] In a 1988 article, Gregory Foster lamented that the several communities haven't yet reached consensus on what the appropriate process for understanding C^2 is.[3] However, such a pessimistic view is not warranted, as there is currently a sufficient level of understanding to symbolize what C^2 contributes to force effectiveness and to mission success.

A cursory survey of symposia proceedings and treatises published from time to time will reveal that the operations research and systems analysis communities have been paying greater attention to this problem area over the decades of the

1970s and 1980s.[4] A lot of early research attempted to answer how C^2 contributes to mission success, but did not bear much fruit. A survey of more recent literature shows the emphasis is much less on contributions of C^2 systems and far more on modeling the C^2 process itself. Examples include modeling of the decisionmaking process and the role of the human element and, in more recent years, how C^2 can be analyzed in the context of artificial intelligence, robotics, and cybernetics.[5] While modeling the process will particularly help in compiling the cause-and-effect relationships between C^2 and the mission, modeling does not directly assess the contribution of C^2 to mission success.[6] Operations researchers and systems analysts are thinking about the problem of evaluating C^2 effectiveness, but seem to be pigeonholing the effort to find the Rosetta stone as "too hard." Many analysts have recognized this absence of consensus. A workshop convened in the early 1980s sought measures of effectiveness for C^2 with respect to mission success. From this workshop, additional conceptual frameworks for evaluating the value of C^2 systems grew and took shape.[7] Some of the key ones are discussed toward the end of this chapter.

In limited cases, analysts have integrated C^2 and C^2-related communications into the modeling efforts associated with wargaming. Not always very specific with respect to C^2, this type of modeling usually incorporates C^2 as an "information pipe" that can be turned on or off. When this modeling takes the extra step to consider the continuum of C^2 performance or varying levels of C^2 degradation in a scenario, it often reflects the C^2 system performance only as imagined by wargame players and controllers. Furthermore, these efforts to model C^2 performance have not usually been widespread. Instead, analysts have designed them for selected scenarios (such as strategic nuclear force execution) or specific operational levels (such as strategic or tactical). Moreover, C^2 systems modeling has usually been "closed loop," in that it investigates how the C^2 system performs and not what effect the C^2 system has on the success or failure of the forces being supported.

Some analysts and decisionmakers will argue that C^2 effects are already modeled into weapons system studies and do not need to be independently viewed. While that occasionally may be true, one could ask why then—for comparison purposes—weapons systems should not also be modeled without C^2 to see how force effectiveness might change if the communications, computers, or human thought processes inherent in C^2 degrade or break down.

This issue has been particularly acute in strategic warfare modeling. Robert Grayson of The MITRE Corporation says that it is difficult to evaluate C^2 in strategic scenarios because the decisionmakers are preoccupied with how the warhead is going to get to the target and what happens when it strikes the target. As he puts it, the enormous destructive powers of nuclear weapon systems dwarf the contributions of C^2. Consequently, analysts rarely give C^2 any special consideration in strategic modeling and often assume it will survive, endure, and perform flawlessly during strategic warfare.[8] This has led to incorrect perceptions about the decisive value of strategic C^2 systems, making it harder to integrate C^2 systems into the strategic force structure.

Some analysts have tried to measure the value of C^2 in military missions by calculating how many pennies it costs to send and receive each message, how many dollars the military might pay per bit of computer processing, and similar engineering measures reflecting wartime use of the system. But these approaches are less than satisfying when we consider that the C^2 system must be oriented to two environments—peacetime and wartime—and the transition from one environment to the other. However, such approaches are valuable in garrison management information system (MIS) applications within the government and the private sector.

The premise that classic Lanchester attrition relationships can be intertwined with the entropy equations representing information warfare suggests that, after further development and validation of the theory, systems analysis may come closer to quantifying the effect of C^2 on battle outcome. Attrition is obviously a likely outcome of warfare, but annihilation or mindless attrition serves no useful purpose. And, as discussed in chapter 3, the operational art of warfare suggests that it is possible to neutralize enemy forces without significant attrition. The warfare modeling of chapter 4 suggests that exploiting or denying information is just as much a part of the operational art as employing weapons. A good C^2 system, in the context of operational warfare, can lessen the uncertainty about the battle and improve the ability of the force commander to adapt to the tempo of a changing situation and further develop his image of an operational concept. Much more work needs to be done in studying battle dynamics in view of what information—what C^2—contributes to mission success. And because conflicts can be resolved without attrition, much more work needs to be done in modeling peacekeeping, too.

Incorporating more battle dynamics in C^2 modeling raises the ante, however, just as a more complex and fluid battle situation is a heightened challenge for the force commander. Orr offers three points to explain why it's very difficult for the commander to manipulate situations in warfare. First, the commander's decisions do not always determine the results of combat; the outcome varies greatly with changes in the situation. Second, even when the commander's decision has significant bearing on the outcome, the random nature of combat means the commander is only influencing the probability of outcomes rather than influencing the outcomes themselves. And third, the randomness in combat is unstable and makes predictions difficult.

Therefore, even if we can model the combat process with high fidelity, the model would probably become exceedingly complex or too difficult to use. Orr explains how the better combat models represent "severely stochastic" processes. The outcome of any one of a commander's potential courses of action can result in widely disparate futures—a classic image of conflict between two roughly equal adversaries. Both the BLUE and RED commanders, practicing the operational art, have to conceive plans to be prepared to encounter less-than-desirable outcomes and to exploit any outcome that they didn't have much hope of occurring.[9] If we agree with Orr that severely stochastic correctly characterizes the outcome of conflict influenced by C^2, then the more "moderately stochastic" or "deterministic" models would be inappropriate for assessing C^2. This trap ensnares the analyst evaluating the contribution of C^2 because of years rooted in Lanchester culture. If the best way to be "operationally artistic" in dealing with conflict requires the commander to cope with a wide range of tempo and uncertainty, then so, too, must the analyst incorporate a wide range of tempo and uncertainty in his models. This predicament suggests that an assessment, built mostly on commanders' subjective judgments about the value of information in conflict, might be the most successful way to measure how C^2 contributes to mission success.

Consider, in making military decisions during conflict, there is no "right" or absolutely correct decision. So asserts David Alberts, in his suggestions for evaluating C^2 systems. The validity of "school solutions" is particularly in question at the operational and strategic levels of warfare, where there are so many ambiguous factors swirling around the outcomes of alternative courses of action and the stressful uncertainties of time and change. At best, the competent commander can only hope to make the most rational decision possible in view of all aspects of his or her environment.[10]

One very clear way of looking at the C^2 modeling predicament is to consider three types of system modeling. The first is the calculation-based system which models processes; the second is the control system model that analyzes events; and the third type is the information system model, where the approach is to model data flows. As we have now confirmed, C^2 systems fit all three types. Meaningful models encompassing all three types of models have not been written.[11]

Measuring C^2 Effectiveness

Experts seeking a Rosetta stone for the relation between C^2 and its contribution to mission success still fight and usually succumb to the compulsion to step right into modeling; modeling's fine for specifying the C^2 system, but not for justifying it in terms of force structure. Only a few exceptions to the dearth of C^2 effectiveness measures can be found in the literature, and most of these have fallen short of the finish line. That is, these effectiveness measures have not provided the yardsticks of affordability needed in planning the force structure. To integrate C^2 resources successfully into a force structure both cost and militarily effective, we must address these tradeoffs.

As early as the mid-1960s, efforts to quantify the cost effectiveness of C^2 systems began. L.A. Leake led a research team focussing their evaluative and wargaming efforts on the US Army's Tactical Operations System (TOS)—one of the first comprehensive systems to automate battlefield C^2 functions of combat units. Leake set out to measure the cost effectiveness of integrating the TOS into combat units, but ended up concentrating on time-responsiveness of automated C^2 systems versus manual C^2 systems. In 1977, the US Air Force pursued similarly unsatisfying efforts to find measures of effectiveness for how C^2 contributes to warfighting.[12]

The TOS model compared an Army battalion operating with TOS to a battalion augmented instead by additional forces which were equivalent in cost to a battalion-level TOS. The researchers first conducted a number of expensive troop trials for statistical certainty and then progressed to "yes-no" answers to the hypothesis that TOS does a better job than its cost-equivalency in troops. Perhaps due to a shortage of Army funding or perhaps a lack of suitable analytical tools, the Leake study didn't go far enough. The value of C^2 systems should be far more than just making information move faster; a study of the value of C^2 must also consider the quality of the decisions to be made by the commander. Was the commander able to build a shared image so that planning was accurate and thorough? Was the commander able to cope with the uncertainty and tempo of the ensuing conflict? Even after TOS field testing in the 1970s, Army research still couldn't conclusively answer the cost-effectiveness question. This research did, however, characterize the importance of responsiveness and other time factors in aiding the commander during C^2 processes.

In the late 1970s, CACI, Incorporated conducted a study of C^2 for the DOD's Director of Net Assessment, using a data base of 41 Marine Corps engagements from World War II to Vietnam and focusing on characteristics of the C^2 process. As their study modeled the C^2 process rather than measuring the contribution of C^2 to the mission, CACI's study did not attempt to quantitatively evaluate the impact of C^2 on warfighting. However, the study did mathematically demonstrate that C^2 does have a meaningful, positive relationship in accomplishing the mission. The study further concluded that, of the many factors potentially bearing on the performance of the C^2 process, adaptive leadership and resourceful planning, risk management, and cohesive control of forces are the strongest factors.[13] Although not evaluated in the context of what the US military now calls the operational art, the study's salient factors track well with the three dimensions we have been examining: dealing with tempo and uncertainty and building the "shared image." The CACI study also established a degree of universality among the factors; across the three combat periods in the study (World War II, Korea, and Vietnam), CACI found that these factors were as meaningful in one period as in another.

Intriguingly, CACI was able to infer trends showing C^2, as a contributor to the successful outcome of an engagement, is increasingly important as the political-military situation becomes more fluid and complex. Their best example is Vietnam; CACI expected that the US military would be increasingly involved in that type of situation after 1980.[14] We recall that the great military theorists have described military power as an extension of political action. Looking at the history of the 1980s, CACI's hunch became true. The Grenada intervention, the strike against Libya, Persian Gulf operations, and the Panama invasion are textbook examples of complex political action carried out by the instrument of military power. Adaptive leadership and resourceful planning, risk management, and cohesive control were all aspects of the C^2 for these operations.[15]

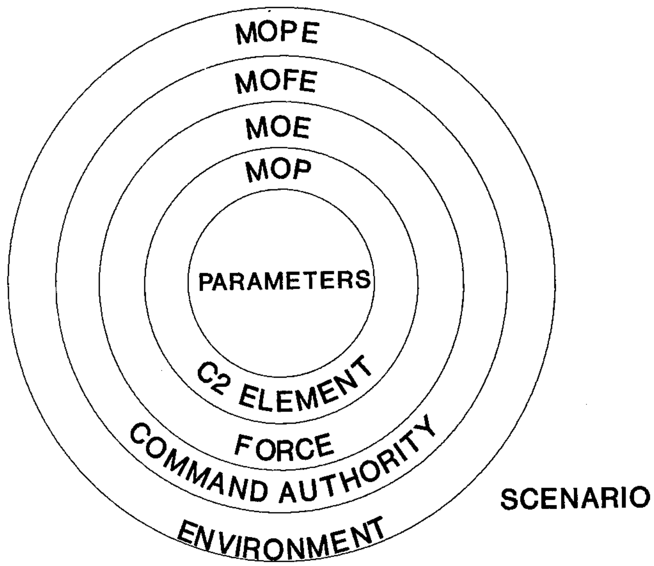
One method close to the idea of measuring the tradeoff between force elements and C^2 resources was published by two General Dynamics engineers, Edward Lindsay and Robert Morris. They illustrated a method for quantifying the value of automation improvements for the US Air Force's 407L Tactical Air Control System, in terms of force elements, to justify the improvements.[16]

Lindsay and Morris put their focus on figures of merit related to "mechanization" of the World War II-based functions of controlling tactical air resources. A vital step in their method is designing an acceptable scenario, to reflects more accurately the interests of the decisionmakers. However, their dependence on analytical modeling apparently included little interaction with decisionmakers.[17] They properly avoided engineering measures such as "time to transmit a message" and turned instead to force effectiveness measures such as "percent of assigned tasks completed" and the "decrease in numbers of friendly casualties."[18] Predictably and unavoidably, the measures of merit used by Lindsay and Morris lean toward automating—not improving—today's procedures, how the US military does business. Their measures also lean back on attrition theories of warfare.

Lindsay and Morris couple the cost of attrition with the cost of doing business. They correlate the military (dollar) value of the C^2 resources to the cost savings from the dollar value of attrition avoided. There are two problems with their approach. First, it continues the preoccupation with attrition. Even under high-fidelity modeling, the dollars saved from attrition avoided will not manifest themselves in peacetime when there is no combat attrition. Furthermore, senior decisionmakers cannot realize (or credibly advertise) any savings in the short-run because there is no combat attrition. Moreover, if we never take the weapons systems and C^2 resources into conflict, we will never realize the long-run savings of avoiding attrition. Secondly, Lindsay and Morris base their method almost entirely on avoiding friendly attrition. It does not account for the "functions-denied" concept where a friendly force can prevail in a conflict without firing a shot but instead with creatively applying finesse and intelligence found in the "operational art."

Next we turn to some of the more qualitative methods for determining force effectiveness. Richard Hayes, a practitioner in C^2 evaluation, has said that the two predominant methods for evaluating C^2 are the Modular Command and Control Evaluation Structure (MCES) and the Headquarters Effectiveness Assessment Tool (HEAT).[19] MCES, sponsored by the MORS C^2 Evaluation Workshop, is a conceptual framework based, in part, on the Lawson model of the C^2 process.[20] This evaluation structure, shown in figure 15, is a way of distinguishing among measure-of-merit categories according to the level of operational activity. MCES is mainly a decisionmaker's tool for understanding the benefits of various alternative solutions to C^2 problems. Very flexible in terms of when it might be applied in the C^2 system's life cycle and to what type of answer is needed for what kind of decision, the Structure can also be used to evaluate C^2 issues on several levels:[21]

FIGURE 15. Specifying figures of merit in the Modular C2 Evaluation Structure



(Source: Sweet 1987)

- Measures of policy effectiveness (MOPE), which check whether the C^2 system meets architectural, cost, and life cycle supportability criteria (usually Command- or Service-unique needs).
- Measures of force effectiveness (MOFE), or the degree of mission success.
- Measures of effectiveness (MOE), that is, what transpires across the boundary between C^2 systems and the forces managed.
- Measures of performance (MOP) of subsystems, within the closed loop of the C^2 system itself.
- Dimensional parameters, measuring technical performance within subsystems.

While the MCES reflects a degree of consensus within the C^2 evaluation community, agreement on the meaning of the broad range of terms is by no means perfect. Richard Hayes listed the many important standards on which the modeling community has not yet reached closure: force effectiveness, C^2 effectiveness, quality of C^2 components, responsive to commander and staff, confidence of commanders and staff, availability, interoperability, and efficiency (or resources consumed to be effective).[22] In fact, measures of effectiveness (how well something contributes to its particular context) are very often confused with measures of performance (how well the thing works by itself). The former set of measures is mainly qualitative, while the latter set is usually quantitative. Sorting this out is critical in evaluating the contribution of C^2. Michael Sovereign and Ricki Sweet explain that the current state-of-the-art in C^2 evaluation usually mixes qualitative and quantitative analysis methods.[23]

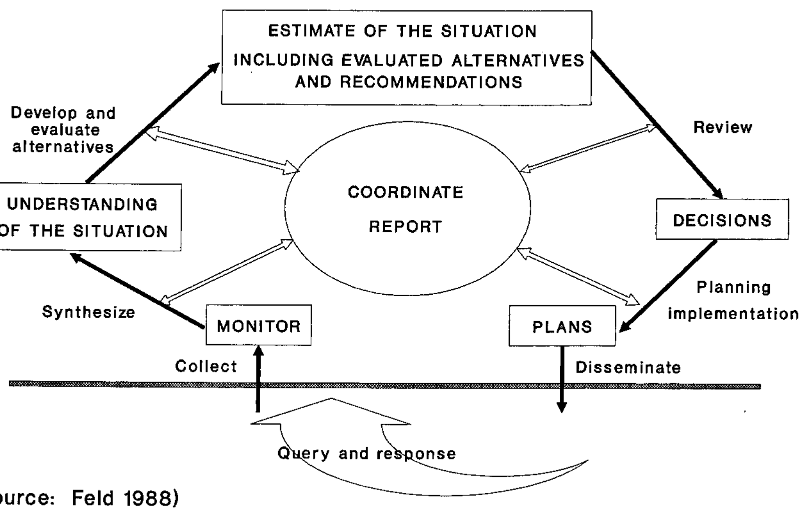
While the idea of measuring force effectiveness (as in MOFE) sounds like it's close to the challenge of this book, such measures demand a great deal of modeling and testing. And when force effectiveness is quantified, it is usually quantified in terms of attrition—not directly accounting for dimensions of the operational art. Measures solely based on attrition may lead to an ineffective use of resources. For example, one downed enemy aircraft per 30-minute sortie may reflect a more effective application of force structure than two downed aircraft in a 60-minute sortie. Shorter, 30-minute sortie turnarounds will consume more fuel dollars to return to base; using extra fuel is inefficient. While the shorter sortie may be less efficient than the 60-minute sortie, it may be more effective. By giving the commander more flexibility in launching or redirecting aircraft to respond to the unknown, he/she can better cope with the uncertainty about when the next enemy air superiority fighter will pop over the horizon.

The Headquarters Effectiveness Assessment Tool, as its name implies, is a method for evaluating how a headquarters reacts to a changing warfare environment and plans various courses of action to be responsive to the changing situation. HEAT assesses the quality of the command and control processes and the systems that support the processes, as well as the overall effectiveness of decisions made and how they are implemented by subordinate headquarters. Of the four ways to control forces—reflexive, adaptive, direct, and trial-and-error—HEAT is based on a concept that a command headquarters is analogous to an adaptive control system, a system able to plan ahead and to plan well enough to be militarily effective. As an alternative way to look at it, a C^2 system flexible enough to cope with developing contingencies assumes an adaptive control posture.[24]

The products of adaptive control are seen in the numbers of viable courses of action the headquarters (that is, the C^2 system) can generate. The types of effectiveness measures include the quality of the plans generated to meet the present and forecast environments.[25] Under a HEAT assessment, a high-quality plan is one which needs very little change, regardless of the turn of events in the conflict. HEAT also evaluates the quality (completeness, correctness, consistency, and so forth) of the directives issued to forces to fulfill the plans. And HEAT measures the time needed to produce the plans and issue the directives. HEAT is a good tool for evaluating incremental changes in C^2 systems and "before-and-after" training, but one of its shortcomings is that it is not a two-sided "gaming" of what dynamics might happen in conflict between adversaries. Without two-sided gaming, it would be difficult to use HEAT to assess how the commander and staff react to changes in battle tempo and cope with the uncertainty of what will happen next—what will their opponent do and when. Force effectiveness measures are more elusive without gaming. Other shortcomings of HEAT are the large numbers of analysts required to use the tool and its tendency to intrude in the ongoing C^2 process. HEAT, a closed-system evaluation, looks at the C^2 system under the microscope (figure 16).

As described in chapter 4, David Alberts' approach follows a different trail than those leading to MCES or HEAT. Alberts' "value-added" approach evaluates the contribution of C^2 to mission performance by counting and weighting conflict results: how many more weapons or targets destroyed with the C^2 capability than without.[26] His method (while it does have a foun-

FIGURE 16. Headquarters Effectiveness Assessment Tool control cycle



(Source: Feld 1988)

dation in attrition theory) is one step closer toward the challenge of this book. Alberts dissects attrition equations and decomposes a probability-of-attrition term in the equation into the expectation a target can be acquired and probability of kill if acquired and probability of kill if the target moves. Although Alberts' approach doesn't address using tempo and uncertainty as an operational advantage in getting the enemy to cease warfare and withdraw or capitulate, his 1983 paper does carry the "value-added" idea another step by assessing the quality of the decisionmaking process, given more alternative options and improvements in the amount and types of information provided the decisionmaker.

While not addressing C^2 effectiveness per se, a 1989 RAND Corporation study offers substantial evidence on why the C^2 process relies so heavily on the nature of the information subsumed in the process. These insights will help us formulate a new approach to evaluating what C^2 systems contribute to mission success.[27]

The Army commissioned the study because of a concern with potential information overload in a unit tactical operations center, an overload that could paralyze a commander and his/her battle staff. The researchers observed 12 Army command post exercises at echelons above brigade in Europe and in the United States and interviewed many senior officers, both active and retired. After reviewing several earlier studies, the researchers found that many efforts had gone off course by trying to catalog all the types of information the commander needs. They found many other C^2 studies had focused on the content and flow of information.

The RAND researchers concluded it is not enough to merely satisfy the commander's need for specific categories of information, the content of those categories, and information flow. Rather, all the components of the C^2 system (human and nonhuman) should be able to imitate and adapt to the commander's *image* of the situation and the *image* of his concept of operations. This image is based on the commander's current view of the situation, as influenced by his mission (interjected by way of senior headquarters guidance), as influenced by updated information about the situation, and as influenced by the commander's doctrine, training, and experience. The commander translates this composite current view into his/her intent and then translates this into action. While these ideas are self-evident to operational and C^2 specialists, the RAND study explains the value of C^2 communications with conciseness other researchers do not often display.[28]

Looking at the C^2 process from this perspective, it's clear that the value of a piece of information cannot be determined out of context, whether it is the context of the situation or the context of the mission. To ensure consistency with the commander's image, the RAND researchers pointed out it is up to the C^2 system (again the human and nonhuman components) to select only that information which is pertinent to his image. Of course, if there is new information which would alter the commander's image, the C^2 system should bring it to his attention. The commander needs assessments far more than he needs raw data. The researchers explained that the human components of the C^2 system will perform this function better, if individuals and staffs are better educated in the C^2 process and trained together as cohesive units for longer periods of time. Computers and communications technology in the C^2 system must also be geared to build and maintain a shared image.

The successful commander will strive to ensure his or her staff and subordinate commanders share and understand his or her image before discussing courses of action and will aggressively use dialogue, augmented by tools like standardized staff planning formats.[29] Admiral Nelson's success at Trafalgar exemplifies the conclusions of the RAND research. Nelson had trained his commanders in his personal doctrine. Over and over they had rehearsed Nelson's operational concepts and tactics to overcome the limitations of naval warfare C^2 in the late 18th century. When Nelson was wounded and taken below decks on his flagship during the early heat of battle that August night in 1798, his commanders were so intimately familiar with Nelson's image of the battle they were able to fulfill successfully his innovative operational concept and defeat the French fleet.[30]

Why is the search for a Rosetta stone important to this book? It shows the essentiality of information within the C^2 system and how the C^2 process uses information to satisfy the commander's needs. Alberts' approach is a bottom-up dissection of C^2 system components, which is then reconstructed into an analytical framework for C^2 system performance. But his approach does not attempt to evaluate cost effectiveness. HEAT concentrates on the C^2 process within a headquarters. MCES characterizes the C^2 process and then looks outward to build a conceptual framework. Other research in wargaming and analysis treats C^2 as an integral component of attrition-oriented weapons system employment but typically does not look at the tradeoffs among force elements, maneuvering units, and C^2 systems within the force structure.

Need for a Credible Solution

This chapter asks if there is a Rosetta stone for C^2 modeling and assessments. While there have been noble quests to uncover one, the answer is, not yet. Without credible answers to the force structure affordability questions, the C^2 advocates' claims of advantage, leverage, and force multiplication are empty rhetoric. The heart of the matter is that understanding information in terms of uncertainty and tempo is the formula for discovering the solution.

Is there a best answer for figuring how much C^2 contributes to mission success? Force structure planners don't need 3-sigma, Monte Carlo, multi-variate networking models to do their job. The resources—time, people, and computing power—will probably not be available to answer the 4-hour-turnaround questions that so frequently crop up during budget deliberations. And most senior decisionmakers won't sit still for high-fidelity modeling either because of healthy skepticism about models or a burning desire to get to the bottom line—now!

A simple analytical framework, which the senior decisionmakers help to build, is the key in evaluating what C^2 contributes to mission success. The framework should be subjective enough to account for senior decisionmakers' experience, wisdom, and judgmental skills, as well as account for the subjective and objective characteristics of C^2 systems. Yet the framework should be quantitative enough to provide discrete results—specific numbers—and an audit trail to support force structure decisionmaking. The remaining chapters will further explore one of the most vital aspects of the politics of C^2: an affordable means to improve chances of mission success.

§ § §

Notes

1. General Robert T. Marsh, USAF, "Air Force C^3I Systems," *Harvard University Command, Control, Communications, and Intelligence Seminar-1982*, 105, cited in Francis W. A'Hearn, *The Information Arsenal: A C^3I Profile* (Cambridge, MA: Harvard University Program on Information Resources Policy, 1984), p. II-22. At the time, General Marsh was the commander of Air Force Systems Command.

2. Charles P. Zuhoski, "C^3I Modeling: Can We Do Better?" *Proceedings: 1987 Joint Directors of Laboratories C^2 Research Sympo-*

sium, 16, 17, 18 June 1987 (Fort Lesley J. McNair, Washington, DC: The Basic Research Group, Joint Directors of Laboratories, September 1987), 331. While I agree with his conclusions about the "state of the art," I disagree with his call for more sophisticated simulation and modeling tools to deal with this problem area.

3. Gregory D. Foster, "Contemporary C^2 Theory and Research: the Failed Quest for a Philosophy of Command," *Defense Analysis* 4, no. 3 (September 1988): 201-228. Many of the articles in this special Command and Control issue seek a "unified theory." For a extensive critique of the more sophisticated methods being used to understand C^2, see Gerald W. Hopple, "An Assessment of the State-of-the-Art of Advanced Analytical Methodologies for C3 Decision Support," in *Principles of Command and Control* AFCEA/*Signal Magazine* C^3I Series 6, ed. Jon L. Boyes and Stephen J. Andriole (Washington, DC: AFCEA International Press, 1987), 343-369. Dr. Hopple is an expert in decision support systems.

4. Reiner Huber noted that, between the 1974 and 1982 NATO military modeling conferences, the papers on C^3I and EW increased from zero to about 20 percent of the total papers. See Reiner K. Huber, ed., *Systems Analysis and Modeling in Defense* (New York: Plenum Press, 1984), 11, 13. A similar comparison between the 1987 and 1988 annual symposia of the Military Operations Research Society (MORS) shows an increase in C^2 modeling papers from about 3 percent to about 13 percent of the papers accepted for the symposia proceedings. See *Proceedings* of the 55th and the 56th MORS Symposium, Washington, DC.

5. For an overview of decisionmaking theories, in the context of military operations, see Major George E. Orr, USAF, *Combat Operations C^3I: Fundamentals and Interactions* (Maxwell AFB, AL: Air University Press, July 1983). Major Orr's work is an in-depth analysis of C^2 theory up to that time.

6. Modeling the process will certainly help in characterizing specific design requirements for those C^2 decision support systems which attempt to emulate the commander-staff decisionmaking processes. However, C^2 decision support system designers must use the results with caution; there is a risk that the designed system will be too personality specific and not applicable to all situations.

7. Ricki Sweet, "Special Session C^2 MOE Workshop Report," *Proceedings of the 53rd Military Operations Research Society Symposium* (Washington, DC: DOD, June 1985), 19-21.

8. Robert W. Grayson, "Evaluating the Impact of Strategic C3 System Performance," in *Science of Command and Control: Coping with Complexity* AIP Information Series vol. 2, ed. Stuart E. Johnson and Alexander H. Levis (Fairfax, VA: AFCEA International Press, 1989), 122-123.

9. Orr, 47, 52-53.

10. David S. Alberts, *Analysis and Evaluation of C^3I Systems* MTR-83W00003 (McLean, VA: The MITRE Corporation, April 1983), 5.

11. Chris Gibson, presentation at the Admiralty Research Establishment (Portsdown), Portsdown, England, 9 May 1990.

12. See L.A. Leake, R.V. Tiede, and S. Whipple, Jr., *Information Flow and Cost Effectiveness* Part II (McLean, VA: Research Analysis Corporation, April 1970) for the TOS research methods. General Cushman also commented on this attempt to study cost-effectiveness. See Lieutenant General John H. Cushman, USA (Ret.), *Command and Control of Theater Forces: Adequacy* (Washington, DC: AFCEA International Press, 1985), 237. As an indication of the difficulty of this C^2 automation problem, the Army was continuing to work on the program in 1990 under a different name. For a description of modeling of combat staff operations for TOS, see Gale R. Mathiasen, "Modeling C3—A Description of the Command, Control, Communications Combat Effectiveness (FOURCE) Model," in Huber, 321-335. See also The MITRE Corporation, *CONSTANT QUEST Modeling Group, Phase I Report* (Bedford, MA: The MITRE Corporation, 2 April 1977), cited by Lieutenant General John H. Cushman, USA (Ret.), *Command and Control of Theater Forces: Adequacy* (Washington, DC: AFCEA International Press, 1985), 237-238. This Air Force model was completed in 1977 and used as late as 1984.

13. Richard P. Clayberg, *Defining and Measuring the Contribution of Command and Control to Unit Effectiveness in Combat* (Arlington, VA: CACI, Inc., May 1980), 4-28 to 4-29. CACI also concluded, not surprisingly, that there are strong interactions among the many aspects of the C^2 process.

14. Ibid., 6-10 to 6-12.

15. See Colonel Stephen E. Anno and Lieutenant Colonel William E. Einspahr, *Command and Control and Communications Lessons*

Learned: Iranian Rescue, Falklands Conflict, Grenada Invasion, Libya Raid (Maxwell Air Force Base, AL: Air University, May 1988), for C^2 in the Grenada and Libya actions.

16. Edward Lindsay and Robert E. Morris, "Automation of the Tactical Air Control System: Military Value," in *Selected Analytical Concepts in Command and Control* ed. by John Hwang, Daniel Schutzer, Kenneth Shere, and Peter Vena (New York: Gordon and Breach Science Publishers, 1982), 227-248. At the time Lindsay and Morris were developing this idea, General Dynamics had a contractual interest in upgrading portions of the Tactical Air Control System.

17. While there's great value in modeling, the modeling must be responsive to the frequent "what-if" sensitivity analyses demanded by senior decisionmakers. If it is not responsive, modeling should not be used.

18. Engineering measures, such as "time to transmit a message" and "number of effective plans written," are extremely useful in comparing two solutions to the same problem (such as a manual C^2 system versus an automated C^2 system), but are rarely helpful in explaining how C^2 systems fit within the overall force structure. Because the commander's perceived value of information is so critical in assessing C^2 in conflict, we need to avoid engineering measures which are equipment-dependent. These measures are least helpful in comparing the C^2 aspects of the force structure against the non-C^2 aspects of the force structure. We may never reach broad agreement on figures of merit among the many stakeholders (force planners, operators, technologists, Congressional staffers, and so forth). Regardless, the methods in this book are offered in hope that we can come closer to such an agreement.

19. Richard L. Hayes, "Different Types of Excellence," lecture given at AFCEA Educational Foundation, Fairfax, VA, 26 April 1988.

20. The Lawson Model defines the C^2 process as "Sense-Process-Compare-Decide-Act." For a description of the Lawson Model, see Orr, 24-25. For some of the history behind the Lawson Model and how it might be expanded for two-sided, force-on-force analysis, see Captain Wayne P. Hughes, Jr., USN (Ret.), *Fleet Tactics: Theory and Practice* (Annapolis, MD: Naval Institute Press, 1986), 185-188. For an example of how the Lawson model can be used, see the discussion in chapter 4 of D.M. Shutzer's 1982 article, "C^2 Theory and Measures of Effectiveness."

21. Ricki Sweet, "The MCES and the Search for Generic Measures," in *Science of Command and Control: Coping with Uncertainty* AIP Information Series vol. 1, ed. Stuart E. Johnson and Alexander H. Levis (Washington, DC: AFCEA International Press, 1988), 107-109.

22. Hayes, lecture.

23. Michael G. Sovereign and Ricki Sweet, "Evaluating Command and Control: A Modular Structure," *The C^3I Handbook* 3rd ed. (Palo Alto, CA: EW Communications, Inc., 1988), 156-161. This article also describes a practical application of MCES relating to naval warfare C^2.

24. Philip Feld, "Measuring Incremental Value Added: Supporting the Evolutionary Acquisition of Command and Control Systems," Defense Systems, Inc., unpublished manuscript, 1988, 3-4. In contrast, Soviet forces typically used the reflexive control method.

25. See also references to J.C. Emery's work on the time-value of information in chapter 4.

26. David S. Alberts, *C^2 Assessment: A Proposed Methodology* MTR-80W00041 (McLean, VA: The MITRE Corporation, January 1980), 19.

27. James P. Kahan, D. Robert Worley, and Cathleen Stasz, *Understanding Commanders' Information Needs* RAND R-3761-A (Santa Monica, CA: The RAND Corporation, June 1989), pp. 15-20, 24, 30, 56,

28. See John F. Jacobs, *Design Approach for Command and Control* MITRE SR-102, adapted from lectures given 16-19 December 1963 at the University of California and the University of Washington (Bedford, MA: The MITRE Corporation, January 1964) for one of the earliest and clearest statements of the essence of modern C^2 systems. In 7-11, Jacobs explains how the ideal C^2 system communicates—in the strictest sense of the word—information. Information is, in turn, the collection of concepts surrounding data. C^2 does not work unless information can be communicated. This communication is, in other terms, "sharing the commander's image." For a slightly different view, see Carl H. Builder, *The Masks of War,* a RAND Corporation research study (Baltimore, MD: The Johns Hopkins University Press, 1989), chapter 11. Builder studies image from the per-

spective of the force element commander, in other words, how well or how poorly the aircraft pilot or ship's skipper understands the mission, intent, and operational concept of their senior commander.

29. The RAND researchers found that many commanders highly valued face-to-face dialogue for just this reason of building a shared image. In addition to formats for plans, the Army often uses the METT-T "memory jogger" for ensuring combat planners have considered all aspects in estimating the situation. (METT-T stands for mission, enemy, terrain, (own) troops, and time available.)

30. For an assessment of the Battle of the Nile with respect to naval doctrine and tactics, see Hughes, 24-25.

6. Wise Men, Warriors, and Whiz Kids

Our quest for a Rosetta stone continues. Leadership of forces in war is *decisionmaking in the face of uncertainty and tempo*; defense force structure planning is *decisionmaking in an uncertain and changing international and domestic environment.* Responding to any challenge requires decisions under uncertainty and changing tempo. Further, decisionmakers must also formulate responses within an intricate web of stakeholder interests, seeking a common image of what needs to be done.

DOD directs the military departments to determine force requirements in the context of national security objectives and meet the operational requirements of the combatant commanders.[1] Ideally, the force structure should be rationally derived from national military strategy. Force planners should identify the force levels, force mix, and sustainment levels, the time scale for building the forces, and the required funding, letting requirements drive what the services need to program. Under typical decisionmaking conditions, however, the services let funding levels determine the force structure. Each accounts for C^2 in the force structure differently; typically, C^2 is buried.

A group of distinguished defense experts, after reviewing the US conventional force structure and the prospects for reduced defense spending, summarized three obvious approaches to remedy force structure problems for the 1990s: increase defense funding at a sustained rate; make the best of what we have; or change current defense priorities and policies, revise strategy and force levels commensurate with resource constraints, and improve the resource allocation process. A group majority understandably preferred the third option, but saw the second option as the most likely " . . . as it conforms to the political realities of the budget process and the usually short-term horizon for decisionmaking."[2]

This chapter does not encourage radical changes to the way decisionmakers currently plan the force structure;[3] such changes happen only after overcoming great inertia. However, this chapter does describe the complex framework for such decisionmaking and identifies criteria for suitable techniques to integrate C^2 smoothly and rationally into the force structure. It describes force structure politics.

A Review of National Security Decisionmaking

Who decides where national security is going? Decisions regarding the defense component of national security policy are largely based on consensus-building among members of the executive and legislative branches. They are tempered by the specific visions of senior military leaders and their civilian supervisors and many other outside influences.

- We expect the leading stakeholder to be the President, but the truth is that the national security decisionmaking system has become increasingly consensual. The President may have the principal mandate, but he must approach decisionmaking as an interdisciplinary, dynamic activity, taking into account all relevant variables, linkages, and the expanded roles of other stakeholders in the multidimensional national security environment. Occasionally from this high level, the President directly influences force structure decisions. Consider President Carter's direction to stop the B-1 bomber program and President Reagan's direction to reinstate it. By making C^2 a top priority in his strategic force modernization program, President Reagan created quite a stir in force structure planning, illustrating one way in which the President can influence C^2 resources.

- Key elements of the Executive Office are also important stakeholders in the decisionmaking system. The

National Security Council and the Office of Management and Budget in particular have become increasingly important in ensuring responsive and decisive action that may not be forthcoming from the executive departments or from Congress.

- The State Department and other executive branch components participate in the decisionmaking process by providing consultation in their areas of expertise. State, for example, provides the diplomatic eyes and ears for gathering information needed for making national security decisions. In the military aspects of national security, State works with DOD on diplomatic dimensions of proposed military actions. In the economic aspects of national security, State works with the Departments of Commerce and Defense to coordinate the transfer of military technology to foreign nations. National security decisions here weigh diplomacy and economic expansion on the one hand against protection of military advantage or certain US industries on the other. The sale of the E-3 AWACS, with its C^2 technical superiority, to Saudi Arabia was one such decision.

- Congress plays a key role in national security decisionmaking, sometimes dictating the composition of the force structure. Congress vigorously investigated the Cheyenne Mountain false alarms in the early 1980s. Followup through the GAO compelled DOD to increase its investments in upgrades to Cheyenne Mountain and other C^2 facilities in the national warning system, thereby changing the US force structure balance. The resulting recognition of the importance of C^2 resources to national indications and warning functions also fueled, in part, the creation of the US Space Command. The addition of USCINCSPACE to the decisionmaking process has had a far-reaching influence on force structure planning, particularly with regard to C^2 systems.

And, of course, Congress enacts laws and appropriates funds needed to carry out national security decisions. Congress also gets involved in decisionmaking through its powerful committee system, which, in recent years, has increased its oversight in national security areas. Investigations into procurement abuses and the downing of the Iranian airliner are examples. Oversight increases proportionally to the extent the Congress does not trust the executive branch to carry out its mandates; Congress passed the Defense Reorganization Act of 1986 because of dissatisfaction with the pace of DOD's plans to transfer more decisionmaking responsibility to the unified and specified commanders. Congress also included provisions in this act to permit more legislative oversight concerning the military force structure.

- The media and special interest groups are also important stakeholders in the decisionmaking process. Today's "wall-to-wall" coverage of major crisis events provides so much current information to both the decisionmakers and the public that national security decisions must often be made immediately and sometimes irrationally. Media attention to such C^2 incidents as the communications shortcomings during *Urgent Fury* and the shoot down of the Iranian airliner by the USS *Vincennes* led to congressional investigations on how to preclude such incidents in the future. Some of the measures to preclude these incidents are now affecting military C^2 doctrine. Special interest groups also attempt to influence decisionmakers on the procurement of weapons systems and C^2 systems.

- One of the principal stakeholders in force structure decisionmaking is the military establishment. Deciding how much military power should be used in any set of national security options is a process of translating national security strategy to a military strategy and the corresponding force mix. This translation must trade

> costs for benefits and vice versa, consistent with the ebb and flow of national priorities. Since the late 1940s, the military's role in this decisionmaking has gradually increased to the point where the combatant commanders (the CINCs) can influence what programs to invest in and what the force structure should look like, in addition to what the military options and plans should be in the CINC's area of responsibility.[4]

In the military establishment, planning and advocacy for C^2 is often left to the communications and computer specialists. While these specialists can help define and resolve force structure issues, the responsibility for planning and advocacy does not belong with them. Instead, the technical specialists must cultivate C^2 advocacy in their commanders. Because the responsibility for advocacy belongs with the operational commander, commanders must understand how incorporating C^2 resources into the force structure can make their mission go better—or get by with less. Communications, computer, and other specialists involved in C^2 must continue to improve their understanding of the military "business" so that they can advise and support commanders in C^2 advocacy.

Ideal decisionmaking is a rational process that systematically defines a problem, identifies and evaluates suitable alternatives, and then decides on a course of action. A systematic approach avoids impulsiveness and enhances the quality of responses to contingencies. However, the degree of rationality in the process is based on the type of decision required, and national security decisionmaking is not always a rational process. More rationality may result in national security decisions that are more defensible, but heightened rationality may have to discount local microeconomic concerns, special interests, and other factors. Further, the interested parties are chartered for widely different political stances, and do not work in perfrect harmony. While decisionmakers should attempt to account for all interests, accommodating too many extreme interests may corrupt the process, resulting in flawed decisions that satisfy no one. And decisionmakers must apply all the skills they can muster in interpersonal relations, group dynamics, and problem solving. Any need to apply such skills should belie claims of a rational process. Even consensual "joint actions" among the services, especially with respect to the military force structure, are almost of necessity political compromises.

Model Criteria and Political Rules

What are the goals for force structure decisionmaking? An ideal force structure decision model should be able to satisfy four key criteria. The decision model should:

- Accommodate uncertainty—uncertainty about the threat scenario and level of conflict; about how own-forces will perform; uncertainty about enemy intentions; about evolving doctrine for employing high-technology weaponry; and about the effectiveness of the increasing functional and geographic span of forces.

- Be responsive to the tempo of change, whether the change is in the military environment or in the world environment.

- Accommodate the complexity of the decisionmaking structure, as well as the senior decisionmaker's vision.

- Incorporate the wisdom and experience of the planners and leaders participating in the decisionmaking process.

Martin van Creveld's standards for a good C^2 system apply equally as well to force structure decisionmaking.[5] Specifically, accurate and timely information from all sources—pro and con—must be continually available to the decisionmakers. Decisionmakers must be able to sort out which information is truthful, relevant, and significant. Together, the participating decisionmakers must have a composite mental frame of reference (the "shared image") sensitive to US national security interests. Goals and alternative solutions chosen by decisionmakers should be desirable and realistic.

Force structure decisions, whether affecting courses of action or policies, should also clearly express what the decision is, why it was made, and when it will be implemented. Once the decision is made, the decisionmaking system should cling to the essence of it. If the political system that made the decision wavers from it, the system will lose credibility in the public's eye. And finally, the decisionmaking system must thoroughly monitor how its decisions are being implemented. If decisions are not carried out accurately and on time, the system's credibility will again suffer.

In addition to the four key criteria a force structure decision model should satisfy, the decisionmaking process must also consider important political issues such as technology transfer, local jobs resulting from award of significant contracts, what federal programs are needed to provide offsets if the jobs go away, whether the public will support defense growth, loss of a jurisdiction's revenue, and so forth. Expanding, contracting, or realigning the US force structure can influence a number of these issues. This is the essence of political economy.

To address the political economy, the model used in deciding the worth of the investment in C^2 must include "political rules" to constrain the modeling results,[6] of which there are many examples. A specific force structure composition dictated by the President, Congress, or the DOD to fulfill a national security objective is one type of political rule that must be incorporated in the model. Another example is not "breaking" existing high-dollar-value development or production contracts for expensive weapons systems, thereby satisfying constituent interests or keeping some element of defense industry viable. Minimizing the types of forces-in-being is a kind of rule often implemented by legislation. Other political rules are found in procurement regulations.[7] Finally, the most significant type of "rule" is the funding constraint.

Why should political rules be included in force structure decisions? The military establishment would prefer to make just objective decisions. But decisions in a representational democracy are never that simple. In a major report on how the defense community uses models and wargames for decisionmaking, the GAO criticized DOD for not incorporating political judgment in models and relying too heavily on quantitative scientific management, without considering the human element when it is appropriate to integrate it.[8] The GAO's finding is enduring.

Human judgment also infers that political rules exist in the surrounding environment. The strategic environment influences acquisition decisions. If war is imminent, national willingness to make weapons system investments is higher. If an external threat to national security is not apparent, or if domestic problems are far more significant than external threats, a lower priority is assigned to weapons system investments.

A geopolitical axiom, often cited by senior political and defense leaders, asserts that perception is reality. A commander will base any response to the threat on how the quantitative measure of the threat and the opponent's intentions are perceived. For a response to be credible (deterrent), the commander will organize a tangible, quantitative force structure and tie it together with intangible C^2 resources. Through his/her actions, the commander will also demonstrate will, cohesion, and intentions as to how a response to the perceived threat will be employed. Therefore, the extent to which any commander perceives the threat is "reality." In the next chapter, we will see how these varying perceptions of threat or risk can be transformed into the decisionmakers' willingness to trade C^2 resources for other force elements within the framework of the military force structure.

How a commander perceives his or her ability to cope with uncertainty and tempo and keep the shared image current, coupled with the size of his force, is a measure of how he or she perceives the force's effectiveness against the "reality" of the threat. Because a commander depends on C^2 information to cope and keep any image current, the value a commander places on such information parallels the perception of how much C^2 information contributes to force effectiveness. We therefore need a method to capture that varying perception of risk because it will influence how much the decisionmakers are willing to invest in C^2 or any other aspect of the force structure.

Challenges in Force Structure Analysis

Some readers may wince at the thought of another model, another whiz-kid solution. Modeling and other forms of systems analysis do have their problems. National Security Council

Staff member Stephen Rosen summarizes many of the recurring complaints about the process of defense systems analysis, especially about the tone set during the McNamara years. He claims that the McNamara whiz kids tried to reduce all decisions to economic theory in pursuit of cost effectiveness, while disregarding practical military wisdom and experience. Consequently, some poor decisions are made because the analysts neglect the way our enemies think about war, fail to recognize how relationships with adversaries continually change and cannot be frozen in time, and often fail to accept the traditional positions of the military institutions.[9]

Despite Rosen's criticisms, force structure decisionmakers need a way of thinking about their tradeoff problems in an organized framework to get the most from their valuable time and knowledge. In a measured defense of systems analysis, Daniel Levine and Stanley Horowitz of the Institute for Defense Analyses explain that disputes among civilian officials and military professionals are bound to break out. Systems analysis can help resolve the differences by building a framework for studying the problem, comprehensively describing the strengths and weaknesses of alternative positions, and presenting "a neutral framework" to the senior decisionmaker for adjudicating disputes.[10]

But the GAO has posed a circular argument to criticize how defense decisionmakers make use of their time and models:[11]

> The message is simple and clear. The rationale that says "Defense decisionmakers do not have time to understand and manage policy assisting models" is a direct contradiction to the literal justification which argues that Defense Decisions use such models to compensate for the inadequacies of military judgment. The ethical burden is unequivocal.

Whether it's precise (but perhaps flawed) quantitative answers from the model or the wise (but perhaps parochial) judgment from a few decisionmakers makes no difference. The decision must still satisfy the political rules: severe fiscal constraints, an increasing public demand for accountability, and the need for an audit trail so we can understand what's been done. This challenge requires a combination of quantitative analysis and the participatory judgment of senior, experienced decisionmakers.

Modeled wargames, rarely designed to present results in the form of a recommended decision, are not always suitable for force structure decisionmaking. Instead, wargaming typically relates to mission effectiveness. It would be stretching the imagination to believe some modeling specialists in the back room could provide incontrovertible answers to complex force structure problems or that some group of senior decisionmakers would accept the answers without question.

With the possible exception of one-on-one firefights or wholesale nuclear exchanges of the scope of Armageddon, the outcome of wargames—that is, who won—is hard to define. Therefore, measures of mission success (with or without C^2 included in the model) are often the subject of disagreement. If the enemy fleet was held at bay so a successful amphibious landing (the primary mission) could take place, would the friendly fleet commander have been faulted if he hadn't destroyed the enemy fleet?

In real warfare, the post-engagement record of conflicts with the enemy is often based on the reporting skills of the commander who tells his superiors how it went.[12] As Lieutenant General Cushman says, the best measurement of outcome in warfare is probably the "informed judgment of those who are close to the problem."[13] This applies equally as well to C^2 investment decisions. Therefore, we need to avoid the problem of second-guessing outcomes, by letting commanders decide what they believe is best in terms of mission success. In other words, let the senior commanders decide how to manage the force structure with the support of simple tools that satisfy the four key criteria—accommodating uncertain perceptions, responding to the tempo of changes, addressing the complex decisionmaking environment, and incorporating wisdom and experience—and yield discrete results. The importance of the commander's preferences will become more evident in chapter 7.

C^2 system advocates may recollect the grillings they have been subjected to in their careers. Senior decisionmakers hear briefings about advances in computational power and improved communications quality and then ask: If we spend the money on that new technology, what's the the return on investment? Can you quantify the benefits? One corporate information officer dryly commented, "There are only two problems in determining the return on investment in information systems: determining the investment and determining the benefits."[14] For many reasons, pinning down the value of C^2 is similarly difficult.

As we saw in chapter 3, the value of C^2 in any situation may change according to the fluidity of warfare (pre-, trans-, and post-attack); the political situation (the robustness of alliances or attitudes among adversaries); and the intensity of the conflict (where it fits on the continuum or spectrum of conflict from peace to general war). If we accept the hypothesis that the value of information changes in relation to the perceived risk level (the degree of uncertainty and tempo), it follows that the perceived value of C^2 resources will increase as the risk level increases. Presuming that the collection of C^2 resources is the source of information in conflict would support our hypothesis.

Commonly used techniques like weights and scores have their drawbacks—for example, decision support techniques using weights and scores often skew the assessment, by amplifying small differences between closely rated alternatives. Based on the assessment that C^2 contributes in some difficult-to-measure way to operational success, one might think that traditional cost-benefit analysis would be a useful tool for methodically integrating C^2 into the force structure. But one of the greatest problems in cost-benefit analysis is the difficulty in quantifying subjective benefits—the same problem as trying to predict the contribution of C^2 to mission success under combat conditions.[15] DOD and others have successfully applied cost-benefit analyses to management information systems and other automation projects. When the cost numbers are not difficult to derive and the benefits are reasonably tangible and quantifiable, cost-benefit analysis works well.

However, a review of the classic definitions of cost-benefit and cost-effectiveness analyses suggests that *cost-effectiveness* analysis will be a better solution for integrating C^2 into the force structure than *cost-benefit* analysis.[16] Cost-effectiveness analysis looks at how resources should be used in the short-term (years), versus long-term strategies that concern whether to invest in a "from-scratch" capital project for the force structure, such as a new space launch facility. Also, this analysis of how to fit C^2 in the force structure will not be a comparison of two tally sheets—one for costs and one for benefits. Rather it will compare how the alternatives (across a fully variable range of C^2 elements versus force elements) stack up to criteria reflecting what the commander perceives he needs in a given mission environment. An important force structure question will be answered: Are resources being used to get the maximum result, maximizing force effectiveness in an existing mission area, subject to budget constraints?[17]

Charles Hitch, the former Assistant Secretary of Defense (Comptroller) who precipitated modern systems analysis in Pentagon decisionmaking, defends cost-effectiveness studies for their ability to answer the question "how much is enough?" Reflecting how military requirements tended to be stated only in absolute terms in the early 1960s, Hitch complained that force structure decisions were "typically a calculation of the forces required to achieve a single hypothesized objective." Such decisions didn't consider the broader perspective of defense missions and the fact that one type of force could serve several missions. We should not ask only if we need additional missiles to destroy 97 percent of the targets, we should also ask if raising our ability to destroy targets from 94 to 97 percent is worth the cost of 100 more missiles. He then specifically claims we should study marginal costs and marginal products (in a microeconomics sense) in addition to total costs. He believes that only with this kind of focus will we have a better understanding of the "bang for the buck."[18] Pursuing this train of thought, we can think in terms of applying marginal analysis and the "law of diminishing returns" to varying numbers of C^2 systems and force elements within the force structure. Jacques Gansler expresses this same concept: "A balanced defense posture will also require the tradeoffs between the marginal gains provided by major investments in one area and the marginal gains that could be provided for the same dollars in another area."[19]

In the decades since Hitch prepared the material for his book, the services haven't changed much in how they determine force structure requirements. In addition to looking for other ways to destroy targets and how a force serves the broad DOD mission, we need to evaluate C^2 in more depth as a cost-effective solution in defense missions. Some critics might say it's not worth the effort, but any rational approach to decisionmaking will only heighten the credibility of defense decisionmakers. Answering criticisms levied against such cost-effectiveness studies, Hitch rephrases the central issue: Which strategy or weapons system will yield the most effectiveness for a given budget (increase or decrease)?[20]

In its 1980 critique of defense analysis, the GAO recognized how the DOD's approach to this issue of effectiveness versus cost—in the Planning, Programming, and Budgeting System—is incoherent. In the planning phase, the JCS configures forces to satisfy the required military capability, based on perceived threat and other factors. In this phase, "effectiveness" is fixed (to meet military needs) while "cost" is variable. The GAO found that in the programming phase, fiscal guidance is passed down from the senior levels of the decisionmaking system. To meet the fiscal guidance, the JCS has to adjust its forces, thereby impacting the desired military capability, hence "effectiveness" becomes variable, while "cost" becomes fixed.[21] In any method that suboptimizing the problem, there are some potential pitfalls and uncertainties. In their 1960 book on defense systems analysis, Hitch and McKean discussed these difficulties at length.[22] For example, the decisionmaker must recognize that unanticipated interdependency among factors may create undesired side effects in areas not even the subject of study. Hitch and McKean called these side effects "spillovers." The decisionmaker must also pick criteria suitable for the level of detail in the context under analysis. And also must choose a context broad enough to realize all the spillovers and fully use the criteria, but small enough to be manageable.

Hitch and McKean also outlined the uncertainties that can crop up in defense analysis. The decisionmaker must make assumptions about costing, which cost elements to include or exclude, and the discount (inflation) factor. He must also assume certain things about the strategic context: when and how likely the scenario will occur; who the enemies and allies will be at that time; and whether the allies will provide access overseas or impose any extenuating engagement rules. The decisionmaker must anticipate the level of conflict in the scenario. He or she must also estimate the capabilities of friendly forces and those of the enemy: quantity, quality, and will. Finally, the decisionmaker must consider the statistical uncertainties inherent in all these estimates.

Nevertheless, there are some useful concepts in cost-benefit analysis that provide insight in developing a suitable method for integrating C^2 systems into a fiscally constrained force structure. One of the essential aspects of cost-benefit analysis is the magnitude of a "willingness to pay," expressed by the consumer (or victim) of the benefit. When you consider the qualitative value-added aspects of C^2 (or any other component of the force structure, for that matter), "willingness to pay" seems to fit the force structure decisionmaker, too. This willingness is the value the consumer assigns to the force structure component—not a measurable quantity but one based on subjective feelings. The value attributed by the consumer to the component is the inherent value of the commodity. In other words, the value is what anyone is willing to pay for goods or services.

In defense spending, we're not talking about boosting "profits" to unconscionable levels, but from the "traditional" perspective of the many operational decisionmakers, a C^2 system does not appear to assist directly in buying more force structure. Rather, these traditional force planners might consider C^2 to be a necessary but painful cost of doing business. If the force planner can accept what has been discussed about how C^2 resources help the commander's C^2 process, it is obvious that C^2 improves the effectiveness of force elements and contributes to overall mission success by enhancing the commander's ability to cope with uncertainty and tempo in warfare. So the force planners can meet national security needs (both military and economic) by planning a less traditional force structure. Or to put it another way, the force planner improves the commander's chances of success in warfare with a smaller traditional force structure.

How much are the commander and force planner willing to pay for this leverage?

Measuring the Usefulness of C^2 Systems

The method for deciding how to integrate C^2 systems into the force structure is a decision support technique aided by microeconomic analysis.[23] Because measuring the contribution of a C^2 resource is a value judgment, we cannot explicitly measure it by rigid quantitative analysis. Instead, we measure the value of C^2 resource contribution by a judgmental analysis using subjective criteria to tell us which C^2 option satisfies mission needs better and by how much.[24]

One reason why subjective assessment is more applicable than precise modeling in this case is that a vital component of the C^2 process is the commander (and his or her staff)—people sensing, deciding, acting. Subjective judgment reflects the personal talents and interest of these warfighters (and peacekeepers). Another advantage is that analysts can prepare a rational, auditable strawman for review and decision by senior decisionmakers who don't have enough time to participate in wargaming, and sensitivity analysis is easier when using an auditable tool. There are risks, however. The integrity of the force structure decision may be compromised if the decisionmakers don't embrace a broad enough cross-section of senior, experienced commanders and "operators" in the decision. The stakeholders should be not only those engaged in C^2 but also Congress and the military departments for funding and political rules and military leaders for their wisdom and knowledge. Another risk is that smart people can disagree.

The list of stakeholders can be small or large, depending on the severity or magnitude of the decision. For the most critical decisions, the National Command Authorities could participate through members of the National Security Council staff or the Office of Management and Budget. From the Joint Chiefs of Staff and the Joint Staff, the Chairman and Vice Chairman of the JCS should participate as should the service chiefs. These individuals would receive inputs from their respective service corporate decisionmaking structures; from the unified and specified combatant commanders; and from the Joint Staff directorates. The results of this process would be the military command chain's recommendations to civilian leadership, that is, the military department Secretaries and Agency heads.

The Under Secretary of Defense (Acquisition) is responsible for establishing policies for and managing the acquisition decisionmaking structure and processes, to include C2 matters. Through its committee system, the Defense Acquisition Board (DAB) assesses possible tradeoffs among cost, schedule, performance, and logistics support to obtain the maximum benefit for the dollars spent. The DAB then evaluates how new systems enhance the military forces' deterrent or warfighting capabilities.[25] For most defensewide force structure decisions, the DAB should probably serve as the functional manager for this analysis, with the JCS and DOD staffs providing point-counterpoint debate between requirements and funding.

Once the relative subjective judgments are made and quantified using this decision support method, we then use microeconomic analysis to quantify the merit of the tradeoffs within the fiscal constraint. This analysis will tell us the approximate "best" balance between proposed C^2 changes and the force elements supported by C^2 in any one mission area.

The final force structure recommendations would be made to the Secretary of Defense. Practical representation by the Office of the Secretary of Defense would be vested in the Deputy Secretary, the Office of Program Analysis and Evaluation, the Comptroller, and the Under Secretary for Acquisition (especially the ASD(C^3I)). And these stakeholders should be supplemented, as needed, by Congress and GAO. Various congressional committees do have significant expertise, as well as power, in defense matters. DOD could use this expertise and power to advantage by permitting Congress to play a more direct role in force structure decisionmaking.

While the method being introduced here could be used to make decisions during wartime—to adjust the force structure to evolving doctrine or to new enemy tactics—the method suggested is principally a peacetime venture. The effects of changing the force structure are long-term, reflecting doctrine, acquisition strategy, and the overarching budget direction; the methods in this book, therefore, mainly satisfy peacetime decisionmaking needs. Although the method is complex, it does not demand much of the senior decisionmakers' time; most of the work can be done by analysis support staffs.

But this method, as with any policy-building method, should never be accepted at face value. As the GAO observed, there are no "truth" criteria when dealing with such difficult problems. The purpose of the method is to make the decisionmaker's expert judgment better; the final decision is the decisionmaker's, not the model's.[26] Tools for decision support and economic analysis are merely tools. As numbers alone do not make a decision objective or—more important—rational, no one should become enamored with a quantitative solution to a problem solely because it is quantitative. Rather, the user of such methods must claim no more than being "in the ball park" and must perform many "sanity checks" of the solution.

By including all the force planning stakeholders in a systematic, nonparochial, accountable way, this new method will rebuild the credibility of efforts to automate C^2 and improve C^2 communications. Over the coming decades, the national security decisionmaking system needs to apply such methods for making rational decisions about C^2 systems. Defense leaders need to decide what C^2 contributes to the effectiveness and success of the US defense establishment. Intuition and other gut feelings leave no audit trail.

§ § §

Notes

1. DOD Directive 5100.1, "Functions of the Department of Defense and Its Major Components," para 5a, 25 September 1987. Many of the 1987 revisions to this directive were based on the fortified requirements for assigning forces, stemming from the Goldwater-Nichols Defense Reorganization Act of 1986, P.L. 99-433, 1 October 1986, sec. 211 and 214.

2. Harlan K. Ullman and others, *US Conventional Force Structure at a Crossroads* (Washington, DC: Georgetown University Center for Strategic and International Studies, 1985), 6. The panel consisted of eight retired flag officers and four senior civilians.

3. See Colonel Robert P. Haffa, Jr., *Rational Methods, Prudent Choices: Planning US Forces* (Washington, DC: National Defense University Press, 1988) for a detailed description of the traditional approach to force structure planning.

4. See also chapter 2 for a discussion of the DOD Reorganization Act of 1986 and the evolving roles of the combatant commanders.

5. Martin L. van Creveld, *Command in War* (Cambridge, MA: Harvard University Press, 1985), 8.

6. Incorporating the "rules" converts an impartial model to a political model.

7. Public contracts are often used to carry out Government policies: social policies such as small and disadvantaged business set-asides; economic policies such as the Buy-American Act; policies to safeguard the integrity of the Government such as standards of conduct; and provisions to support the auditing and investigatory needs of the Government bureaucracy.

8. Comptroller General, *Models, Data, and War: A Critique of the Foundation for Defense Analyses* Report No. PAD-80-21 (Washington, DC: US General Accounting Office, 1980), 3-6.

9. Stephen Rosen, "Systems Analysis and the Quest for Rational Defense," *The Public Interest* no. 76 (Summer 1984): 3, 7-9, 16-17. It's important to always distinguish between operations research and systems analysis. The former determines the best way to employ existing resources in warfare; the latter helps in deciding which new resources to buy or invest in.

10. Daniel B. Levine and Stanley A. Horowitz, "The Role of Systems Analysis in Defense Planning: Strengths and Shortcomings," *Proceedings of the 54th Military Operations Research Society Symposium* (Washington, DC: DOD, June 1986), 145-146.

11. Comptroller General, 75.

12. With the possible exception of hard physical evidence like photographic reconnaissance after a precision bombing strike.

13. Lieutenant General John H. Cushman, USA (Ret.), *Command and Control of Theater Forces: Adequacy* (Washington, DC: AFCEA International Press, 1985), 238.

14. G.M.K. Hughes, "The Dreaded ROI Question," Information Week 258, 19 February 1990. Hughes is Pfizer Pharmaceuticals' vice president for systems and communications.

15. For a comprehensive assessment of the good and bad aspects of cost-benefit analysis, see Peter G. Sassone, *Cost-benefit Analysis* (New York: Academic Press, Inc., 1978).

16. Cost-effectiveness analyses have their problems, too. Because they usually try to compare two systems as stand-alone systems, defense analyst Francis Hoeber contends that elaborate cost-effectiveness models seldom help in tradeoff decisions unless the cost difference between the alternative systems is very large. Since we are addressing cost tradeoffs within a constraint (the defense budget), we are not trying to quantify cost effectiveness of any one alternative in an absolute sense. Thus we can avoid some of the pitfalls of elaborate models. Francis P. Hoeber, *Military Applications of Modeling: Selected Case Studies* Military Operations Research, vol. 1 (New York: Gordon and Breach Science Publishers, 1981), 19. For an excellent list of over 20 pitfalls in cost-effectiveness analyses, see A.D. Kazanowski, "Cost-Effectiveness Fallacies and Misconceptions Revisited," chapter 8 in J. Morley English, ed., *Cost-Effectiveness,* University of California Engineering and Physical Science Education Series (New York: John Wiley and Sons Inc., 1968), 151-165.

17. See Christopher K. McKenna, *Quantitative Methods for Public Decision Making* McGraw-Hill Series in Quantitative Methods for Management (New York: McGraw-Hill, Inc., 1980), 128-129 for an objective comparison of cost-benefit and cost-effectiveness analyses.

18. Charles J. Hitch, *Decision-Making for Defense* (Berkeley, CA: University of California Press, 1965), 50-51. The famous expression "how much is enough?" was spoken by former Defense Secretary McNamara who explained in a speech that the Defense Secretary has to apply judgment in making the tough decisions, even in a rational governmental system, to determine how to spend Defense dollars effectively. He has to do this while considering military missions, the potential for global instability triggered by introducing the system, and all available alternatives. Speech to American Society of Newspaper Editors, DOD Press Release 548-63, Washington, DC, April 1963, cited in Alain C. Enthoven and K. Wayne Smith, *How Much is Enough?* (New York: Harper and Row, 1971; reprint ed., Millwood, NY: Kraus Reprint, 1980), 197-198.

19. Jacques S. Gansler, *Affording Defense* (Cambridge, MA: MIT Press, 1989), 135.

20. Charles J. Hitch, *Decision-Making for Defense* (Berkeley, CA: University of California Press, 1965), 46-47.

21. Comptroller General, 37-38.

22. Charles J. Hitch and Roland N. McKean, *The Economics of Defense in the Nuclear Age* (Cambridge, MA: Harvard University Press, 1960; reprint ed., New York: Atheneum, 1966), 188-194.

23. Chapter 7 provides an overview, while appendixes A and B show the details of this proposed method.

24. The C^2 options addressed here are components of those C^2 systems used at echelons just above the force elements and higher. In this way, we will not confuse the C^2 of an independent force element decisionmaker (like a pilot flying his fighter, a company commander directing his platoons, or a skipper sailing his ship) with the echelon-above operational C^2 of those force elements. Generalizing, we will deal with the C^2 systems that direct two or more force elements.

25. Wilbur D. Jones, Jr., *Introduction to Defense Acquisition Management* (Fort Belvoir, VA: Defense Systems Management College, March 1989), 9, 11-12.

26. Comptroller General, 17-18, 20.

7.
Command, Control, and Consumerism

The economic issue concerning C² systems (and other weapons systems) is how much C² or how many weapons should be bought, with respect to the rest of the military force structure. Given an opportunity to upgrade or pare down a segment of the force structure, how should the decisionmakers decide? If they receive a $180 million appropriation to upgrade the counter air mission area, should the decisionmakers buy $180 million worth of fighter aircraft or a lesser number of fighters and some additional C² assets to support fighter operations?

We often don't approach this kind of dilemma systematically. We don't often identify what and how much we want to buy in a way that can be traced to the national military strategy and in turn to national security objectives. And we often don't look at the broader perspective of our force structure decision environment when called on to solve the dilemma. In other words, we don't follow the principles of consumerism, when we should be protecting the C² user from inferior products, misleading advertising, and unfair pricing.

For the difficult area of C² systems, this chapter responds to this challenge. These dilemmas, of course, are the types of resource allocation problems faced nearly every day in defense management. Selecting the best resource mix to buy for the force structure becomes a constrained function, an optimization question to be solved where senior decisionmakers seek to maximize force effectiveness, subject to the constraint.[1]

Are the economics of C² systems a measure of efficiency? No. This book does not address industrial (or any) efficiency.

Rather, it is concerned with effectiveness. We'll bridge the gap in a way that should contribute to an understanding of the difference between the two in the context of force structure decisionmaking. Effectiveness, rather than efficiency, should be the underlying measure of merit for C^2 systems. External effectiveness, as in mission success, reflects the quality and usefulness of the C^2 system's product.[2]

To date, no one has developed a viable quantitative approach to answering questions of C^2 system cost-effectiveness or affordability in terms of the military force structure and operational warfare (especially conflict without attrition). Traditional force structure analysis has been how many more (or less) "things" can we afford for the delta change in the budget. But counting "how many C^2 systems" for the dollar is a totally inadequate assessment of the force structure. Even though the "value-added" of C^2 systems is intangible and interdependent with the forces supported by C^2, finding a common unit of measurement is nevertheless necessary to understand how C^2 can best contribute to force effectiveness.[3] In chapters 4 and 5, we looked at several approaches for evaluating what C^2 systems contribute to mission success. While many of the approaches are successful in understanding the C^2 process, they do not significantly relate the contribution of C^2 to force effectiveness. More important, those methods do not show how C^2 fits in the force structure.

As in the business world, the best way to approach this delicate problem is from the perspective of the user or consumer. The consumer in our force structure analysis would be the commander of forces. What the commander perceives is needed, coupled with what he/she is "willing to pay," will guide us in deciding how to configure the force structure. The commander's willingness to pay is the degree of tradeoff possible among the categories of forces assigned, including C^2 systems. Under free market mechanisms, a consumer expresses preferences by choosing the mix of categories of goods or services desired. In this analysis, a commander expresses preferences for the mix of forces, based on experience and perception of the threat. Capturing the commander's preferences is vital to this economic analysis.

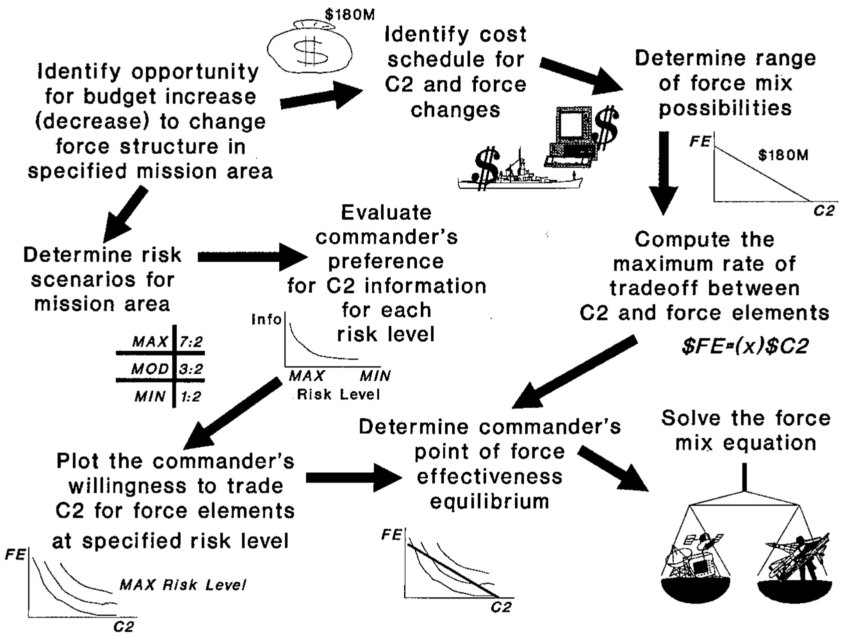
Let's take a look at one approach to rationally cutting a force structure budget. To set the stage, let's pretend a congressional committee is dissatisfied with the size of a DOD budget proposal for additional tactical air forces. The committee believes the request for more forces is unrealistic in the context of the world environment. Congress consequently recommends that the DOD find a way to cut the proposal by $180 million.[4]

To select what items to cut, senior DOD decisionmakers should first define (or redefine) the current mission environment, considering threats, existing force and C^2 capabilities, opportunities, higher level constraints (such as political rules), and other factors. Then the decisionmakers should characterize how the force structure components contribute to the mission by satisfying deficiencies, improving force effectiveness, and fulfilling desired characteristics (from chapter 3). Once the contributions of the force structure elements are known, the DOD decisionmakers analyze cost tradeoffs within a range of scenarios or risk levels. Then, to test the robustness of their answer to be given to Congress, the senior decisionmakers conduct sensitivity analyses. Figure 17 is an overview of the process.

Systematically Cutting the Force Structure

To look at an example in more detail, DOD had proposed to buy 24 additional fighter aircraft, some modular control equipment (for tactical air C^2), and a tactical intelligence fusion facility to beef up the theater air forces. DOD selected these force enhancements to support land forces with close air support and deep interdiction which would be more responsive to Army needs. In force structure terms, defense wanted to add one tactical fighter squadron and some complementary C^2 resources—$504 million of force structure. But Congress has told DOD that the budget increases are not affordable. How can DOD accommodate the requested $180 million cut in the budget estimate? The schedule of the desired force enhancements as well as of the congressional cut includes all life-cycle costs for the weapons systems, the people to operate and maintain the weapons systems, the logistics support structure, doctrinal development, training, and so forth[5] (figure 18).

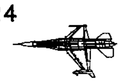
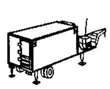
FIGURE 17. Overview of C2 system economics



Based on our definition of C² systems, which includes human components as well as nonhuman components, the list of C² system improvements could have also included funds for updating doctrine, training, and other aspects which lead to unit cohesion and improved force effectiveness.

DOD decisionmakers respond to the congressional guidance by first studying the applicable mission area: Close Air Support and Interdiction (Mission Area 223).[6] After studying the mission area, one of the DOD force planners suggests the C² enhancements should be cut first. Another wants to cut the force enhancements by 59 percent and the C² enhancements by 59 percent, corresponding to the 59 percent cut from Congress. But before they decide how to "downsize" the proposed additions to the force structure, these decisionmakers need to define the image or context of the conflict environment and the

FIGURE 18. Schedule of force structure improvements

Quantity	Item	Unit cost	Total
	Desired improvements in forces		
24	Improved fighter aircraft 	$18M	$432M
	Desired improvements in C2 system		
6	Modular control suites 	9M	54M
1	Intelligence fusion facility 	18M	18M
		Grand total	$504M
		Proposed congressional cut	-180M
		Net available	$324M

(notional data; $ are constant dollars)

interrelationship between the C^2 resources and the force elements. Reviewing national security interests and validated threats, the decisionmakers concede that the threat in that region of the world can be downgraded. They also consider how other forecasted changes in threat may relate to the end of equipment life cycles.[7] On the basis of how they perceive military assessments of force balances and qualitative differences between adversaries, and after consultation with the responsible field commander, the decisionmakers agree that the risk level in that region of the world is moderate to minimum.

The decisionmakers also know they must meet the $180 million reduction imposed by the Congress (the reduction is a "political rule"). What is the range of force-mix possibilities created by this cut? To scale back the proposed increase, the decisionmakers could cut 10 of the 24 fighters ($180 million divided by \$18 million per fighter), all \$72 million of the C^2 improvements and six fighters, or some combination between these two extremes.[8] As the lowest common denominator of the cost of the C^2 improvements is \$9 million, the proposed procurement of C^2 capability is "8 increments" (\$72 million divided by \$9 million).[9] we already know the maximum reduction of the proposed force elements is 10, we can thus portray the budget reduction target as:

(1) \$180 million = \$18 million (FE) + \$9 million

where *FE* is a number of force elements (fighters) between 1 and 10 to be cut from the proposed budget; and

C2 is a number of C^2 increments between 1 and 8 to be cut from the proposed budget.

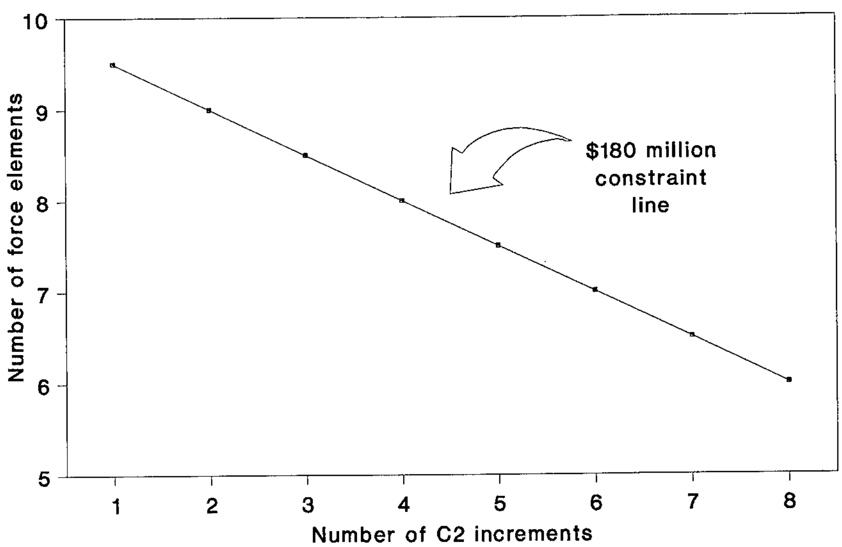
Reducing and solving equation (1) for the number of fighters (*FE*):

$$FE = 10 - (0.5)C2 \qquad (2)$$

Equation (2) defines a linear relationship between the number of C^2 increments and the number of force elements in the force structure reduction tradeoff (figure 19). Because there are several combinations of *FE* and *C2* that will solve this equation, the decisionmakers need to next understand how the fighters and the C^2 resources interrelate in a moderate-to-minimum risk scenario.

We know there are many variables contributing to military force effectiveness—the skills and experience of trained people; the performance of weapons and equipment; the initiative and mental agility of the force leaders; the morale, will, and cohesion of the forces; harmonious doctrine and tactics; command and control; knowledge of weapons technology; and other similar factors. According to Wayne Hughes, numbers alone do not reveal military superiority; what does is "a comparison of force, not of forces."[10]

FIGURE 19. Force structure reduction as a function of fiscal constraints



To focus on the issues of this book, we will concentrate on two of these factors and, for the most part, hold the other factors constant. For the selected mission area, these two factors are the number of force elements under the commander's control and the number of C^2 assets the commander uses in managing the force elements assigned. Intuitively, there must be some tradeoff between the number of force elements and the number of C^2 assets to achieve a desired level of force effectiveness, in a given mission area in a perceived risk environment. Customarily, a commander's perception of the risk environment corresponds to what the force ratio is believed to be between the command and that of the adversary. As the force ratio (which considers the size of the forces and other factors in a force-on-force comparison) increases to his disadvantage, he perceives his environment to be riskier. The size or level of the force in this estimation is the same as the traditional force structure "count" of force elements. Similarly, we will "count" C^2 in increments which augment or detract from our existing C^2 system.

In earlier chapters, we found that some difficult-to-measure relationship exists between the performance of C^2 resources helping the commander and the overall effectiveness of his/her forces. And generally, there is some tie between the amount of information the commander uses in managing forces and the information which transfers to the commander from the available C^2 assets.

When the depth or breadth of the commander's shared image increases, other things held equal, the commander has a higher chance for success in pitting smaller forces against similar or larger opposing forces. That is, the commander experiences a higher force effectiveness. This higher effectiveness is experienced by being able to employ limited forces more effectively, reducing own-force casualty rate, or by buying time to hold his own until replacement forces can be brought to bear on his enemy. In other words, C^2 improves the ability to communicate concepts and intentions, to deal with the tempo and uncertainty of the conflict, and to practice the operational art. C^2 resources help project the commander's image of the situation and plans through the chain of command to forces—as if the commander were actually there.

Thus the power of information (the contribution of C^2) and the collection of force elements, under differing estimates of risk (force-on-force comparison), are two key elements contributing to force effectiveness. This conclusion suggests the function:

$$\text{(3) force effectiveness} = f(\text{size of force, quantity of } C^2)$$

If both these factors have to be present in some form to achieve any level of force effectiveness, then we can portray the function as a product of the two composite factors. This follows because a force cannot be effective without C^2, and C^2 alone—without forces—is worthless. Most likely, each factor (force size or quantity of C^2) contributes to force effectiveness at a different rate. The degree to which either factor bears on effectiveness should parallel the commander's perception of the value of either factor in the particular risk environment. Our relationship for force effectiveness then becomes:

(4)

E = relative force effectiveness

$$E = (\text{size of force})^{\text{influence of forces}} \times (\text{quantity of } C^2)^{C^2 \text{ influence}}$$

For purposes of this analysis, the final magnitude of the results of this force effectiveness equation is not important, so long as the value increases with increasing additions of either C^2 or force elements. Therefore, we will refer to the results by the term "relative force effectiveness." For a certain level of relative force effectiveness, we now see a tradeoff between the two terms in the equation. If the number of force elements increases, the amount of C^2 must decrease and vice versa.

The question to pose to the senior commander is, to what extent would he or she be willing to trade off forces assigned for an enhanced C^2 capability? On the other hand, we could question how willingly the commander would give up the C^2 resources for managing forces, if he or she were not recompensed with increased military strength from additional force elements. Would the commander's interest in trading forces for C^2 be different at higher or lower threat levels? What risk is the commander willing to endure? If the force ratio increases to own-force disadvantage, perhaps a preference for more C^2 information—and C^2 resources—will be shown to compensate for a want of forces. As the commander's level of uncertainty about the conflict situation increases or the battle tempo increases, he or she might perceive that the risk of achieving combat success also increases.

Further, a typical commander, faced with a choice between force elements and C^2 assets, often will continue to show a preference for force elements over C^2 long after the conflict situation becomes increasingly risky. But as the commander loses forces to combat or the enemy begins to amass a force advantage, the friendly commander's uncertainty and inability to cope with tempo increases. Accordingly, the own-force risk level increases.

A commander displaying the normal psychology of a military leader who has risen through the ranks with hands-on experience in operating high-technology weapons systems or with the experience of troop duty will more likely believe that chances of success are "guaranteed" by a greater number of forces assigned. Such a commander will be less willing to give up assigned forces or trade them off for an increase on C^2 assets. C^2 assets, as we discussed in chapter 2, do not fit the mold of the traditional force structure.

Under increased risk, the commander will probably become more willing to trade off lack of assets (a reduction in the number of force assets from where the commander thinks the level should be) for an increased level of C^2 assets. If the commander has lost force assets in battle or otherwise doesn't have force assets readily available, a greater preference for C^2 assets,[11] rather than force assets, is likely, in order to make the best of what is left in the face of adversity. In other words, the commander would very likely want more C^2 than force elements, until replacement forces could be brought forward or until the risk crisis passes. Then preferences will likely revert to more forces.

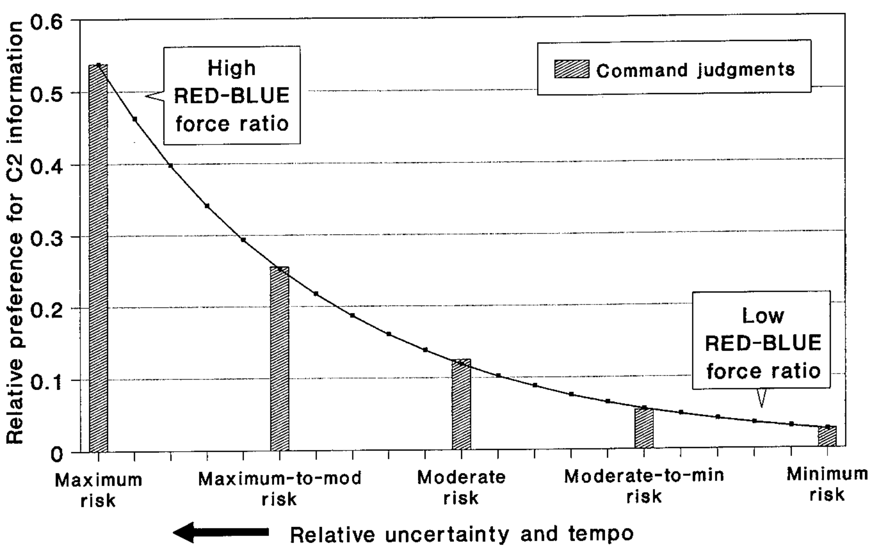
Why does this happen? First, a loss of force advantage limits the commanders' ability to exploit opportunities. He does not have enough forces to apply against enemy targets or functions, which by denying them would give the commander significant leverage in later phases of the conflict. Second, the commander is subject to a greater chance of catastrophic losses, because of the lack of information (and processed information or intelligence) about enemy actions and intentions. An increase in information about the enemy normally comes about by having force assets that can reconnoiter the battle area and having the intuitive reports that can come only from friendly forces actually engaging enemy forces. (In a sense, these "eyes and ears" on the front lines are the commander's "directed telescope.") Third, with the decreased employment flexibility that comes with fewer forces, there is an increased chance that the battle tempo will pick up and overpower the ability for the friendly commander to cope with it. Time needed to make rational, effective decisions is then lost.

Many military leaders would respond to this question of trading off force elements for C^2 resources by saying, "It depends on the scenario." But this response, while inherently true, is usually a ruse to avoid dealing with the quandary. We will deal with the question by measuring the personal risk preferences of the field commander. Force effectiveness in conflict (from crisis to general war) is strongly tied to the commander's ability to get and use pertinent information. Significantly, a commander's perceptions about the forces' ability to get and use information reflect self-confidence as a commander. We need to measure the degree to which commanders feel they are risk averse, risk neutral, or risk prone.

Under a conflict situation of increased uncertainty and tempo and a murkier image (that is, a perceived higher risk level), the commander will likely desire more C^2 assets. As the risk level greatly increases, the commander is likely to show a much stronger preference for C^2 assets over force elements to provide the force effectiveness advantage.[12] The unified and specified CINCs, through articles in military journals and in their submissions to the Joint acquisition priority lists, often endorse C^2 projects that would help counterbalance the threat in their areas of responsibility.

Under the moderate-to-minimum conflict risk level in our example, the decisionmakers judge that the commander's relative preference for information (that is, for C^2 assets) would be 0.054 for Mission Area 223. Their determination stems from a decision support technique that captures decisionmakers' qualitative judgments to generate relative priorities among the risk levels.[13] In the relative priorities the decisionmakers place on the five possible risk levels in our problem, comparing the moderate-to-minimum risk level to the other four, we can see that the corporate decisionmakers place little value on information under this risk level (figure 20). Their perception reveals an understanding that with a perceived lower threat level (a better force advantage), the commander doesn't anticipate being faced with unmanageable levels of uncertainty and tempo. Thus information is not valued as highly as it would be under a higher risk environment. Because the information comes from C^2 systems, this relative preference affects how the decisionmakers feel the C^2 term influences our relative force effectiveness equation (4). We can portray this "C^2 influence" as an exponent of the *C2* term in the equation. The degree of force influence on relative force effectiveness can also be reflected as an exponent to the *FE* term.

FIGURE 20. Preference for information relative to BLUE's perceived risk level



Note: Risk based on BLUE's perception of force ratios

Because the *FE* term in the equation is the size of the force, and since we have assumed in this example that the tradeoff between contributors to relative force effectiveness is a tradeoff between *C2* and *FE*, the exponents for the two terms should add to one (1).[14] Thus, the degree (exponent of *FE*) to which forces influence relative force effectiveness is 0.946 (or 1 - 0.054). Relative force effectiveness *E* for our moderate-to-minimum risk scenario is:

(5)
$$E_{\text{moderate-minimum risk}} = C2^{b} \times FE^{C}$$
$$E_{\text{moderate-minimum risk}} = C2^{0.054} \times FE^{0.946}$$

where *E* is the relative force effectiveness

C2 is the number of C^2 increments

FE is the number of force elements

b is a coefficient reflecting the influence of *C2* on *E*

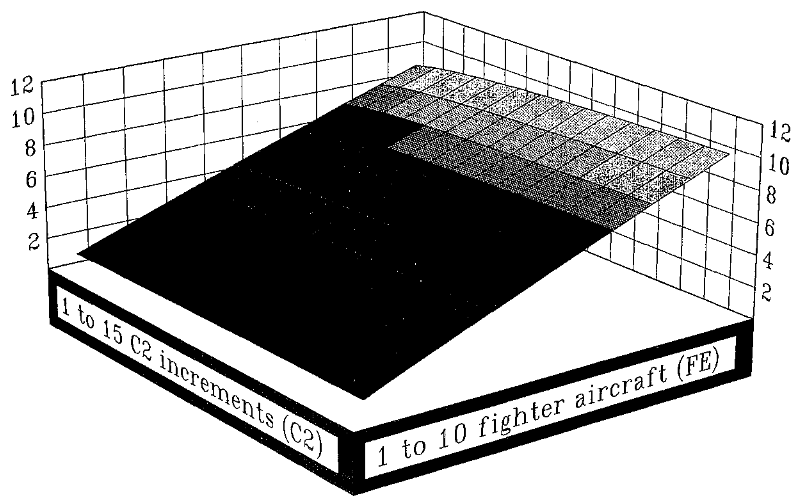
c is a coefficient reflecting the influence of *FE* on *E*.

In this three-dimensional relationship, as the number of *C2* increments increases from 1 to 15, the relative force effectiveness (*z*-axis) increases only slightly because of the small magnitude of the exponent *b* (figure 21). In other words, because the commander perceives the greater force advantage exists, heavy reliance on C^2 resources for any further force advantage is not needed. As the number of *FE* increases from 1 to 10, relative force effectiveness increases more quickly. As both *C2* and *FE* increase, relative force effectiveness increases at an even greater rate.

We continue by investigating the separate contributions of C^2 and force elements to relative force effectiveness *E*. Military leaders see the force level as contributing directly to the effectiveness of forces for a given mission area. But, as in classic economic theory, beyond a certain point there are diminishing returns to the commander. Increases in forces yield smaller and smaller increases in force effectiveness to the point where adding more forces is uneconomical. We can also extend the same law of diminishing returns to C^2 resources. There will be a point at which adding more C^2 resources to the force will not economically increase the relative force effectiveness for the amount invested in the additional C^2 resources. Figure 22 shows a typical relationship between additional C^2 resources and force effectiveness, for a given number of force elements (5). This same relationship shows up in figure 21 if we slice the three-dimensional surface with a thin vertical plane where *FE* equals 5. The curve defined along the line where we sliced the surface is the same curve as in figure 22.

Now let's explore how the two terms in equation (5) work together to influence relative force effectiveness. We start with

FIGURE 21. Relative force effectiveness as a function of C2 and FE



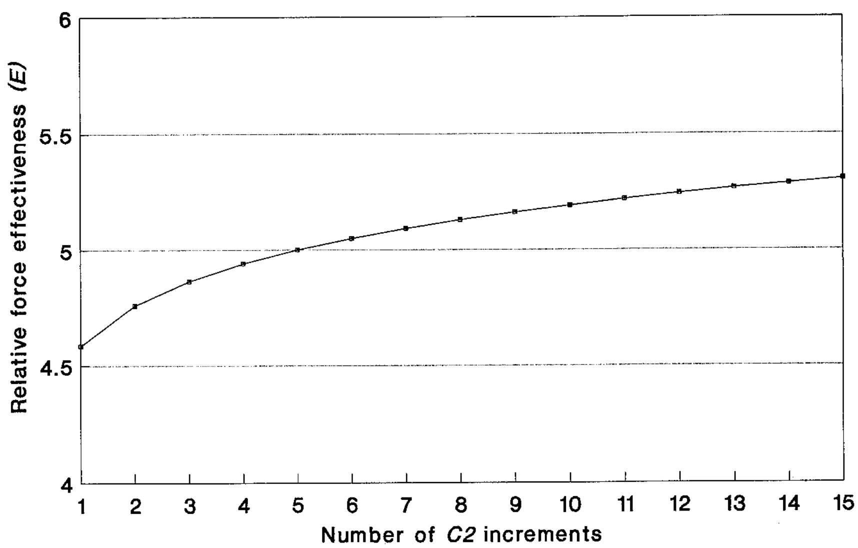
(b=0.054, c=0.946)

three levels of force effectiveness in the context of the moderate-to-minimum risk level scenario: 3, 6, and 9.[15]

$$E = C2^{0.054} \times FE^{0.946} \text{ for } E = 3, 6, 9 \quad (6)$$

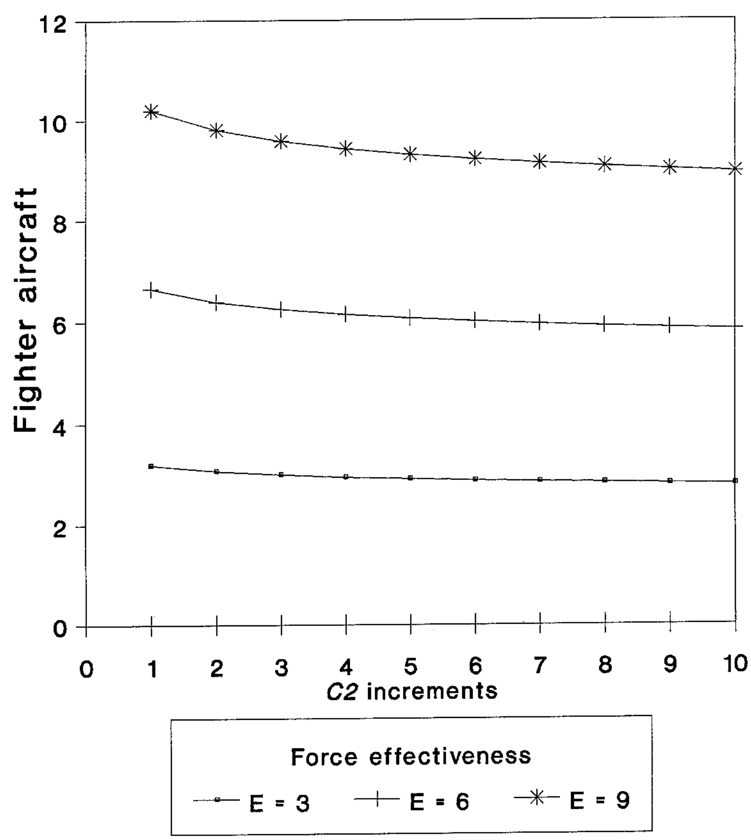
When we plot the three resultant curves for each of the force effectiveness levels, we see what economists call indifference curves. An indifference curve reflects the degree of preference the consumer (in this case, the commander) has for one consumption item over another. The tradeoff, as we decided, is between the "consumption items" of force level and the quantity of C^2 (figure 23). Along any one curve, it makes no difference to the commander how *C2* is traded off for *FE* because the perception is that the same relative force effec-

FIGURE 22. Diminishing returns for C2 (force elements = 5)



tiveness is obtained regardless of the mix of *C2* and *FE*. Let's look at the 6-unit force effectiveness curve. As the commander's *C2* assets on the *x*-axis decrease, a larger force level (more force elements) is needed to sustain the same relative force effectiveness value of 6. As force elements are lost during warfare (a lesser value on the *y*-axis), more *C2* is needed to sustain the same relative force effectiveness. If a higher level of force effectiveness (say, 9) is needed, as in the case of being overwhelmed by the magnitude of enemy forces, information uncertainty, or increased battle tempo, a new, larger combination of *C2* and *FE* is needed. If *FE* or *C2* remains the same as for *E*=6, then either *C2* or *FE* or both must experience a quantum leap to achieve *E*=9.

FIGURE 23. Relative force effectiveness (along commander's indifference curves)



The steeper slope at the upper end (left side) of each curve indicates the commander is willing to experience significant losses of force elements (on paper or in combat) before starting to invest in additional C^2 resources. The shallow slope on the lower end of each curve suggests the commander is anxious about the increased risks of not having sufficient forces for the conflict and is willing to invest in C^2 more aggressively than when a larger force was enjoyed. (When the exponents *b* and *c* are closer together in magnitude, the slopes of these indifference curves are more pronounced.) There are other ways to look at these data, using the same type of indifference curve, in the context of the scenario risk level (figure 24). The amount of C^2 notwithstanding, commanders and decisionmakers maintain a risk-based view of the military force structure. (Of course, the perception of risk is based on the perception of the threat magnitude.) When the commander perceives a higher risk, that is, not enough forces to succeed in the conflict, preference for C^2 resources increases. If more force elements are in the force structure, the risk in meeting the threat is lessened. From time to time, the JCS states its perception of the most desirable force structure—what they call a minimum-constraint force. At the opposite end of the spectrum from the minimum-constraint or lowest-risk perspective, the maximum-risk force level would be far smaller. This smaller force size would approach a "barebones" force structure.

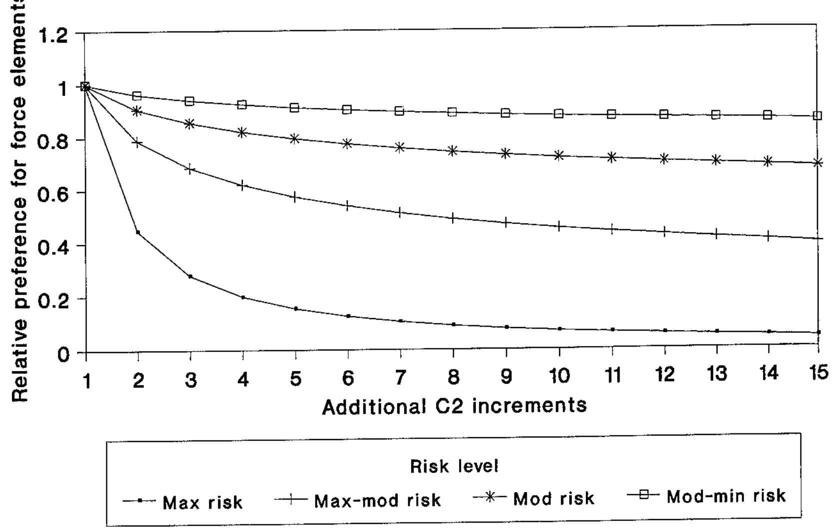
A second way to look at these data is in terms of the shared image and uncertainty and tempo. If the commander perceives that uncertainty about the combat situation and the conflict tempo have increased, and that these changes can no longer be managed effectively, the perception will be an increased-risk environment. A rational increase in C^2 assets (if available) can be used to increase the commander's ability to cope with uncertainty and tempo. This increase in C^2 increases the value of the objective function (equation (4)) to maintain the desired level of force effectiveness.

A final way to look at the same preference curve is in terms of force ratios. As the relative level of friendly forces decreases (down the *y*-axis), the commander's risk level increases. This smaller friendly-to-enemy force ratio can be offset, in part, by an increase in C^2 assets.

Intuitively, the commander must bring an increasingly larger influence of C^2 to bear as the own-force magnitude is reduced, to maintain the same competitive posture (even though we can only characterize the posture in a qualitative sense).

We can put this in perspective with an operational example. A commander can give up the opportunity to have two additional aircraft and instead opt for improved communications links with forward radars and an improved decision support capability for rapid retargeting. Or the commander can take the

FIGURE 24. Force structure tradeoffs as a function of risk level



two additional aircraft to keep at least one combat air patrol airborne at all times to support unplanned close air support and interdiction missions. While both alternatives might produce the same relative force effectiveness, the commander may prefer one over the other for flexibility. The preference will be based on the perception of the threat and what is needed to cope with uncertainty and tempo.

Returning to figure 23, we now calculate the marginal rate of substitution, that is, the rate at which the decisionmaker or commander is willing to trade off force elements for C^2 enhancements in the moderate-to-minimum risk scenario. The first derivative (or slope) of any one of the indifference curves corresponds to this rate. For a desired relative force effectiveness level of 6, we differentiate *FE* with respect to *C2* to determine the rate:

$$\text{marginal rate of substitution} = \frac{dFE}{dC2}$$

$$E = C2^{b} \times FE^{c}$$

(7)
$$FE = \left(E^{\frac{1}{c}}\right)\left(\frac{1}{C2^{\frac{b}{c}}}\right)$$

$$FE = 6.65 \times C2^{-06}$$

$$\frac{dFE}{dC2} = -(0.38) \times C2^{-1.06}$$

The linear relationship between force elements and increments of C^2 from equation (2) depicts the straight-line or rigid fiscal tradeoff between our two factors contributing to relative force effectiveness. From the commander's indifference curves, we have a marginal rate of substitution which is the derivative of the objective function. We now need to apply the fiscal constraint to find the point at which the commander can both enjoy equilibrium for the given risk level and meet the fiscal constraint. The point where the slope of the constraint curve (-0.5) and the slope of the equilibrium curve (equation 7) are equal define the solution point for this force structure problem.

(8) slope of constraint curve = slope of equilibrium curve

$$\frac{\Delta FE}{\Delta C2} = \frac{dFE}{dC2}$$

$$-(0.5) = -(0.38) \times C2^{-1.06}$$

$$C2 = 0.77 \text{ increments}$$

This says that for the moderate-to-minimum risk level, a relative force effectiveness level of 6, and a suggested cut of $180 million in the commander's proposed force improvement budget, all the commander believes he/she can afford to cut is "three-quarters" of a C^2 increment. Recalling that a C^2 increment is $9 million, perhaps we can cut one suite of modular control equipment. Let's go on to see how many force elements we should cut. Based on equation (2):

$$FE = 10 - (0.5)\,C2$$

$$FE = 10 - (0.5)\,(0.77) \qquad (9)$$

$$FE = 9.6 \text{ fighter aircraft}$$

On the basis of our criterion that the number of C^2 increments to cut ranges between 1 and 8, we round up to 1 increment of C^2 and round down to 9 fighter aircraft. Since we have an auditable trail of where we have been, we can also analyze the sensitivity of our decision to other factors by varying either the relative force effectiveness or force element and C^2 costs. From this we can derive our procurement schedule and report back to the Congress. We now have to make a decision as to whether we will cut one or both types of C^2 equipment on our proposed procurement schedule (figure 18). Reviewing the performance characteristics of our proposed C^2 equipment and the nature of warfare in Mission Area 223, we find that the intelligence fusion facility is a good match for providing the commander with early warning and adaptability.[16] We will keep this facility in our improvement budget. As we have to cut "one increment of C^2" from the schedule, we will therefore reduce the purchase order of modular control equipment from 6 units to 5 units. As we have also decided to cut 9 aircraft from our proposed squadron of 24, we will report to Congress that we will buy only 15 new fighters for the mission area. This adjustment satisfies the congressionally recommended \$180 million cut in the proposed \$504 million budget increase and also satisfies the desired military strategy—commander's preferences and other factors considered.

Meeting C^2 Needs in Selected Mission Areas

To focus on features of conflict that will become increasingly important in the next decade, we will now cover some C^2 aspects of strategic warfare, land warfare and tactical air warfare, naval warfare, and strategic crises. We choose mission areas representing the varied service interests, the continuum of conflict, and the three levels of warfare (strategic, operational, and tactical).

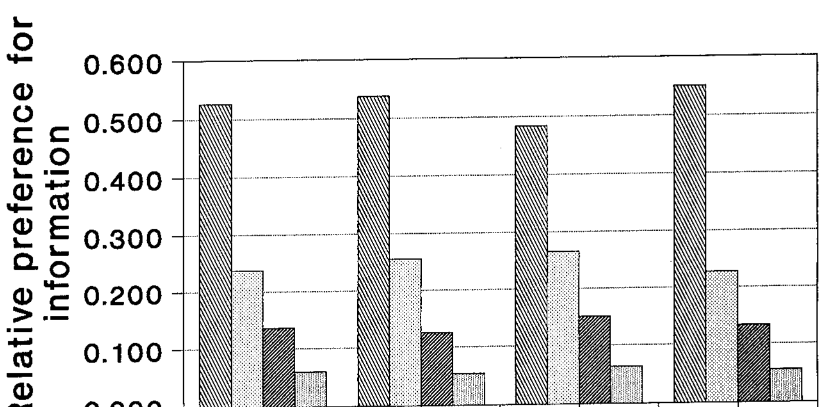
Notional risk-level profiles relating to how the commander might value information in each of the four mission areas may look similar, but there are some subtle differences (figure 25). For instance, information is very valuable in a maximum-risk strategic crisis environment for keeping the National Command Authorities (NCA) apprised of "triggers" which could escalate a conflict or which would dictate pursuit of alternative options. Information is highly valued in a maximum-risk, air-land warfare environment largely because of the tempo in that environment. In comparison, information is slightly less valued in a maximum-risk naval warfare environment. This could be attributed in part to the traditions of naval doctrine which emphasize seeking the enemy and attacking first regardless of in-depth information about the enemy. This lower value for information could also be attributed to the fact that information priorities are more balanced across the risk levels since naval forces must be able to operate in a dispersed mode with little externally provided information. The degree to which information is valued in any one mission area corresponds to how the commander prefers force elements over C^2 resources, with respect to the perceived risk.

For each mission area, the DOD definition of the type of warfare is paraphrased and a list of the 10 most significant characteristics is included for C^2 systems in that mission area.[17] These analyses follow.

The principal objectives of strategic warfare are to first deter adversaries that could threaten the security of the United States and, if deterrence fails, to prevail over those adversaries in any ensuing conflict. Key areas of emphasis include penetration of adversary defenses and an effective US homeland defense based on integrated tactical warning and attack assessment. In addition to the ability to carry out nuclear war plans, there must also be an ability to terminate the hostilities at any time.

Using DOD mission area definitions, Strategic Offense (Mission Area 110) includes the capabilities required to deliver weapons in support of national objectives against resources

FIGURE 25. Value of information relative to perceived risk levels in four mission areas



	Strategic Warfare	Air-Land Warfare	Naval Warfare	Strategic Crisis
Maximum	0.526	0.538	0.484	0.550
Max-mod	0.238	0.256	0.266	0.227
Moderate	0.136	0.125	0.150	0.133
Mod-min	0.060	0.054	0.063	0.055

Risk
Maximum — Max-mod
Moderate — Mod-min

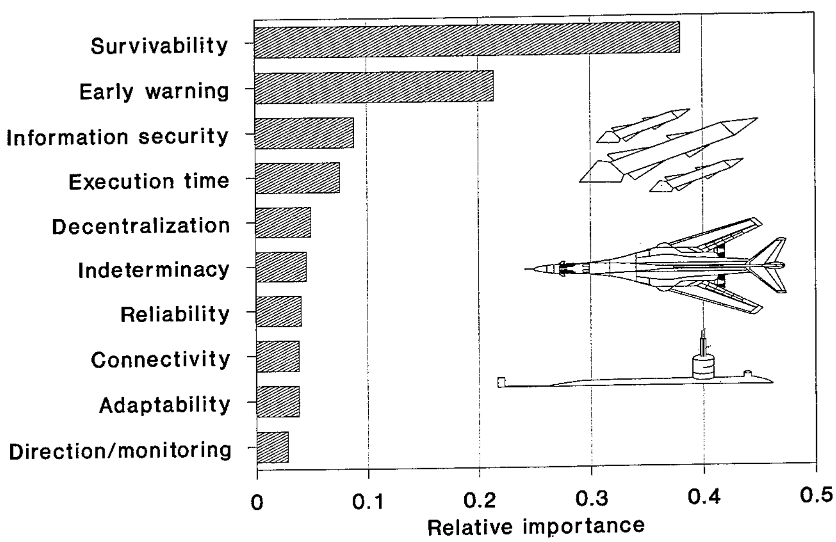
critical to the effective survival of an opposing power. Strategic Defense (Mission Area 120) addresses those capabilities required to detect attack against the continental United States and to defend against that attack. Strategic Defense also includes capabilities to neutralize enemy space resources which could adversely affect US force posture. In the Strategic Offense and Defense mission areas, force structure planners trade force elements for strategic C^2 systems and tactical warning and attack assessment systems. The force elements include strategic bombers, missiles, submarines, and defensive interceptor squadrons.

C^2 at the strategic level of conflict requires the management of forces far beyond the horizon. The NCA needs unambiguous indications and warnings from around the world. Because of the relatively short flight times of nuclear weapons, protecting the time window needed to make force execution decisions is critical, and because nuclear war plans are understood and rehearsed in advance, the idea of the shared image is not as important as in other conflict areas.

C^2 helps to reduce uncertainty in strategic warfare by giving timely advice to the NCA as to when launches or nuclear detonations have occurred and what the resultant damage is. This enables the NCA to restrain the use of forces rather than responding spasmodically, which would likely breach thresholds into higher levels of conflict. C^2 helps the NCA keep up with the tempo of the conflict, determine whether one of the parties desires to terminate hostilities, and decide whether mission-deployed forces need to be redirected to different targets. C^2 system development for the strategic warfare mission area should emphasize the 10 C^2 criteria in figure 26. Judgmental analysis shows that, to prevail in a nuclear conflict, survivability is of paramount importance. Amassing forces to be able to prevail in any conflict and having the resources to deny the enemy from performing his functions are key objectives in land warfare and tactical air warfare.

DOD defines Land Warfare (Mission Area 210) to include the resources needed to use tactical combat power against threatening ground maneuver forces. Air Warfare (Mission Area 220) addresses the capabilities required to achieve and maintain air superiority and to use tactical air combat power against threats in the immediate battle area and beyond. In these mission areas, force structure planners trade off C^2 resources for land-based combat divisions and tactical fighter wings. Mission area 223, analyzed earlier in this chapter, is one subset of these two mission areas.

FIGURE 26. C2 system characteristics most significant for Strategic Warfare



The air-land battle coordinator also needs to "see" beyond the horizon to strike deep into enemy territory and interdict or suppress those functions that could compromise his intentions. Operational art doctrine, practiced more intensely in land warfare and tactical air warfare than in the other mission areas, charges the commander to win the first battle with initiative, agility, depth, and synchronization.

According to Brigadier Simpkin, the commander must use the physics of warfare for leverage; must adapt to the statistical elements of risk, chance, and surprise; and must engage in a clash of wills with his adversaries.[18] Therefore the commander needs sophisticated C^2 to "do more with less," to see over the horizon and perform artful maneuvers like pivoting and enveloping. C^2 resources ensure that these actions occur at the precise time and with precise timing, consistent with the tempo of the conflict. C^2 also helps the air-land warfare coordinator cope with uncertainty by providing more indepth knowledge of targets and better knowledge of the status of own-forces. C^2 also provides the adaptability and connectivity to communicate outside the coordinator's zone or sector and permits the coordinator to be positioned wherever the conflict situation dictates. C^2 further helps the air-land battle coordinator respond to changes in tempo by permitting a faster turnaround in planning and changes to tasking orders.

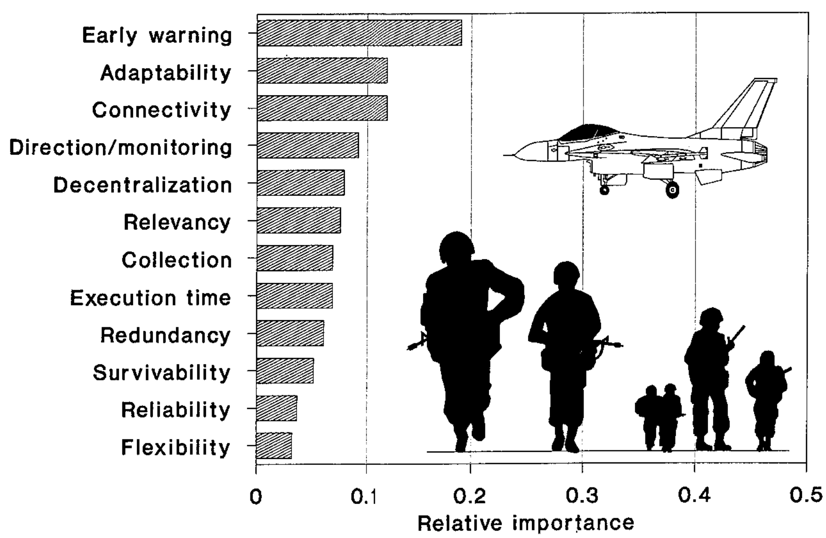
In the salient C^2 system characteristics for these mission areas (figure 27), early warning is again an important characteristic but survivability has a lower priority than strategic warfare because the C^2 resources need only be as survivable as the force elements being supported.

The objectives of naval warfare, especially antisurface naval warfare, are to seek the enemy and to destroy his capability and will to fight—to attack effectively, first. DOD defines Mission Area 230, Naval Warfare, to include the capabilities and support directed at achieving and maintaining naval supremacy over threat naval forces. The ultimate objective of naval warfare is to permit free use of the seas and necessary reinforcement and resupply. The principal force element type that must be balanced against C^2 resources in naval warfare is the combatant ship. Other important force types are the carrier attack wing and the tactical submarine.

With the advent of supersonic antiship air threat and missile warfare, the naval commander often lacks the visual contact with the enemy traditionally enjoyed. Now the commander needs to be in the below-deck operations room to have access to the over-the-horizon warfare information needed to "fight the ship." But because of the cultural traditions of naval warfare, he or she still wants to "see" and control what is going on. Thus the naval commander must now rely on sophisticated visual C^2 systems for this perspective. How does C^2 help the naval commander in building a shared image, mitigating uncertainty, and coping with the tempo of the conflict? Simply, the "battle outcome rests on information, collected and denied before the weapons are fired."[19]

According to Hughes, the proliferation of missile warfare, especially cruise missiles and surface skimmers, has also

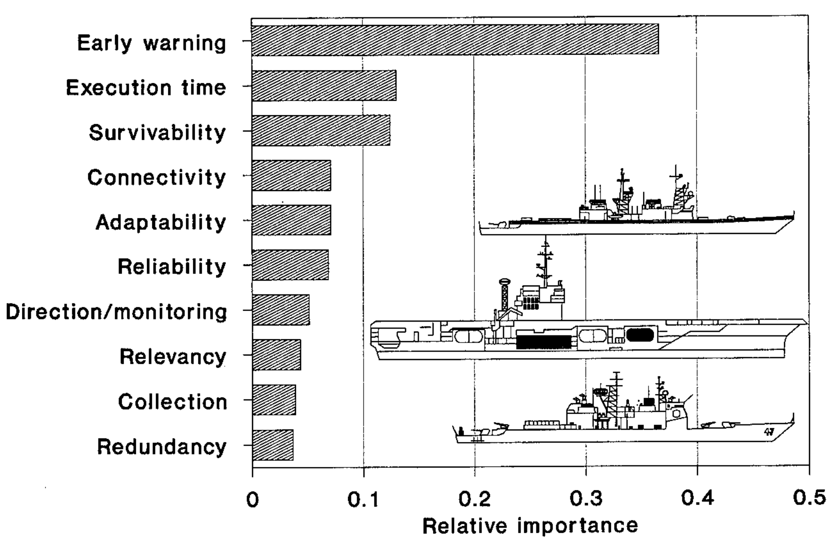
FIGURE 27. C2 system characteristics most significant for Air-Land Warfare



raised another C^2 issue: should warship formations be massed or dispersed? There is a tendency to invest in warships with more offensive firepower than defensive capability for cost-effectiveness. Warships such as these operate best as loners or dispersed forces; in a massed tactical formation, they have little to contribute to the massed defense. In either case, effective C^2 is vital. As soloists, the heavily offensive ships need to have their own offensive firepower coordinated to concentrate fire on enemy targets often from great distances with no visual contact. In a massed formation, their limited defensive capability must be effectively directed (by C^2) to defeat the targets chosen by the formation commander.[20]

C^2 systems help reduce the uncertainty about when to strike and what the potential for success is. With long range lethality and advanced scouting and antiscouting systems, C^2 is the activity that leads to success in modern naval warfare. C^2 resources help the naval commander mass the needed firepower at the time and place of his choosing.[21] Thus, a demand for effective C^2 early warning appears as the most critical naval C^2 system criterion (figure 28).

FIGURE 28. C2 system characteristics most significant for Naval Warfare



The principal objective in resolving strategic crises is to support US foreign policy and broader national interests. Crises are probably the principal type of conflict US forces will encounter in the coming decades. The objectives in strategic crises are largely the same as for strategic conflict—to deter, and then to prevail if deterrence fails. But there is one important difference: the successful resolution of a strategic crisis demands timely and accurate knowledge so that the NCA can control escalation at political and diplomatic levels to avoid war. C^2 is particularly difficult when the conflict is very fluid and politically complex.

Mission Area 333, Strategic Communications, addresses those capabilities required to communicate among the NCA and strategic force C^2 elements. It also includes communications links with theater C^3. Because this mission area is a "defense-wide" activity, there are no clearcut force structure tradeoffs as there are in other warfare areas. In short, the decisionmakers may trade off strategic-level C^2 systems for any type of traditional force element.

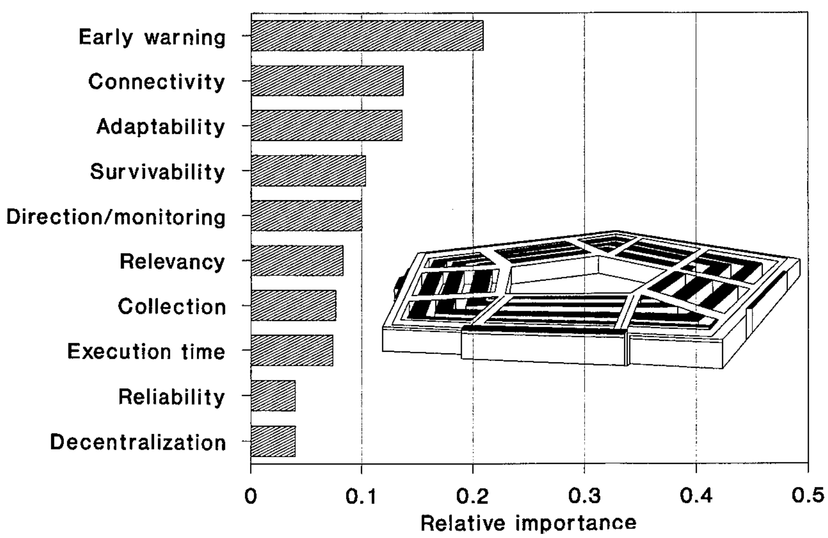
Hughes explains that off-the-scene commanders in far-removed command posts can easily overestimate the quality and timeliness of the image of a conflict, just as on-scene commanders can underestimate the strategic and political implications of their tactical decisions.[22] The off-the-scene commander (such as the NCA) needs enough early warning and adaptability to the tempo of change in the situation to be able to react, and also needs the connectivity to monitor how instructions are being carried out by the on-scene commander. This connectivity will reduce the commander's uncertainty and maintain a shared image of what needs to be done.

This early warning and connectivity, two critical characteristics (figure 29), prevent escalation of the conflict into politically undesirable situations. If the NCA learns through diplomatic channels that a naval blockade has been successful and the adversary has capitulated, the NCA can prevent the on-scene commander from following through the rules of engagement for an intercept-in-progress and avoid a diplomatic incident.

To prevent more serious crises, political control through C^2 is often necessary—and in some alliances and in some countries statutorily required—to ensure measured responses to conventional conflict actions cross the nuclear threshold only when necessary to ensure desired political and economic aims.[23]

In strategic crises, C^2 resources help national leadership cope with uncertainty and tempo by providing better intelligence, better communications among senior leaders (both military and civilian) and the forces, and decision support tools

FIGURE 29. C2 system characteristics most significant for Strategic Crisis



to comprehensively consider the wide range of options in exercising national power in a rational way.

§ § §

Notes

1. Students of microeconomics and utility theory will recognize this unfolding approach as an example of finding consumer equilibrium under constrained maximization. We use component parts of force effectiveness to yield a family of consumer indifference curves, then we match the marginal rate of substitution (slope) of each indifference curve to the slope of the budget constraint curve to solve for the point of tangency. One might also think of the problem in terms of production theory, where the force effectiveness curve is rep-

resented by a Cobb-Douglas production function. Appendix B covers the details of the pertinent microeconomics.

2. See Paul A. Strassman, *Information Payoff* (New York: The Free Press [Macmillan, Inc.], 1985), 116 for a good discussion about the importance of distinguishing efficiency from effectiveness. Strassman is an expert in measuring the value of automation in business environment.

3. This objective is even more challenging for the large C^2 systems which serve a diverse cast of many users concurrently. Examples include the Air Force Theater Air Control System, which services air traffic control, combat intelligence, air intercept operations, and other missions. Another example is the Defense Satellite Communications System, which serves tactical land forces, nuclear force execution, diplomatic missions, and other activities. Another challenge is in measuring the human components of the C^2 system.

4. Because I designed this example for simplicity, it only covers a small-scale mission, which tends to be service-unique. Also, the example deals with incremental changes in the balance between force elements and C^2 resources within one functional area. But the method certainly may be applied to much larger-scale force structure decisions. All that's needed is Joint Service participation in the decision-making process. Although senior decisionmakers must participate to make the method credible, most of the work can be performed by a supporting analytical staff. Senior decisionmakers meet to discuss the scope of the problem, independently answer questionnaires, and then meet again to review and accept (or reject) results. The technique can also be used for analyzing force increases as well as decreases. Appendix B provides the details of this analytical method, using an example which deals with a budget increase.

5. Force structure decisions, indeed all budget decisions, must incorporate all life cycle cost impacts. These include the cost categories of Research, Development, Test, and Evaluation (RDT&E); Procurement; Military Construction; Military Personnel; Operations and Maintenance (O&M); and others.

6. The Close Air Support and Interdiction mission, as used in this chapter, is defined by the Director of Defense Research and Engineering (USD(DDR&E)) as addressing those capabilities required to provide close air support and to destroy transient and fixed targets

including reinforcing ground forces before they enter the immediate battle area, logistic war materiel, and command installations. It includes strike capabilities of ground and ship-based aircraft and long range missiles. It also includes associated target acquisition systems. United States, Department of Defense, *USDDR&E FY 87-91 Mission Assignments*, unpublished materials, 26 February 1986, A-31. The USD(DDR&E) prepares these standard mission area definitions for warfighting missions, "garrison" missions, and research and development activities. In addition to the standard definitions of some 150 mission areas prepared and distributed by the USDDR&E from time to time, the OJCS has also developed its own list of mission areas. The OJCS list, while similar to the DOD list, is more like a "warfighting" subset of the USD(DDR&E) list. I will use the highest precedence (DOD) list.

7. Typically, we end up building defense systems for use in peace—not war. Systems built for deterrence or in preparation for the next war are systems built for peace. New systems built during wartime mobilization are often not deployed before the war is over. Consequently, the 20-to-30 year life cycle for major weapons systems is an important factor in force planning and acquisition decisions because the vision of the force structure must be long-term while the investment issues are short term. During wartime attrition in which the weapons system life cycle may be on the order of weeks or hours, systems acquisition may be more accurately called replenishment.

8. We presume that appropriate authorities have documented the mission's C^2 deficiencies in a formal requirements document and have approved the acquisition of the C^2 improvements. We also presume that the existing force structure in Mission Area 223 is a balanced mix of C^2 resources and force elements.

9. For a discussion of this concept of "C^2 increments," see appendix B.

10. Captain Wayne P. Hughes, USN (Ret.), *Fleet Tactics: Theory and Practice* (Annapolis, MD: Naval Institute Press, 1986), 275.

11. Realistically speaking, additional C^2 assets would probably not be immediately available in a conflict situation. By the same token, replenishment force elements are not always immediately available either. There are, however, C^2 resources like those of the Joint Com-

munications Support Element that can be deployed worldwide on short notice.

12. Provided these are his two principal choices for increasing force effectiveness.

13. See appendix A for a detailed explanation of this technique, called the analytical hierarchy process. A different group of decisionmakers would probably come up with a different set of numbers. Therefore the reader should not be overly concerned with the level of precision in these numbers. Precision indicates the degree of resolution possible in this method—not an absolute accuracy.

14. The objective equation is a Cobb-Douglas function for which we assume a constant return-to-scale. Therefore the exponents sum to unity, for simplicity. See appendix B for a more detailed discussion of the reasoning why the exponents add up to (1). For higher fidelity in representing the interaction, other factors may be added to this objective function for relative force effectiveness. However, graphically depicting the interactions among three or more factors is difficult.

15. The relative force effectiveness levels are arbitrarily chosen to show the interaction of the *FE* and *C2* terms in the equation; we would be hard-pressed to pin down an absolute value for force effectiveness.

16. Appendix A explains how to match the C^2 system characteristics to mission area needs, using the analytical hierarchy process.

17. The priorities for these characteristics are based on personal assessments, using the analytical hierarchy process described in appendix A.

18. Brigadier Richard E. Simpkin, UK (Ret.), *Race to the Swift* (Washington, DC: Brassey's Defence Publishers, 1985).

19. Hughes, 253.

20. Ibid., 248-250.

21. Ibid., 266-268.

22. Ibid., 227.

23. Simpkin, 278-279.

Concluding Thoughts

As US security interests change, national security strategy will also change, responding to reduced superpower tensions and to the squeeze of budget reductions. National military strategy, a vital component of the national security strategy, will also continue to change in concert with changes to the national security strategy. Defense decisionmakers will increasingly experiment with major institutional changes, in military culture and in military organization, to validate these changes in the military strategy. The institutional experiments will lead to major changes in force structure and warfighting doctrine.

Accepting the realities of a new defense establishment with reduced size and mission, military planners talk of transitioning to a strategy of flexible, graduated responses to challenges to US national security interests. Under this type of reduced-response strategy, C^2 assets will become even more vital at both the strategic level and the operational level—to exercise positive control over the unfolding, onsite situation. To deal with the uncertainty and tempo of the situation, with a shared image of what the commander wants to happen, it will be necessary to deploy more C^2 resources will have to be deployed to the theater earlier to better manage fewer military forces initially on shore.

Operation *Desert Storm* in the Persian Gulf, an important test of this new strategy, drew media attention to the technology of modern warfighting. Smart munitions were popular subjects. But the media also became interested in the technology of C^2 systems in the Gulf. C^2 resources were vital to the success of *Desert Storm*, but what commanders learned about waging fast-paced operational warfare with coalition partners was probably equally important. Many of the commanders learned how to muster effectively limited resources and how to use different types of national forces to decisively prevail against Iraqi forces. We should continue to learn how to organize those limited-size forces, to assure similar chances of mission success in responding to challenges to US national interests.

In this book, we explored a number of ways to move toward that goal: developing future military organizations and operational doctrine by fully integrating C^2 resources into the force structure. Our expeditions should stimulate further thinking about processes that can help us systematically plan future US military strategy. C^2 assets are indeed effective in improving the chances of mission success by providing the commander the information he needs to adapt to the threat. Because we can measure how C^2 resources contribute to mitigating the commander's perception of risk, defense decisionmakers can now successfully integrate C^2 assets within the force structure.

But we must not become mesmerized with methodology. The degree to which we invest in technology to support the command and control of military forces is driven by the wishes of the commander of those forces. And the wishes of the commander evolve from the commander's psychological character: how confident he or she is as a leader; how confident he or she is in the capability of the forces; how nervous he or she is about the strength, will, and intentions of the adversary; and how comfortable he or she is with other forces, whether they are other services of allied forces.

Apart from a commander's own psychological makeup, his or her skills in command and control are the means of gathering and handling information—whether it is from staff, communications, computers, or a combination of all three.

If any aspect of a commander's confidence is softened by action or change in capabilities, how he/she commands and controls will change (or the commander may perish). Perception becomes reality. Changes in perception will transfer into a "different way of doing the business" of command and control. That different way will cause placement of a different level of emphasis (increase or decrease) on C^2 assets. Many times choices for emphasis boil down to two: either the commander can seek tools to provide useful information or can add more forces (force elements) to the force structure. The second option is far less likely to happen.

Planners who understand the changes in the world situation and the ideas in this book should begin to change their institutional interests. Such changes should lead force planners away from amassing the types of weapons systems vital to their institutional interests and toward a more integrated joint environment where all weapons systems (including C^2 systems) can effectively and economically fit within a balanced military force structure which fulfills the national military strategy. This in turn could lead to dissolution of the barriers between the military strategy and the rest of the national security strategy, especially in the domain of foreign policy, because military warfighting—and peacekeeping—are instruments of foreign policy "commanded and controlled" within the domain of national leadership.

At the national level, we can change our emphasis on command and control resources in the force structure. This will be a major institutional change—a cultural change—from counting "things" in attrition warfare, to evaluating warfighting capability in operational warfare. The "Forces for" document will increasingly continue to reflect the significance that the unified and specified commanders and other defense planners place on C^2 resources.

Using the force structure decisionmaking methods in this book will make arms control and force structure reduction measures more understandable. Strategic and conventional force reduction talks have continued to "count things" rather than evaluate the inherent effectiveness of the residual forces. Incorporating the intangible force effectiveness factors like C^2 will add more coherence to multilateral force reduction negotiations. Force planners might not give up C^2 resources so easily without first considering how these resources make the traditional force elements work more effectively.

Someday we will be able to build a fully articulated and comprehensive military architecture representing all aspects of the force structure, to include C^2 assets as well as force elements. With modern defense analysis, we embarked on a course toward this goal in the 1960s. Now, with a method to account for the commander's preference for information under risk and the intangible contributions of C^2 resources toward mitigating that risk in the context of available forces, we will be able to take another essential step toward that goal.

Appendix A. The Value of Command and Control Information

Decisions Under Risk and Uncertainty

It seems the greatest challenge in any force structure decision concerning C^2 resources is how to evaluate objectively psychological (and even emotional) preferences for C^2 resources over force elements or vice versa. Just like a battle commander, a defense decisionmaker must learn to cope with uncertainty and tempo; the decisionmaker's uncertainty, however, is more about the future than about the present, and the tempo is in meeting decision suspenses rather than adjusting to the tide of battle. Moreover, in the complex national security environment, the defense decisionmaker must build consensus about future requirements rather than dictate a vision of the future.

Many tools are described in the literature for rational decisionmaking under such circumstances. The analytical hierarchy process, described in this appendix, was developed at the Wharton School of Business by the noted mathematician Thomas L. Saaty. This process has been used in planning higher education in the United States, understanding the conflict in Northern Ireland, and other complex situations. The next paragraph summarizes some of the special advantages the process gives us in the area of force structure decisionmaking.[1]

First, the process encourages participants to represent all constraints and considerations of force structure decisionmaking in a single, orderly conceptual framework. Second, it lets decisionmakers systematically address each small piece of the problem rather than trying to solve the entire problem at once. The process also checks the consistency of the decisionmakers' judgments. Third, it helps the decisionmakers put intangible factors and priorities on a quantitative scale instead of just ranking them. Fourth, the process accommodates the often widely disparate stakeholder interests of participants in force structure decisions, particularly those involving C^2 assets. Even when consensus about the relationships among factors cannot be reached, the process records the differences and synthesizes a composite outcome. And fifth, the process is iterative and auditable.

The analytical hierarchy process can account for as many or as few of the interdependent factors influencing force structure decisions as the decisionmakers need. Using the process, the decisionmakers can identify the cause-and-effect relationships among factors and subfactors and then select the most important factors. As the interdependencies become quantified and understood, stakeholders' preferences appear in an agreed-to framework with a corresponding quantified priority. These traits are important because decisionmakers must spend some time developing and structuring the problem before grabbing the calculator. As Enthoven and Smith reminded us, the meat of systems analysis is not the final mathematical computation. It is the "uninteresting" preliminaries—deciding what the goal of the decision is, what the assumptions are, and what factors should bear on the problem.[2]

This appendix describes two examples, illustrating how this process can aid in C^2 force structure decisionmaking. In the first example, the decisionmakers think about how information contributes to success in warfighting or peacekeeping, in differing risk environments. They decide how they perceive the value of information derived from C^2 resources helps the commander in building a "shared image" and coping with uncertainty and tempo in conflict.[3] The value they place on C^2 information can be used to depict the influence of C^2 resources on force effectiveness.

In the second example, the decision makers agree how to apportion available funds for upgrading C^2 to best satisfy a certain mission area's information needs. In other words, they decide how to assign acquisition priorities to C^2 resources under a constrained budget, whether the C^2 resources are being added under an increasing Defense budget or deleted under a decreasing budget. The results can be used in selecting which C^2 resources to buy, once the level of C^2 required for the risk environment has been determined.

Example: Perception of Information Value

For the broader force structure analysis, we will organize a problem for evaluating the value of information in conflict. Because C^2 systems help the commander lead by providing information to solidify concepts and to cope with uncertainty and tempo in warfare, force structure decisions involving C^2 systems should focus on the value of information in conflict. Our objective in the problem then is to decide how important is the information that helps the commander cope in each of several risk levels. We will now play roles as decisionmakers. Together, we decide to select several risk levels or scenarios, because we recognize that the value of information will change depending on how the BLUE commander perceives he can cope with tempo and uncertainty. As participants, we may decide to define risk levels in terms of force-on-force comparisons, probabilities that an adversary will act out his intentions, or some other characterization of forces or threats.[4] For this example, we will describe force-on-force levels as maximum, maximum-to-moderate, moderate, moderate-to-minimum, and minimum risk scenarios. (The number of levels the decisionmakers decide on should be consistent with their desired degree of precision in the decision process.)

We will estimate the value of information, based on our perception of the magnitude and quality of our BLUE forces. By estimating the value of information, we avoid the engineering measures which are equipment-dependent. Additionally, the idea about how the commander perceives the value of information relates to peacetime and training missions as well as to the continuum of conflict. While there are many ways to slice the problem of defining risk levels, decisionmakers are likely to make decisions about the value of information in view of force count differentials, only because force ratios are easier to visualize than qualitative ratings.

To begin this process, we agree on a common goal—in this case, to assess the value of information for a specified mission area. After brainstorming, we suggest all the factors we feel bear on the goal and all viable alternatives we believe should be considered. We further agree on precise definitions of the factors and the alternatives at this time.[5] Table A-1 shows our goal and the defined factors.

Intuitively, the value of information relates to the quality of information. If the information produced by the C^2 system is of higher quality (for example, more responsive, more timely for the commander), then the BLUE commander would probably value it more highly. This linkage begs the question: Does the BLUE commander have to know what the C^2 system (as it exists or will be modified) can do for him or her before the value of the information provided for the mission can be judged?

The BLUE commander should indeed have a good perspective not only of the types, content, and flow of information needed, but also of what quantity and quality needed to build shared images. The commander should know what is to be received without the added C^2 resources as well as what can be expected from the changed C^2 system. (This relationship will become more apparent in the second example.) This premise would normally demand an absolute measurement; but by using the analytical hierarchy process, we avoid that problem since comparisons are relative. Therefore, we are assessing the relative value of information.[6]

Once we have defined the goal and factors, this force structure decision problem begins to take shape. As participants, we next organize the factors bearing on the problem into a "wiring diagram" or hierarchical structure to represent our ideas about how the factors interrelate. With these elements arranged in a framework showing the risk level factors, we now may view the context of this decision problem about the value of information.[7] Figure A-1 shows how the risk levels relate to the goal in our example.

More important than anything else, we must ensure that judgments made during any aspect of our force structure decisionmaking are made within the context of the domain and ob-

TABLE A-1. *Factors for analyzing BLUE's value of information relative to risk level*

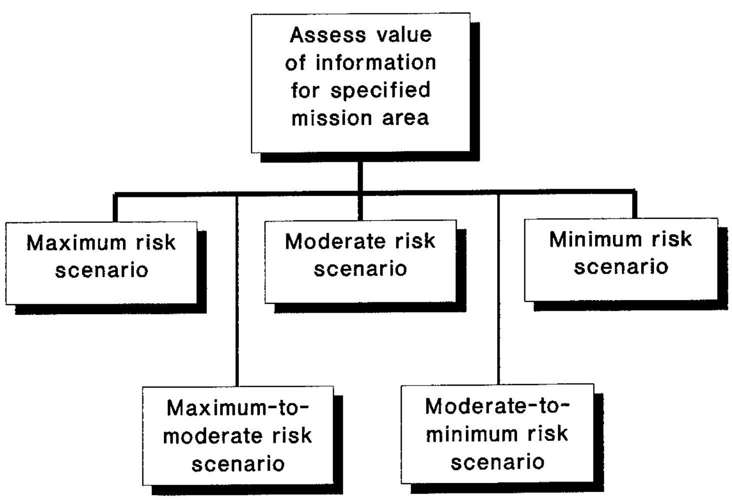
Goal: To assess the value of information for a specified mission area

Factors: (based on BLUE's perspective, defensive posture)

Maximum risk:	BLUE perceives own forces to be at a maximum disadvantage relative to enemy forces, either on a numeric or qualitative basis.
Maximum-to-moderate risk:	BLUE perceives own forces are at a risk level between maximum and moderate.
Moderate risk:	BLUE perceives a moderate level of risk for own forces in comparison to enemy forces.
Moderate-to-minimum risk:	BLUE perceives own forces are at risk level between moderate and minimum.
Minimum risk:	BLUE perceives numeric or qualitative disadvantages with respect to enemy forces to be minimal or nonexistent.

jectives of a specified mission area. And, as decisionmakers, we must temper how we interpret the mission area with relevant national security interests in a specific theater or region and the attendant geopolitics. If we needed more detailed assessments about the value of information, we would evaluate a separate hierarchial problem for each specified mission area in each theater of interest. But here we choose to explain the process using a generic mission area, from the BLUE commander's perspective.

FIGURE A-1. Structure for analyzing information value relative to scenario risk level



Sorting out what's important is the next step in the process. As divergent stakeholders contemplating the analytical structure in figure A-1, we decisionmakers could probably reach an approximate consensus on the relative ranking of perceived information value among the five risk levels. But widely divergent stakeholders would probably find it far more

TABLE A-2. A comparison scale for relative importance

Intensity of Importance	Definition	Explanation
1	Equal importance	Two factors contribute equally to the context of the comparison
3	Moderate importance	Experience and judgment slightly favor one factor over another
5	Essential or strong importance	Experience and judgment strongly favor one factor over another
7	Very strong importance	Participant strongly favors a factor; dominance of the factor widely recognized by experts
9	Extreme importance	Within the context, evidence favoring one over another incontrovertible
2, 4, 6, 8	Intermediate values between two adjacent judgments	Compromise between two judgments
Reciprocals	When we assign an integer judgment in comparing one factor to another (such as 5), then the comparison of the second factor to the first results in a reciprocal judgment value (1 over 5, or 1/5)	

Source: Saaty 1988

difficult to pin down whether the second-ranking risk level is almost as important as the first ranking or whether it is far less important than the first and almost equally important as the third and fourth. Using the analytical hierarchy process, we will decide on the specific importance of information under each risk level by comparing risk levels with each other, in the context of the agreed-to goal. We will compare only two factors at a time, speeding the tradeoff among the several factors in C^2 force structure decisionmaking. This systematic process will capture our wisdom as decisionmakers, without compelling us to rank many factors at once.

To start these "one-on-one" or pairwise comparisons, we place the set of five risk levels or factors in a matrix. We will use a convention that compares the first element of a pair (in the left-hand column of the matrix) with the second element of a pair (the next element in the row on top of the matrix). We measure the intensity or importance of one factor over another in each comparison using a scale from 1 to 9, as shown in table A-2. If we believe factor *A* has a level of moderate importance over factor *B*, we would attach an intensity level of 3 to that comparison. Comparing the second factor to the first conversely appears as a reciprocal value (comparing factor *B* to factor *A* would have an intensity level of 1/3). When comparing one factor to itself, the comparison yields unity (1).

For our first example in evaluating the value of information, we would use one matrix for each mission area of interest. However, to illustrate the process, we are using a generic mission area. Figure A-2 depicts our comparison matrix for the generic mission area.

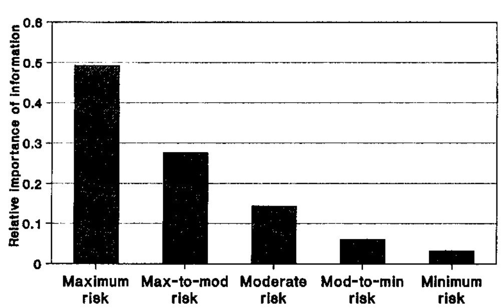
To fill out the matrix, we may choose to rate the importance of factors in a group session or we may independently fill out questionnaires relating to each matrix. (The dynamics of group sessions can lead to a deeper, shared understanding of the meanings of the comparisons. But in the interest of time, questionnaires are usually a better choice than a group session.) Table A-3 is a sample questionnaire for our assessment of the value of information, showing the context for the questions asked and how the rating scale relates to each question. I have already marked the questionnaire according to my opinions for this example. The analyst derives reciprocal

FIGURE A-2. Sample matrix arithmetic for value of information in a specified mission area

SPECIFIED MISSION AREA CONTEXT	Priority judgment: Max	Max to mod	Mod	Mod to min	Min	Normalized priority: Max	Max to mod	Mod	Mod to min	Min	Average priority
Maximum risk	1	3	6	7	9	.57	.66	.53	.38	.32	.492
Max-to-mod risk	1/3	1	4	6	8	.19	.22	.35	.33	.29	.276
Moderate risk	1/6	1/4	1	4	7	.10	.06	.09	.22	.25	.144
Mod-to-min risk	1/7	1/6	1/4	1	3	.08	.04	.02	.05	.11	.060
Minimum risk	1/9	1/8	1/7	1/3	1	.06	.03	.01	.02	.04	.032
Sums	1.75	4.54	11.39	18.33	28.00						1.000

Note: Some numbers are rounded off.

Summary priorities
showing value of information relative to
specified mission area context



values from marks on the right-hand side of the questionnaire scale, so we decisionmakers will not have to convert integers to reciprocals. Since the lower-left portion of a comparison matrix is the "reciprocal image" of the upper-right portion, we need only to answer enough questions to complete the upper-right portion of the matrix.[8]

Once we have collected all participants' inputs, we next compute the priority values for each risk level or factor by mathematically combining all the judgments made in comparing each pair and determining the weighting associated with each factor and subfactor. Because participants' answers to any one question may be a combination of integers and reciprocals, we must "average" all collected judgments for each question by computing the geometric mean of the participants'

TABLE A-3. Sample questionnaire for evaluating the value of C2 information in a specified mission area

QUESTIONNAIRE TO EVALUATE THE VALUE OF C2 INFORMATION RELATIVE TO RISK LEVEL

CONTEXT: Based on your experience and knowledge of the mission area and the following pairs of risk levels, under which level in each pair of risk levels is information more important and by how much?

<<-- Maximum																Maximum-to-moderate -->>
9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9
<<-- Maximum																Moderate -->>
9	8	7	**6**	5	4	3	2	1	2	3	4	5	6	7	8	9
<<-- Maximum																Moderate-to-minimum -->>
9	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	9
<< -- Maximum																Minimum -->>
9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
<<-- Maximum-to-moderate																Moderate -->>
9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9
<<-- Maximum-to-moderate																Moderate-to-minimum -->>
9	8	7	**6**	5	4	3	2	1	2	3	4	5	6	7	8	9
<<-- Maximum-to-moderate																Minimum -->>
9	**8**	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9
<<--Moderate																Moderate-to-minimum -->>
9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9
<<--Moderate																Minimum -->>
9	8	**7**	6	5	4	3	2	1	2	3	4	5	6	7	8	9
<<-- Moderate-to-minimum																Minimum -->>
9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9

answers.[9] We place these numbers (or "average" judgments) in the matrix. Figure A-2 shows the questionnaire results and the computations needed to determine the priorities. When the questionnaire results appear in the matrix, they begin to reveal the relative importance of the factors (risk levels in this example). Taking a sample judgment from the matrix, we see the value of information in a maximum-to-moderate risk level has a moderate to strong level of importance (rating of 4) over the value of information under a minimum risk level (following table A-3 our convention of reading "right and up"). The value of information at a minimum risk level has a very insignificant level of importance (1/9) relative to information at a maximum risk level. Recalling the use of reciprocals in this process, and again reading "right and up," we also note that the maximum risk level's value of information is at an extreme level of importance (9 or the reciprocal of 1/9) compared to the minimum risk level.

Now that we have a complete matrix, we will determine the average priority of each of the five risk levels or factors. We normalize the "average" judgments in each column by first summing the column, then we calculate the relative weight of each priority judgment with respect to the sum by dividing each priority judgment in a column by the sum of that column, for each matrix position. The results of this normalization process appear in the portion of the figure labeled "Normalized Priority." Finally, we compute the average priority for each risk level by averaging the normalized values in each row for each of the five risk levels. These relative priorities are shown in bar-graph form in the lower half of figure A-2.

Interpreting the results of these computations, we find the BLUE commander values information at a maximum risk level nearly 1.8 times as important as information at a maximum-to-moderate risk level (0.492 to 0.276). At the minimum risk level, the BLUE commander perceives the value of information relative to mission success to be the least important (0.032). These results show that the BLUE commander, understandably, places much greater significance on the advantage of information in a maximum risk scenario.

If participants in the decisionmaking process believe the results are not consistent with national security interests or the domain of the mission area, the group can postulate different factors, restructure the hierarchy, answer the matrix questions again in a different order, or reiterate the process using a combination of these techniques. We can also apply a mathematical method for evaluating consistency.[10] The consistency ratio in our example is 2.9 percent, well within the standard of 10 percent, showing that our answers to the questions were not too random.

How will we use the results of this example in force structure decisionmaking? What we have done so far is to pin down specific numbers concerning how the BLUE commander values information in each of five risk levels or scenarios, in the context of a mission area. Ensuring that a shared image of information has been developed and communicated becomes more important to the BLUE commander as the perception, risk level, uncertainty, and tempo are increased. We recall that the information the BLUE commander needs to cope with uncertainty and tempo comes, for the most part, from C^2 resources because the C^2 system includes both the human and nonhuman components. It follows that how the BLUE commander values information corresponds, in a relative sense, to how C^2 resources are valued in each risk scenario. In appendix B, we will use the numbers from this example in deciding how the BLUE commander is willing to trade C^2 assets for force elements in each risk scenario.

Example: Assigning Priorities to Desired C^2 Enhancements

This second example is more complicated than the first, mainly because there are more factors, subfactors, and alternatives to deal with. In deciding how available C^2 money should be spent, we decisionmakers will organize a problem for evaluating alternative C^2 equipment resources that meet the BLUE commander's information needs in a specified mission area. We will put ourselves in the shoes of the BLUE commander—with his/her command doctrine and operational concepts—and decide which alternatives best help to build "shared images" and to cope with operational tempo and uncertainty in the mission area. Then, by analyzing the major C^2 system characteristics or factors with respect to the mission area, we will further determine the sensitivity of the BLUE commander's programmed C^2 capability in fulfilling mission area objectives.

To begin this example, we again agree on a common goal, this time "to assign priorities for implementing C^2 increments" in a specified mission area. The use of "increments" here relates to a means of breaking down the total proposed suite of C^2 capability into smaller pieces, as described in appendix B. We break down the suite into smaller increments or desirable combinations of increments so the most desirable C^2 elements can be acquired if there is not enough money to acquire all of them.

After deciding on the goal, we brainstorm and define the factors and subfactors which we feel have some bearing on this force structure decision. Figure A-6 shows the goal and lists our defined factors and subfactors, in no particular order except alphabetically by factor and subfactor. As the factors and subfactors selected for solving this problem could be any set we might agree to, this list is only one example. (The list in table A-4 does correspond to the list of desirable C^2 system characteristics discussed in chapter 3).

We find that there are several alternative pieces of equipment which can help the BLUE commander: new radars, new computers, new satellite communications terminals, and a new intelligence fusion facility. Features of the new radar include digital signal transmission from locations remote to command headquarters, high sidelobe suppression of the radar beam to reduce detectability, self-contained operation and error monitoring, and short setup and teardown times for the equipment. The advanced high speed computers are augmented with extended battery backup for continuous operation. They also have the ability to process signals from many high-speed peripheral devices such as the radars and are hardened against nuclear weapons effects.

The satellite communications terminals also have high-speed digital signal processing features. The terminals can automatically track overhead communications satellites and have high-mobility features including self-contained generators and antenna dishes which may be quickly assembled. The van-mounted tactical intelligence fusion facility can receive

TABLE A-4. Factors for assigning priorities to C2 increments

Goal: To set priorities for implementing C2 increments in a specified mission area

Factors:

Dispersion to support decentralized operations
- Decentralization to maintain C2 during fluid and lethal conflict
- Flexibility to support maneuver of forces
- Independence to operate in stand-along mode

Invulnerability against active and passive attack
- Indeterminancy to make information vague to adversaries
- Information Security to keep adversaries from exploiting friendly information
- Survivability againt loss or degradation of information

Mobility to support tempo of conflict
- Modularity to interconnect effectively C2 system parts
- Redundancy to ensure access to information
- Self-repairability to correct C2 failures
- Good technical design for supportability and interoperability
- Homogeneity among means to acquire and transfer information

Responsiveness to the needs of commander and staff
- Adaptability to contingencies and in foreseen needs
- Data transformation to manipulate raw data into information for decisionmaking
- Connectivity for prompt communications among users
- Decision support to aid commander and staff in formulating and testing courses of action
- Direction/monitoring to help commander and staff issue orders and monitor implementation
- Knowledge maintenance to maintain adequate knowledge base about mode of operations
- Relevancy to identify and exploit the most useful information

Timeliness to provide sufficient warning and execution time
- Early warning time to forewarn commander sufficiently
- Execution time to provide sufficient time for commander to make best decision
- Reliability in providing high-quality, complete information

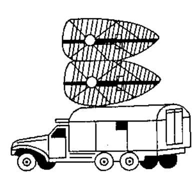
many signals and advisories from field units and process them in a high-speed computer. An advanced feature of the fusion facility is a new collection of expert system software which can interpret the unique signatures of many thousands of electronic emitters, quickly correlate the signatures to an electronic order of battle, and advise the commander about specific ground and air threats.

But we must remind ourselves that there are also logical and "political" rules about how the increments interrelate; for example, a new computer may not be useful if there are no radar data to feed it. Further, because product development cycles may not mesh with our deployment schedule, we may not have the correct type of appropriation funds available when we are ready to buy a certain C^2 element. While we could conjure up scores of alternate permutations among the increments—even accounting for the limiting "rules"—we will direct our analysis to the four classes of C^2 equipment, shown in figure A-3.

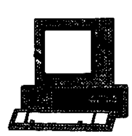
FIGURE A-3. C2 alternatives

Equipment options

5 Search and track radars

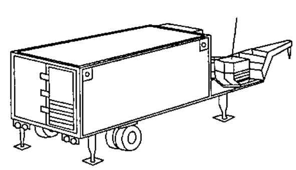


2 High-speed computers



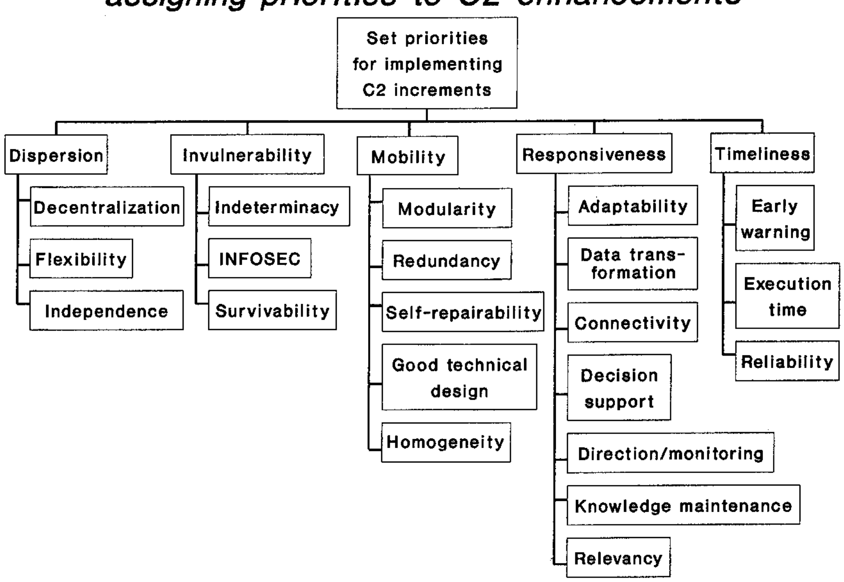
6 Satellite communications terminals

1 Intelligence fusion facility



We can now categorize the factors to begin to show their relationships. We organize the factors, subfactors, and alternatives into a hierarchial structure for analysis. We decide the factors are mission area-dependent and that the subfactors are mission area-independent. In other words, the subfactors or detailed C^2 system characteristics apply to all mission areas and the factors or broader criteria change from one mission area to another. Figure A-4 shows one way of organizing the elements; we will use this hierarchy for the rest of this example. In the process of assigning priorities to C^2 increments, we would normally evaluate a separate matrix for each mission area of interest. But here again, as in the first example, we choose to explain the process using a generic mission area.[11]

FIGURE A-4. Analytical structure for assigning priorities to C2 enhancements



Because we decided that the relative importance of the subfactors holds true for all mission areas, we will now evalu-

TABLE A-5. Factor priorities relative to Mission Area 223

	Factor priority	Subfactor priority	Weighted priority	Adjusted priority
Dispersion	0.038			
Decentralization		0.642	0.024	0.00349
Flexibility		0.256	0.010	0.00139
Independence		0.102	0.004	0.00055
Invulnerability	0.061			
Indeterminancy		0.089	0.005	0.00078
INFOSEC		0.172	0.010	0.00150
Survivability		0.740	0.045	0.00645
Mobility	0.076			
Modularity		0.175	0.013	0.00317
Redundancy		0.475	0.036	0.00860
Self-repairability		0.075	0.006	0.00136
Good tech design		0.203	0.015	0.00367
Homogeneity		0.071	0.005	0.00128
Responsiveness	0.480			
Adaptability		0.236	0.113	0.03776
Data transformation		0.131	0.063	0.02096
Connectivity		0.237	0.114	0.03792
Decision support		0.046	0.022	0.00736
Direction/monitoring		0.174	0.084	0.02784
Knowledge maintenance		0.032	0.015	0.00512
Relevancy		0.144	0.069	0.02304
Timeliness	0.345			
Early warning		0.648	0.224	0.03194
Execution time		0.230	0.079	0.01134
Reliability		0.122	0.042	0.00601
SUM:	1.000			0.24151

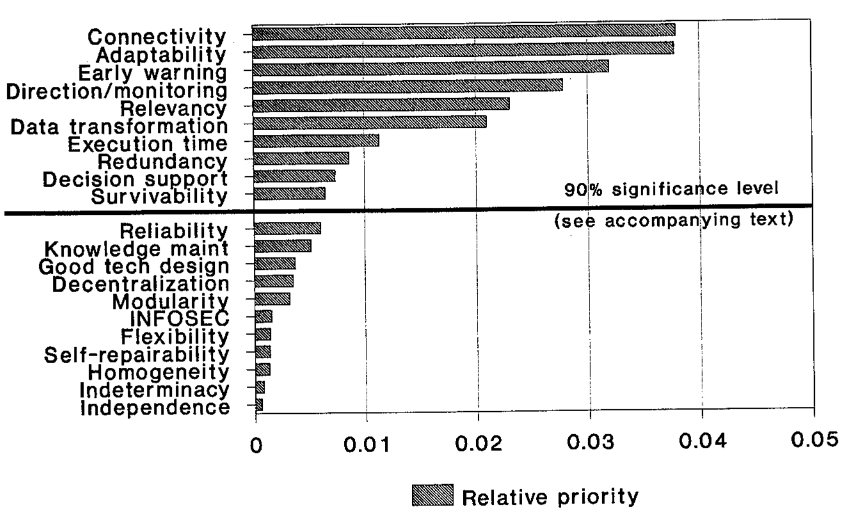
ate each set of subfactors in the context of their respective parent factors. Using the same comparison scale (table A-2), we complete five matrixes—one each for the factors of *dispersion*, *invulnerability*, *mobility*, *responsiveness*, and *timeliness*. In comparing each pair of subfactors, we answer such questions as: Which subfactor has more influence on the parent factor and by how much? For example, with respect to the parent factor *dispersion*, is *indeterminacy* more important than *survivability*? By completing questionnaires and arithmetically computing priorities, we decisionmakers might conclude the priorities within each parent factor are those depicted in the "subfactor priority" column of table A-5.[12]

In the realm of *timeliness* of how C^2 resources perform for the BLUE commander in coping with tempo and uncertainty of conflict, we judge *early warning* to be the most important characteristic (a priority of 0.648). Within the factor of *responsiveness* of the C^2 resources to the commander and his staff, maintaining a knowledge base is least important (0.032 priority). And in the area of *invulnerability*, *survivability* is the most important characteristic. In a specific mission area and with the judgmental values of other decisionmakers, these example priorities would of course be different.[13]

Next we explore the relative importance of the five factors for a mission area we are interested in, Close Air Support and Interdiction (Mission Area 223).[14] Putting our BLUE commander hat on, we decide which C^2 system characteristics are most important in the domain of Mission Area 223. Our results appear in the "factor priority" column of table A-5. Interpreting the results of these comparisons, *responsiveness* to the commander and staff is the most important factor, followed closely by *timeliness* for giving the BLUE commander sufficient warning and execution time. Based on these results, *dispersion*, *invulnerability*, and *mobility* are far less important than *responsiveness* and *timeliness*.

We then use the resulting average priorities for each of the five parent factors in combination with the priority values of the subfactors to determine the most significant subfactors bearing on the C^2 acquisition decision in our mission area. Multiplying the priority value for each subfactor by its respective parent factor's priority value gives us a weighted priority for each subfactor ("weighted priority" column in table A-5). But some parent factors have more children than others. To avoid diluting the weight of a subfactor by having too many siblings, we must structurally adjust each family of subfactors to balance the playing field. As the total number of siblings in our problem is 21, we multiply each weighted subfactor priority by an adjustment number equal to the number of siblings in its respective family divided by 21. The adjustment value for the *responsiveness* subfactors is 7/21 because there are seven siblings, while the adjustment factor for the *timeliness* subfactors is 3/21. These adjusted subfactor priorities appear in the "adjusted priority" column of table A-5.

FIGURE A-5. Subfactor priorities (Mission Area 223)



To get an idea of the relative importance among our 21 subfactors, we reorganize the list in descending order of "adjusted priority" (figure A-5). This step now identifies the relative importance of our subfactors, from *connectivity* as our most important subfactor to *independence* as our least. Seeing that *connectivity* is over 68 times as important as *independence*, we recognize that the less important factors probably won't have much influence on our final decision. To reduce the complexity of the problem, we can weed out the subfactors which will have little bearing on our decisionmaking.

From the list of weighted and adjusted subfactor priorities, we want to select the most significant criteria for C^2 systems in Mission Area 223 and disregard the rest. For our example, we arbitrarily decide the most significant are those which add up to no more than 90 percent of the sum of the adjusted subfactor values. After totaling the list (0.24151), we multiply the total by 0.9 to establish the significance level (0.21736). Cumulatively adding the list of subfactor values, we stop at *survivability*. The resulting shortened list includes only the 10 most significant criteria for Close Air Support and Interdiction C^2 systems.[15]

If we participants in the process think the results are not consistent with national security objectives or the domain of the mission area, we can choose different factors, restructure the hierarchy, answer the matrix questions again, or reiterate the process using a combination of these techniques.

Having walked though that portion of the decisionmaking process, we can now figure out how the four different classes of equipment in figure A-3 stack up to these most desirable C^2 system criteria. For problems with many important criteria and a large number of alternative solutions, using matrixes to evaluate all alternatives would be very time consuming. To avoid this inconvenience, we will use ratio-scale ratings for evaluating each of the alternatives.[16] Before we record our preferences for each C^2 resource type, we should "normalize" our list of the 10 most significant subfactors. To do this, we divide each of the 10 weights by the total of all weights in the shortened list. Our results appear in the "normalized value" column in table A-6.

We next reflect on each type of C^2 equipment, in the context of how it can help the BLUE commander satisfy each of these 10 most important C^2 system characteristics. To take one example, we think that a satellite communications terminal

TABLE A-6. Preference for categories of C2 elements

Significant subfactor		Normalized value	SCT	HS C	S&TR	Intel Fus Fac
Connectivity	0.0379	0.1779	2	-1	-2	-1
Adaptability	0.0378	0.1771	1	2	1	2
Early warning	0.0319	0.1498	1	0	2	1
Direction/monitoring	0.0278	0.1306	2	1	-2	-1
Relevancy	0.0230	0.1081	-1	2	0	2
Data transformation	0.0210	0.0983	-1	2	1	2
Execution time	0.0113	0.0532	0	1	-1	1
Redundancy	0.0086	0.0403	1	-1	1	-1
Decision support	0.0074	0.0345	-2	2	-2	2
Survivability	0.0064	0.0302	1	-1	1	1
SUM:	0.2132	1.0000				
COMPOSITE WEIGHT:			0.7389	0.7714	-0.0935	0.7205

Legend: SCT = satellite communications terminal
HSC = high-speed computer
S&TR = search and track radar
Intel Fus Fac = intelligence fusion facility

Rating Scale

2	Outstanding solution for satisfying criterion
1	Above average solution for satisfying criterion
0	Average solution for criterion
-1	Below average satisfaction of criterion
-2	Unsatisfactory solution for satisfying criterion

is an outstanding solution for satisfying the connectivity criterion. Accordingly, we rate it with a "2," using the rating scale in table A-6.[17] The last row in the table represents the composite weights from this rating process—the final "score" for each of the alternatives. For each alternative, we calculate the composite weight by multiplying the priority of each criterion times the rating and then summing the products. From the final scores, we conclude that the high-speed computer is the best type of C^2 equipment for meeting the BLUE commander's needs and the search and track radar is the least satisfactory. (But remember that there may be other "rules" that upset this priority order.)

§ § §

Notes

1. Thomas L. Saaty, *Decision Making for Leaders* (Pittsburgh, PA: RWS Publications, 1988), 23-25.

2. Alain C. Enthoven and K. Wayne Smith, *How Much is Enough?* (New York: Harper and Row, 1971; reprint ed., Millwood, NY: Kraus Reprint, 1980), 62.

3. This first example is described in detail to show how the analytical hierarchy process works.

4. A suggested way to define the risk levels, based on force comparisons, appears in appendix B.

5. Classic brainstorming at this point in the process is very desirable; even though some of the "brainstormed" factors may be later found to be quantitatively insignificant within the realm of the force structure decision, it is important early on to consider all factors which stakeholders propose. In this way, stakeholder interests receive equitable consideration.

6. See J.C. Emery, "Cost/Benefit Analysis of Information Systems," reprint from Society for Management of Information Systems, 1971, in *Writings of the Revolution: Selected Readings on Software Engineering* ed. Edward Yourdon (New York: Yourdon Press, 1982), 19-

22, for a provocative notional theory on the relation between value and cost of information.

7. When organizing factors into a hierarchial structure, seven factors under one parent is a good target number; larger numbers of factors under any one parent makes the resulting number of "one-on-one" comparisons too unwieldy. See Saaty's work for the mathematical reasoning behind these constraints.

8. The required number of questions for a 5 by 5 element matrix is (5)(5-1)/2, or 10 questions.

9. The geometric mean is the *n*th root of the product of all *n* inputs for one comparison.

10. Multiply each column of priority judgments in Figure A-5 by the summary row priority. In other words, multiply each of the numbers in the first column by the first row priority, the second column by the second row priority, and so forth. Sum the five new products in each row. Divide each new row sum by the original summary priority for each row. Average the resulting five dividends. Compute the consistency index (CI) by subtracting the number of matrix elements (5) from the average of the five dividends and divide the remainder by 2. The resulting CI is 0.033. Select a random CI for the number of elements in the matrix (5) from the following table:

Elements	1	2	3	4	5	6	7	8	9
Random CI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Divide our CI by 1.12 to get a consistency ratio of 0.029 or 2.9 percent. See also Thomas L. Saaty, *Decision Making for Leaders* (Pittsburgh, PA: RWS Publications, 1988), 82-85.

11. Chapter 7 looks at several specific warfighting mission areas.

12. The sample data in table A-5 are based on my opinions and computations.

13. All factors *(dispersion, invulnerability, mobility, responsiveness, and timeliness)* have the same priority with respect to the goal at this time.

14. Chapter 7 covers mission areas in greater detail.

15. Participants could use any percentage that reasonably reduces the size of the list. In another mission area, the list of most important criteria will very likely be different.

16. The method which follows in this explanation may appear like "weights and scores" techniques often used in decisionmaking, but it uses ratio scale numbers to avoid the bias from assigning ordinal numbers.

17. These assigned ratings are my own, to illustrate the process.

Appendix B. Economic Analysis of Command and Control System Affordability

This appendix explains how decisionmakers can apply economic analysis to military force structure affordability decisions, especially those decisions which involve significant command and control (C^2) resources. Hitch's and McKean's classic *Economics of Defense in the Nuclear Age*, which did not attempt to grapple with the subjective, intangible area of C^2, is the seed for this approach.[1] From time to time, defense analysts have adapted elements of basic economic theory as Hitch and McKean first did. In the mid-1980s, researchers at the Air Force Institute of Technology and Headquarters US Air Force proposed to allocate resources by using response surface methodology to graphically portray force structure options.[2] But such approaches have compared relatively consistent force elements (weapons types) against other force elements and not force elements against C^2 portions of the force structure.

At the outset, the reader should understand that the method described here does not pretend to be a precise, absolute solution to this difficult problem of C^2 economics. Rather, the method is merely an economic suboptimization, comparing only a few elements out of the enormous breadth of defense functions. As Alain Enthoven put it, a high-level DOD decision may regard the mix of strategic forces and tactical forces, in a view of general war as opposed to limited (theater) war. A low-level decision might address the best mix of bombers, missiles, and submarines within the strategic forces. "At the highest level, the decisionmakers seek a grand optimum. At lower levels, they sub-optimize."[3] Analyzing the larger force structure problem, one could build a complex, "nested" analysis which concurrently treats all C^2 levels in DOD's warfighting and peacekeeping capabilities.[4] Achievable but difficult, this "nested" approach would probably be more contentious in view of the number of stakeholders that would have to participate in such a decision. Although the analysis in this appendix sub-optimizes force structure decisionmaking, it does account for the interest of all principal stakeholders in a specified mission area.

The analysis described here is based on consumer behavior and utility theory. Because the concepts of consumer behavior rest on some arguable assumptions, it is important to discuss the assumptions here as they relate to force structure decisions.[5] These assumptions probably fit the defense decisionmaker better than they fit the classic consumer in economic theory.

- First, utility theory assumes the consumer knows completely all factors bearing on his consumption decisions. The consumer knows the full range of goods available on the market and knows the technical capacity of each good to satisfy a want. Defense decisionmakers, because of their experience and education as leaders and managers, have a thorough perspective of the military environment and what defense industry can offer—especially within their mission area or the scope of their management responsibility. Whether the defense decisionmaker, as consumer, can judge the technical good inherent in each product is a more difficult question. Appendix A describes a method for establishing a decisionmaker's preference for information under differing risk levels or environments. By showing preference for varying levels of information, the decisionmaker is assigning a different rate of technical satisfaction[6] to one level of C^2 support versus another and to C^2 system components versus force elements.

- Second, theory assumes the exact price of each good is known and the consumer knows that these prices will not be changed by his actions on the market. For purposes of defense acquisition planning, this assumption holds true. But because the DOD is often a single buyer of a category of goods, the purchase of a certain defense item sometimes severely constrains or radically accelerates the item's future price.

- Third, the consumer knows what the available income will be during the planning period (although anyone familiar with US defense budgeting will find this assumption amusing.) The defense decisionmaker also has a relatively accurate estimate of the funding for the "short-run."

- Fourth, the theory assumes the consumer tries to maximize satisfaction from consumption, given the limited income. As stewards of national defense, senior government decisionmakers continually strive for this goal.

Using Microeconomics to Evaluate Command and Control Affordability

The economic analysis in this appendix consists of eight steps:

- Identify the opportunity for a budget increase (or decrease) in the force structure for specified mission area(s).

- Determine the risk levels or scenarios for the specified mission area(s).

- Determine the limits in the range of force mix possibilities.

- Compute the maximum rate of tradeoff between C^2 resources and force elements.

- Plot the commander's willingness to trade C^2 for force elements in maximizing force effectiveness.

- Compute the marginal rate of substitution between C^2 resources and force elements.

- Determine the commander's point of equilibrium in optimizing force effectiveness.

- Solve the force mix equation.

• *Identify the opportunity for a budget increase (or decrease) in the force structure for specified mission area(s).* We start this analysis by stating a typical economic problem: maximize a consumer's total utility (the objective function), subject to a budget constraint.

Next we state the problem in terms of a force structure analysis.[7] Senior decisionmakers have determined, for political and alliance reasons, that the BLUE theater air forces in an overseas subcontinental theater need to be increased over the next several years to fulfill national security strategy. DOD leadership has identified $180 million to do the job. Should the decisionmakers buy $180 million worth of fighter aircraft for the BLUE forces or a lesser number of fighters and some additional C^2 assets to support the new forces (and the rest of the force structure)? What's the best mix of resources to buy for the force structure, a mix which will maximize force effectiveness within the $180 million budget constraint?

To understand how the overall force structure might be affected and to understand the domain of the decision problem, we precisely define the mission area. The applicable domain is Mission Area 223, Close Air Support and Interdiction. As the DOD defines the mission area, it includes those capabilities required to provide Close Air Support and to destroy transient and fixed targets including reinforcing ground forces before they enter the immediate battle area, logistic war materiel, and command installations. The mission area also includes strike capabilities of ground- and ship-based aircraft and long-range missiles and those directly-associated capabilities for target acquisition.[8]

• *Determine the risk levels or scenarios for the specified mission area(s).* Within this mission area, how do field commanders and senior decisionmakers perceive the threat? More specifically, what is the perceived need for mission area warfighting information, for each risk level?

We start this step by defining five risk levels (or threat scenarios) the BLUE theater air force commander may encounter. (The number of levels is not critical, but should be three or greater to set the stage for a higher resolution analysis.) A long paragraph describing each level would be ideal for characterizing each risk level or scenario. For purposes of this analysis, however, we will describe risk levels in terms of relative force levels. Table B-1 depicts five risk levels and sample force ratios pertaining to the mission area in this force structure problem.

The decisionmakers may wish to further define a risk level in terms of absolute force levels. The lower part of table B-1 shows a rough calculation of selected differences between the North Korean forces and the combined South Korean and US forces on the Korean Peninsula.[9] These force-on-force comparisons, not tempered by qualitative aspects, seem to put the South Koreans (as defenders) at a maximum-to-moderate risk level. If the decisionmakers also want to assign "virtual" force level values based on qualitative considerations, this would be the point to do it. However, it is probably easier to record perceptions of qualitative differences in the risk level narrative.[10]

Using the analytical hierarchy process described in appendix A, we decisionmakers then rate a relative preference for warfighting C[2] information in each scenario (that is, each risk level) in the domain of the specified mission area. Our relative preferences should reflect what the BLUE commander thinks he needs to prevail in a maximum-to-moderate risk conflict. In considering our preference for C[2] information, we reflect on our perception of the threat and our own existing capabilities (force elements and C[2] resources). In other words, what information does the commander need to construct a "shared image" and cope with uncertainty and tempo in the risk environment? In line with this example, the BLUE theater air force commander's preferences could be like the data shown in table B-1.[11] The commander's relative preference for informa-

TABLE B-1. Sample scenarios
(BLUE in defensive posture)

BLUE's perceived risk level	Force ratio (attacker: defender)troops	Systems density (defender) wpn system wpns/km	Systems density (defender) ADA wpns/km	CAS density (attacker): sorties/km/day
1. Maxiumum risk	4.6:1	30	2.9	14.0
2. Max-to-mod	3.1:1	51	3.9	9.8
3. Moderate risk	1.6:1	71	5.0	5.5
4. Mod-to-min	1.1:1	111	8.5	3.5
5. Minimum risk	.67:1	150	12.0	1.6
	active division forces	weapons	wpns/km	jet combat aircraft
Korean peninsula	1.7:1	39	0.5	834*

Note: ADA is air defense artillery; CAS is close air support; * is an absolute total.

Ratios adapted from McQuie 1988

tion (perceived C^2 information value) in each risk environment directly corresponds to his need for C^2 resources to provide that information. The relative preferences for information in a maximum-to-moderate risk level, our example, is 0.256.[12]

TABLE B-2 Schedule of costs

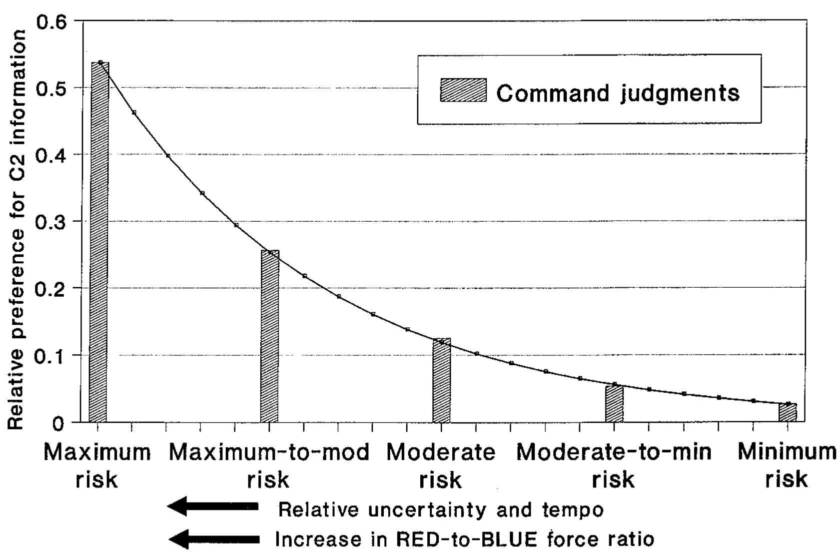
(Force elements and C2 increments)

$180 M PROPOSED INCREASE TO BLUE'S BUDGET

Quantity	Item	Unit cost	Total
	Desired improvement in forces		
10	Improved fighter aircraft	$18M	$180M
			$180M
	Desired improvement in C2 system		
6	New search and track radars	$ 1.8M	$ 10.8M
3	Advanced high speed computers	3.6	10.8
8	Satellite comm terminals	1.8	14.4
1	Intelligence fusion facility	18	18
			$ 54M

The curve in figure B-1 is instructive in a number of ways. First, it illustrates the relative preference for information in a specified environment. Under a maximum risk level or threat scenario, the commander places great value on information to help him in conflict. Anxious about being overwhelmed by the enemy's force advantage, the commander will want more C^2 information to assist in effectively managing smaller (numerically or qualitatively) forces. The commander acknowledges the potential for heightened uncertainty and tempo in conflict and desires more information so he can consolidate his image of the operational concept and be prepared to cope with the potential for increased uncertainty and tempo.

FIGURE B-1. Preference for information (relative to BLUE's perception of risk)



Second, as the commander's force advantage (qualitative or quantitative) begins to increase and the risk transitions to lesser levels, the commander perceives that the information he/she might get from C^2 resources is no longer as important in coping with the tempo and uncertainty of the conflict.

Third, as the risk further transitions to the lowest levels, the rate of change in how he perceives the value of information becomes smaller and smaller. As things get hotter, on the other hand, the BLUE commander is increasingly concerned about how to maximize force effectiveness.

And fourth, the relative preferences assigned to all risk levels sum to 1. Because the analytical hierarchy process was used, the BLUE commander and decisionmakers did not have to decide on an absolute "preference" value for each risk level.

This aspect is useful since we are embarking on an analysis of marginal economics; in this budget problem, we are dealing with changes to force and C^2 resource levels rather than measuring absolute force effectiveness.

- *Determine the limits in the range of force mix possibilities.* To further define this resource allocation problem, we now look at the range of what we can buy within the budget constraint. Recall that the budget for the Close Air Support and Interdiction mission area is to increase by $180 million. Using a limited definition of what it takes to increase force effectiveness, two things can be purchased with this proposed increase: additional force elements and additional, complementary C^2 assets. (A subsequent step in this analysis will explain this limited definition.) Whatever we can afford to purchase in modifying the force structure is some productive mix of additional C^2 assets and additional force elements.

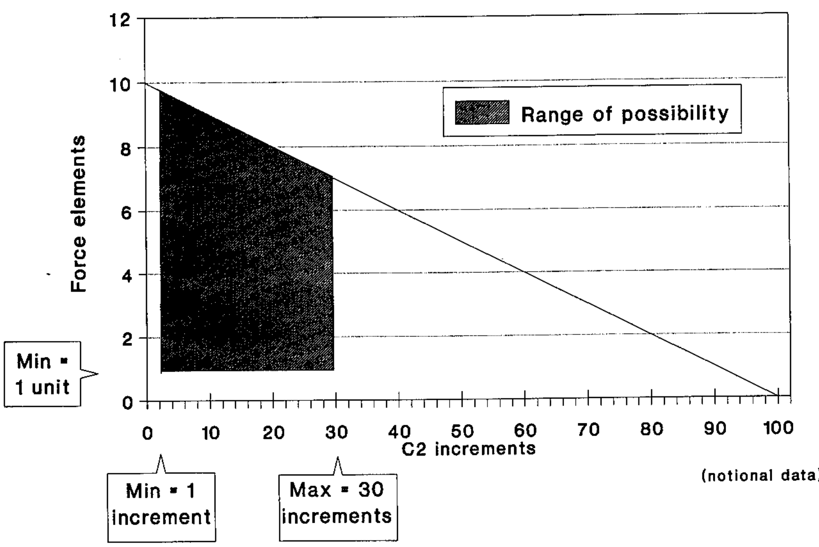
Table B-2 represents a possible cost schedule for what may be purchased with the $180 million: improved fighter aircraft, new search and track radars, advanced high-speed computers, satellite communications terminals, and an intelligence fusion facility. To be objective, an analyst must use comprehensive life cycle costing (in constant dollars) for the equipment to be purchased. In addition to the development and procurement costs, comprehensive costing includes the people to operate and maintain the weapons systems, the logistics support structure, military construction, operational testing, training, doctrine, and so forth. For this analysis, we will keep the costing simpler. First, we look at the approximate "flyaway" cost for the fighter. At $18 million each copy, we know that there are not enough funds in the proposed budget increase to procure even half a squadron of fighters.[13] We sense that we want some of the C^2 improvements, but if we buy all $54 million of them, we consume over one-fourth of the proposed budget increase and cut deeply into our potential to buy additional force elements (fighters). We now reconsider the schedule of possible enhancements to C^2. The units costs for C^2 are all multiples of a common denominator, $1.8 million. While this is an artificial breakdown, it is useful for the quantitative decisions which follow. Furthermore, nothing would preclude computing a common denominator for the force elements as well, had they been a mix of different fighter aircraft, ships, missiles, or other weapons systems.[14]

The force structure challenge boils down to this: Within the budget constraint of $180 million, we have a choice of buying $180 million worth of improved fighter aircraft, spending $54 million to enhance the C^2 system and $126 million for seven fighters, or some other combination between the two extremes. What's the smartest mix of force elements and C^2 assets to fulfill a meaningful force effectiveness level?

Next, we plot the range of force mix possibilities for a $180 million budget. At an "average unit cost" of $1.8 million for each C^2 increment, we can buy anywhere from zero to 100 increments. At a unit cost of $18 million, we can buy anywhere from zero to 10 aircraft ($180 million divided by $18 million per aircraft). Plotting the range of C^2 increments on the *x*-axis and the range of fighter aircraft on the *y*-axis and connecting the extreme points, we can visualize the budget constraint (figure B-2a). Each point along the $180 million budget line represents some possible combination of C^2 increments and fighter aircraft which we can purchase, fully using the budget increase. For example, we could purchase 8 fighters and 20 C^2 increments or we could buy 9 fighters and 10 C^2 increments. The triangular area underneath the line defines all possible nonnegative combinations.

But there are some other constraints here. The total bill for all planned C^2 enhancements is $54 million. Thus the range of realistic possibilities is one to 30 increments of C^2 ($54 million divided by $1.8 million per unit). Moreover, we know that (unless we are upgrading existing C^2 assets) it is unrealistic to invest in C^2 enhancements without investing in force elements—because the force elements are the reason why C^2 resources exist. Thus it seems the realistic possibilities for how to spend the $180 million on force enhancements are in a range of one to 10 aircraft. With these two constraints, called the "range of possibility" in figure B-2a, we limit our range of realism to a smaller portion of the triangular area under the $180 million budget line. (We could also assume a purchase of zero increments of C^2, but then there wouldn't be a force structure issue of how much C^2 to buy in balance with the force elements.)

FIGURE B-2a. BLUE's spending constraint for a $180M budget



Representing the possibilities by formulas,

$$TC = \$180M$$

$$\text{(B1)} \qquad TC = \$18M\ (FE) + \$1.8M\ (C2)$$

$$\$180M = \$18M\ (FE) + \$1.8M\ (C2)$$

where *TC* is the total cost of the proposed increase

FE is the number of force elements (fighters) in the proposed force structure increase

C2 is the number (increments) of C^2 enhancements

and where $FE \geq 1$ and

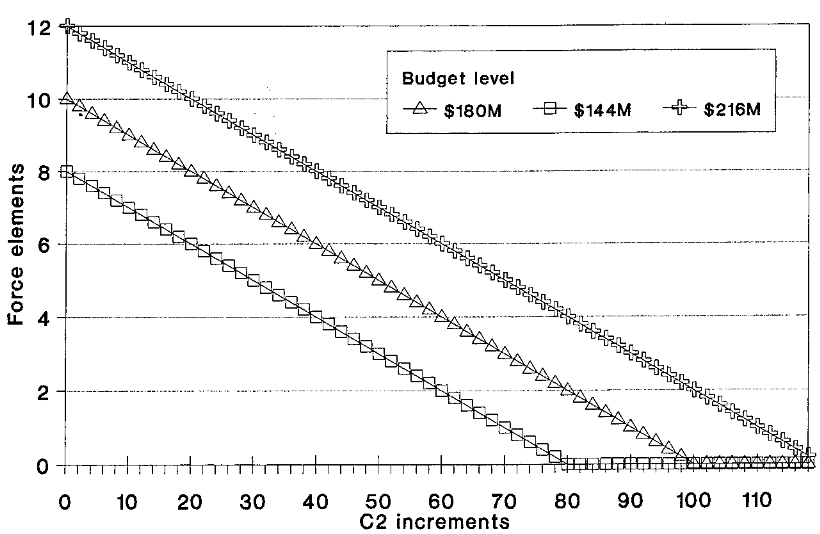
$30 \geq C2 \geq 1$

Solving for the possible number of force elements (fighter aircraft) to be purchased for the force structure, the linear equation for the $180 million budget line simplifies to:

$$\text{(B2)} \qquad FE = 10 - (0.1)(C2)$$

As the overall budget for improving these mission areas increases beyond $180 million, the budget line pushes outward. As it decreases, it pulls inward. These different funding levels appear in figure B-2b.

FIGURE B-2b. Constraints for different budget levels



(notional data)

• *Compute the maximum rate of tradeoff between C^2 resources and force elements.* Put another way, the maximum rate of tradeoff is the rate at which the independent costs of C^2 and force elements will permit substitution. This rate is simply the derivative or slope of the linear equation (B2) for the $180 million budget line. In economic terms, the slope is the negative of the price ratio between the two commodities (*C2* and *FE*).

(B3) $$\frac{d(FE)}{d(C2)} = -0.1$$

is the derivative of the linear equation.

(B4) $$-\frac{p(C2)}{p(FE)} = -\frac{\$1.8M}{\$18M} = -0.1$$

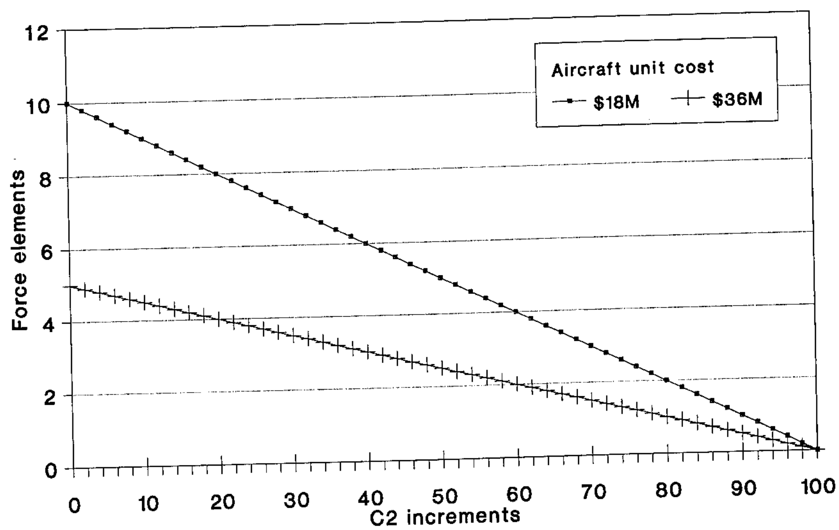
is the negative price ratio (although in this analysis we are using cost rather than price, price being cost plus profit).

As the price or cost of one commodity changes, the slope of the line changes and the total number of the commodity (*C2* or *FE*) which can be purchased changes. An example is shown in figure B-2c.

This slope or ratio represents the limit to which we decisionmakers can trade off C^2 increments for fighter aircraft. At the ratio of -0.1, the maximum cost tradeoff is one fighter aircraft for 10 increments of C^2. We could trade one fighter for 12 units of C^2 enhancements, but this point would fall below the $180 million constraint line—a non-optimal use of the proposed budget increase. In the other direction, we could give up 20 increments of C^2 to get two fighter aircraft. But we know that a prudent decisionmaker will not make such mechanical tradeoffs within the complexities of the military force structure. In the next section, we will gain some insight into what extent we (as decisionmakers) are willing to make the tradeoff between C^2 and fighter aircraft.

- *Plot the commander's willingness to trade C^2 for force elements in maximizing force effectiveness.* While the previous step computes a strict cost tradeoff, it does not reflect what the senior decisionmaker and BLUE field commander are actually willing to trade off in force elements for improvements in C^2. At either extreme of the straight budget line in Figure B-2a, unrealistic alternatives appear which have little bearing on the worth the BLUE commander places on an overabundance of C^2 versus a paucity of fighters (or the reverse). Such extreme alternatives contribute little to force effectiveness.

FIGURE B-2c. Constraints for different values of unit costs



(notional data)

Force effectiveness is clearly a function of many factors or variables. But if we can limit how we evaluate force effectiveness to a tradeoff between two factors, we could say—for example—that it is a tradeoff between the scope of the force and the "quantity of C^2." The scope of the force is the same as the traditional count of force structure elements. The "quantity of C^2" is the collection of C^2 resources, counted in "increments," which contributes to the commander's ability to lead and manage forces. Thus the power of information (the contribution of C^2) and the force structure (fighter aircraft in our example), coupled under differing risk levels, are two elements comprising force effectiveness. This coupling suggests the following function:[15]

$$\text{(B5)} \quad \text{force effectiveness} = f(\text{size of force, quantity of } C^2)$$

We could add more factors or variables to the right-hand side of this function, representing force effectiveness with higher fidelity. But we may never be able to account for all relevant factors. And since we will incorporate the most abstract of the two factors (the value of C^2) in relative terms, function (B5) can be useful in showing the interrelationship between forces and C^2 resources. One might question here whether force elements and C^2 assets are interdependent variables in function (B5). It is possible that a change in either factor will influence the "worth" of the other factor. For instance, more force elements might reduce the value of C^2 resources and vice versa. So, while some sense of this interplay appears in the relative value of information under different risk levels, we will assume that both factors are independent variables in function (B5).[16]

Borrowing a concept from microeconomic theory, we can say "force effectiveness" is the level of the consumer's utility determined by the commingling of the composite terms. One specific type of mathematical function used in utility theory (and more often in production theory) is the Cobb-Douglas function. A Cobb-Douglas function assumes a certain link among variables and is stated as the product of the composite variables. This assumption is logical in terms of *C2* and *FE*, since force effectiveness cannot be achieved unless both C^2 and forces are both present to some degree in the scenario.[17] A force cannot be effective without C^2, and C^2 alone—without forces—is nearly worthless. Further, *FE* and *C2* each contribute to force effectiveness at different rates depending on the scenario. Thus, we postulate that our objective function for force effectiveness fits the form of a Cobb-Douglas function:[18]

$$\text{(B6)} \qquad E = (a)\,(C2)^b\,(FE)^c$$

where *E* is the level of force effectiveness
a is a non-zero constant

C2	is the "quantity of C^2" resources
FE	is the number of force elements
b	is a coefficient relating to the influence of *C2* on *E*
c	is a coefficient relating to the influence of *FE* on *E*
$b + c = 1$	since we assume a constant return-to-scale for the function

A study of equation (B6) highlights several points. First, for purposes of this analysis, the final magnitude of force effectiveness (*E*) is not important, so long as the value *E* increases with increasing additions of either C^2 or force elements. Accordingly, equation (B6) doesn't claim to measure absolute force effectiveness.

Second, *C2* and *FE* each have to co-exist in some quantity to achieve any level of force effectiveness. If there are no forces, the *FE* term in the function is zero and the quantity of C^2 alone cannot contribute to force effectiveness. Similarly, force effectiveness is "zero" without some level of *C2*. If both the variable terms are greater than zero, an increase in either term will increase force effectiveness *E*.

Third, the function represents the degree to which the "commodity" factors—*C2* and *FE*—may be substituted for one another to achieve a continuous level of "utility" or force effectiveness.

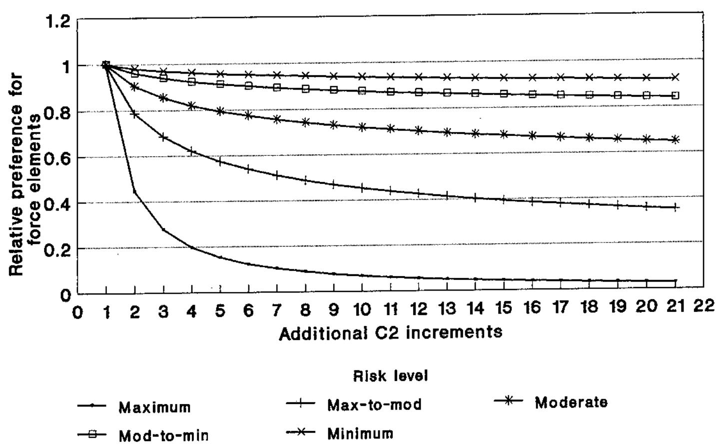
Fourth, the two factors, *FE* and *C2*, will rarely have equal influence on force effectiveness. Under some circumstances, force elements are more important to force effectiveness than C^2 resources. Under other circumstances, the reverse may be true. For these reasons, we have introduced variable exponents for each of the two terms to reflect the degree to which they respectively influence force effectiveness. The magnitude of exponents *b* and *c* indicate how the commander thinks the factors should bear on force effectiveness, in a specified risk environment.

And fifth, we will assume that the exponents *b* and *c* in the Cobb-Douglas function sum to unity which, in economic terms, indicates a constant return to scale. (This means that if the quantity of *C2* and *FE* each increase by 25 percent, the value *E* will increase by 25 percent.) Since we are presuming that sustaining a given level of force effectiveness *E* is a tradeoff solely between *C2* and *FE*, the constant return-to-scale assumption is reasonable.

For the value of the coefficient *b*, we can use the BLUE commander's preference for information in Mission Area 223, for each of the five risk levels discussed in the second step. Those relative preferences relate how much the commander perceives C^2 information will help him in achieving force effectiveness at a particular risk level. Knowing the perceived value of information *b*, we can then infer the "stated" preference for forces *c* since $c = 1 - b$. We could also use a decision support method like the analytical hierarchy process to directly compare the relative preference for *FE* or *C2* in each risk environment, but this approach would put the decisionmaker or commander back into the same dilemma we have been discussing throughout this book: are forces more important than C^2 or vice versa? Similarly, we could also use a decision support technique to independently derive the coefficient *c*, reflecting the commander's preference for forces. Then the two coefficients could be normalized with respect to one (1) and used in equation (B6).

The preferences for C^2 (corresponding to the magnitude of the bars in figure B-1) appear again in the lower half of figure B-3, along with the inferred preferences for forces (*c*). If we incorporate these exponents into our force effectiveness equation (B6) and hold both *E* and *a* equal to 1, we can plot curves showing the relative preference for *FE* as a function of C^2 resources at each risk level. Figure B-3 displays the results. Note the curve for the maximum information risk level has a sharp knee. As the numbers of C^2 resources increase for the BLUE commander from a value of 1 to 2 under maximum risk, the commander is willing to "give up" over half his forces for more C^2 resources.[19] He/she perceives the C^2 improvement will give an "extra edge" in coping with the tempo and uncertainty that an overwhelming adversary might create. As the number of C^2 resources continues to increase, the BLUE commander is less and less willing to discount the value of his forces. At the other extreme of risk levels (minimum risk), the BLUE commander is least likely to give up forces for any increase in the amount of C^2 resources. Having the higher force advantage,[20] the BLUE commander doesn't see very much value-added in more C^2 and therefore prefers additional forces over more C^2.

FIGURE B-3. BLUE's relative preferences as a function of scenario risk level



BLUE's relative preference coefficients

Risk level	Preference for C2 coefficient (b)	Preference for FE coefficient (c)
1. Maximum risk	0.538	0.462
2. Maximum-to-moderate risk	0.256	0.744
3. Moderate risk	0.125	0.875
4. Moderate-to-minimum risk	0.054	0.946
5. Minimum risk	0.027	0.973

We now return to the force effectiveness equation (B6). Substituting the preference values for the coefficients *b* and *c* at each risk level or scenario, relative force effectiveness is:

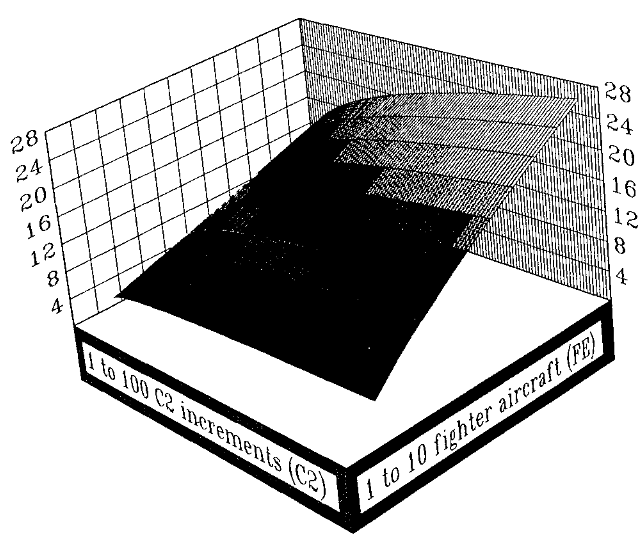
$$
\text{(B7)}\quad
\begin{aligned}
E_{\text{Maximum risk}} &= a\ C2^{0.538}\ FE^{0.462}\\
E_{\text{Maximum-moderate risk}} &= a\ C2^{0.256}\ FE^{0.744}\\
E_{\text{Moderate risk}} &= a\ C2^{0.125}\ FE^{0.875}\\
E_{\text{Moderate-minimum risk}} &= a\ C2^{0.054}\ FE^{0.946}\\
E_{\text{Minimum risk}} &= a\ C2^{0.027}\ FE^{0.973}
\end{aligned}
$$

It is useful to show the (B7) family of equations in three dimensions, where *C2* and *FE* form the *x-y* plane and *E* is the vertical or *z*-axis. Plotting these three variables creates a three-dimensional curve called a utility surface. The utility (force effectiveness) surface for our maximum-to-moderate risk scenario is shown in figure B-4 and represents the range of all possible values of *C2* and *FE* for the objective function:

$$\text{(B8)} \qquad E_{\text{Maximum-moderate risk}} = 1.5\ C2^{0.256}\ FE^{0.744}$$

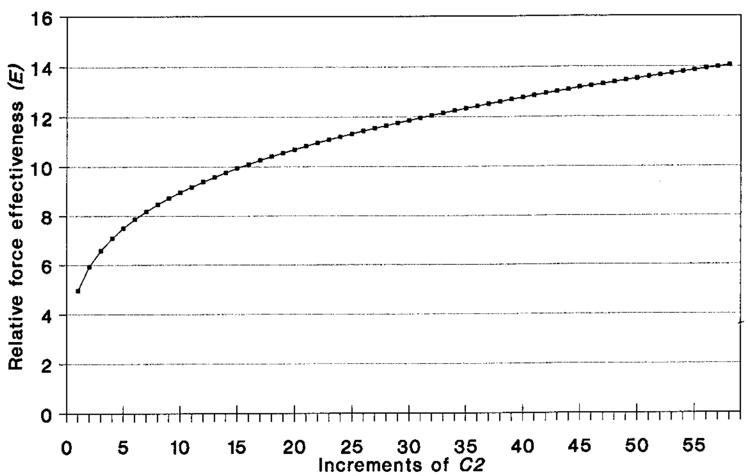
where a *is set to 1.5 for scaling the graphic representation of the function. The factor* a *has no bearing on the outcome here.*

FIGURE B-4. Relative force effectiveness as a function of C2 and FE



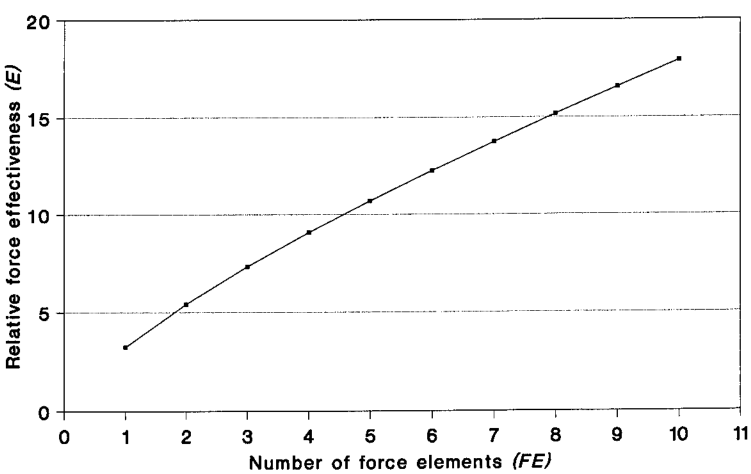
(a=1.5, b=0.256, c=0.744)

FIGURE B-5a.
Diminishing returns for C2



(*FE*=5, a=1.5, b=0.256, c=0.744)

FIGURE B-5b.
Diminishing returns for FE



(*C2*=20, a=1.5, b=0.256, c=0.744)

If we look at any function of force effectiveness *E*, where *E* is either a function of *C2* holding *FE* constant or a function of *FE* holding *C2* constant, we see another characteristic of a "return-to-scale" function—diminishing returns. Figures B-5a and 5b shows the characteristic diminishing marginal returns for each variable term of the objective function where a = 1.5.[21]

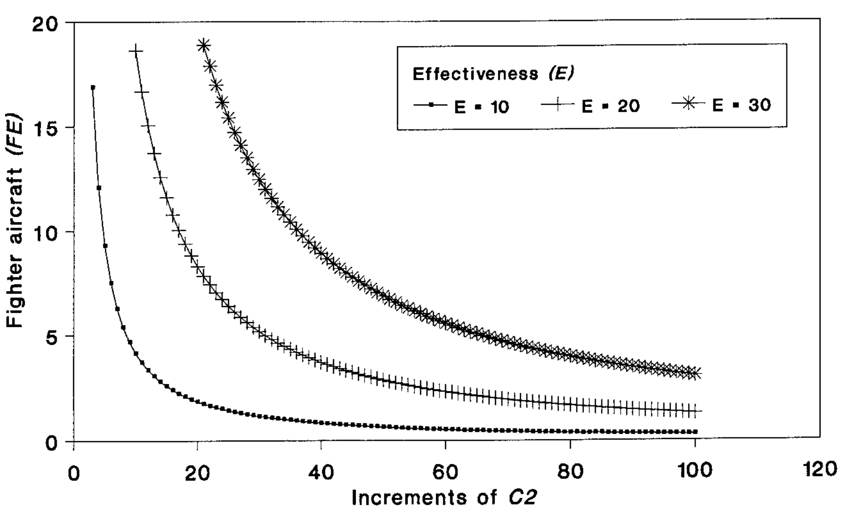
What does this mean in a force structure sense? As the amount of C^2 resources at a given force level increases beyond a certain point—from the commander's perspective—adding another increment of *C2* to sustain a definite level of *E* tends to contribute decreasing value to *E*. The commander needs more and more increments of C^2 resources to hold force effectiveness *E* at that level. Spending those additional dollars may not be a prudent use of resources. Similarly, as forces (*FE*) are added relative to some fixed level of *C2*, the commander also perceives diminishing marginal returns.

Now that we have looked at how each variable independently affects relative force effectiveness, we will study how *C2* and *FE* in our objective function interrelate. Using the utility surface depicted in figure B-4, we hold the relative force effectiveness on the *z*-axis constant at certain values (*E* = 10, 20, and 30). Then, slicing the utility surface parallel to the *x-y* plane for *E* values of 10, 20, and 30, we define three *x-y* curves which show the relationship between *C2* and *FE* for each of those *E* values. (There are, of course, an infinite number of quasi-concave curves of the objective function, representing each value of *E*). Each selected curve represents all combinations of *C2* and *FE* values which, from the BLUE commander's perspective, yield the same force effectiveness *E* at a maximum-to-moderate risk level.

In economic terms, these curves are called indifference curves. They are so called because they reflect the extent to which the "commander" is willing to substitute C^2 resources for fighter aircraft (and fighters for C^2) to sustain a desired level of force effectiveness *E*. Within each risk level or scenario, the corresponding family of force effectiveness indifference curves go up and to the right (as long as *E* increases) and do not intersect each other. Three such curves for the maximum-to-moderate risk level appear in figure B-6.[22] The extent to which the BLUE commander prefers fighter aircraft or C^2 resources in any scenario (figure B-3) is the basis for these curves.

Suppose that the BLUE commander desires to achieve or maintain a relative force effectiveness of 10. According to figure B-8, if many fighters are added to the force structure, he/she feels only a few increments of C^2 resources need to be added to complement them. Conversely, if the commander prefers a large C^2 suite, he/she perceives the force structure can get by with fewer additional fighters to help reach a force effectiveness level of 10. Higher or lower levels of *E* require respectively higher amounts of *C2* and *FE* or lower amounts of *C2* and *FE*. Each "higher" curve is a higher level of force effectiveness; but recall more may be better but not affordable.

FIGURE B-6.
Relative force effectiveness
(BLUE's indifference between FE and C2)



To digress for a moment, there are two theoretical approaches for measuring a user's utility: cardinal and ordinal. The cardinal approach assumes that we can measure the consumer's preference for any one commodity (in this case, for C^2 resources or for force elements) as an absolute value. In the ordinal approach, adopted here, the consumer's utility is not measurable; and we represent the consumer's preferences only as relative rankings. For integrating difficult-to-define resources like C^2 into the force structure, the relative ranking or ordinal approach is more supportable.[23] In our example, we use the analytical hierarchy process to give us a two-fold advantage: relative rankings and numerically significant differences between each of the rankings.

- *Compute the marginal rate of substitution between C^2 resources and force elements*. Once we have selected force effectiveness curves related to our maximum-to moderate risk scenario, we next find the marginal rate of substitution between the two commodities (*C2* and *FE*) on each curve. This marginal rate is the rate, for a given level of force effectiveness *E*, at which the BLUE commander is willing to sacrifice *C2* for more *FE* or *FE* for more *C2*.

Because these indifference curves slope down and to the right, their slope fits the general expression:

$$\text{(B9)} \qquad -\frac{\Delta FE}{\Delta C2}$$

As the decisionmaker chooses to decrease *C2*, he/she tends to increase the number of fighter aircraft (*FE*) to offset the loss of *C2* and to sustain the same level of force effectiveness *E*. From a different view, a commander losing fighter aircraft to attrition or other combat losses must apply more *C2* to manage the remaining forces at the same level of effectiveness.

To find the BLUE commander's marginal rate of substitution for a maximum-to-moderate risk scenario, we differentiate:

$$\text{(B11a)} \qquad E = a\, C2^{b}\, FE^{c} \qquad \text{for FE} \left(\text{that is, } \frac{dFE}{dC2}\right)$$

Rearranging the terms, we have

(B11b) $$FE^c = \frac{E}{a\,C2^b}$$

(B11c) $$FE = \sqrt[c]{\frac{E}{a\,C2^b}}$$

(B11d) $$FE = \left(E^{\frac{1}{c}}\right)\left(\frac{1}{a^{\frac{1}{c}}}\right)\left(\frac{1}{C2^{\frac{b}{c}}}\right)$$

Substituting our known coefficients of $b = 0.256$ and $c = 0.744$, and for a desired force effectiveness level of 10, the expression for *FE* becomes

(B11e) $$FE = \left(10^{1.344}\right)\left(\frac{1}{a^{1.344}}\right)\left(\frac{1}{C2^{0.344}}\right)$$

Simplifying,

(B11f) $$FE = (22.084)\left(a^{-1.344}\right)\left(C2^{-0.344}\right)$$

The *a* term only becomes important in trying to calculate an absolute rather than relative force effectiveness, so we can disregard it. Thus the derivative for *FE* with respect to *C2* is

(B12) $$\frac{dFE}{dC2} = -(7.597)\,C2^{-1.344}$$

which represents the marginal rate at which the BLUE commander would be willing to exchange *C2* for *FE*, while still achieving a relative force effectiveness level of 10.

Table B-3 summarizes the BLUE commander's marginal rates of substitution for relative force effectiveness levels of 10, 20, and 30 for each of the five risk levels.

- *Determine the commander's point of equilibrium in optimizing force effectiveness.* Somehow the indifference curves representing what the BLUE commander is willing to trade off and what can be traded off within budget constraints must match. The point where the objective function matches our budgetary constraint is a straight line tangential to the commander's preference curve. In economic terms, the slope of the indifference curve at the point of the consumer's equilibrium equals the slope of his budget constraint line.[24]

In equation (B3), we determined that the derivative or slope of the budget constraint line is -0.1. The BLUE commander's point of equilibrium in a maximum-to-moderate risk scenario, for a relative force effectiveness level of 10 along the indifference curve, is then where the derivative (B11) equals -0.1. Mathematically,

(B13)
$$\frac{dFE}{dC2} = -(7.597)\ C2^{-1.344}$$
$$-0.1 = -(7.597)\ C2^{-1.344}$$

Solving for *C2*,

(B14)
$$C2 = (75.97)^{\frac{1}{1.344}} = 25.077 \text{ increments}$$

which says for the maximum-to-moderate risk level and a budget constraint of $180 million, the BLUE commander would prefer to acquire 25 increments of C^2 to achieve a relative force effectiveness of 10.

Figures B-7a-7e depict the relationship between relative force effectiveness and the $180 million budget constraint for each of the five risk levels. The labels on the *x*- and *y*-axes directly apply to the linear budget line. However, the indifference curves do not directly correspond to the labels on the axes.

FIGURE B-7a.
Relative force effectiveness
(a=1.5, b=0.538, c=0.462)

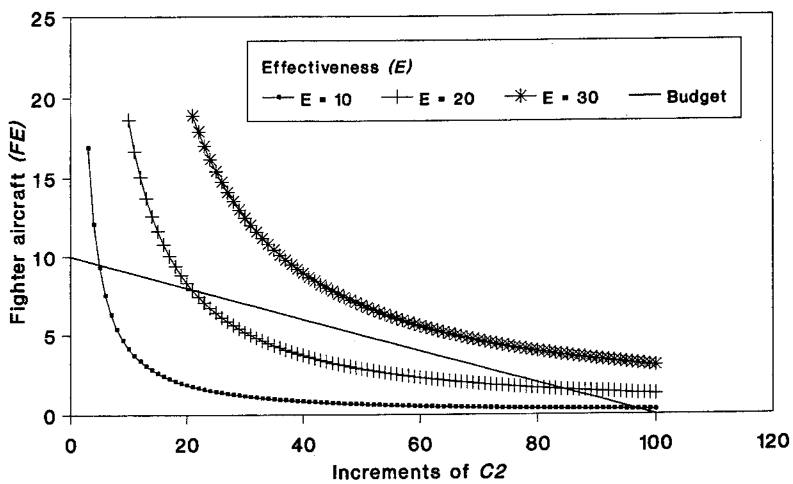


FIGURE B-7b.
Relative force effectiveness
(a=1.5, b=0.256, c=0.744)

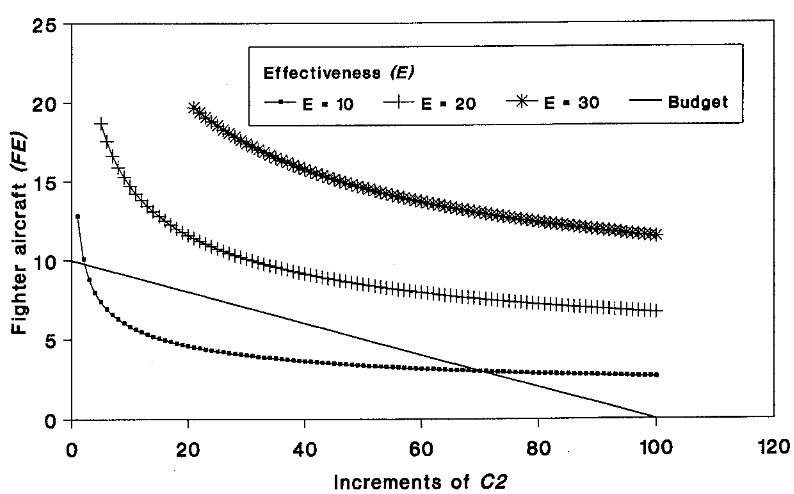


FIGURE B-7c.
Relative force effectiveness
(a=1.5, b=0.125, c=0.875)

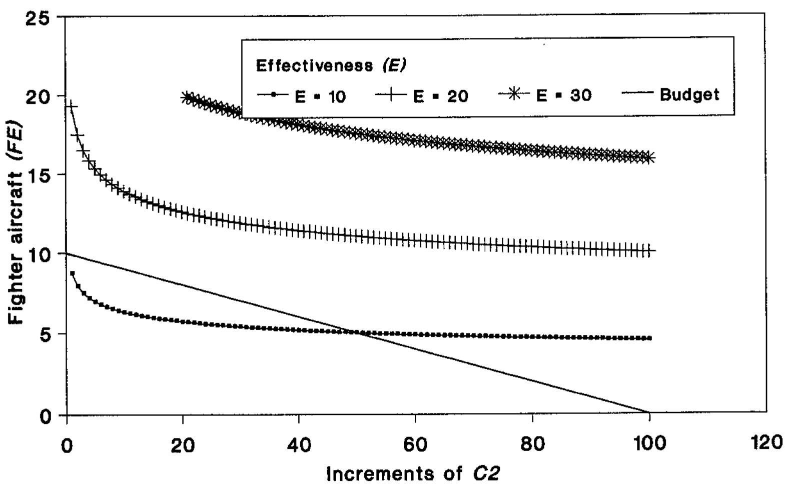


FIGURE B-7d.
Relative force effectiveness
(a=1.5, b=0.054, c=0.946)

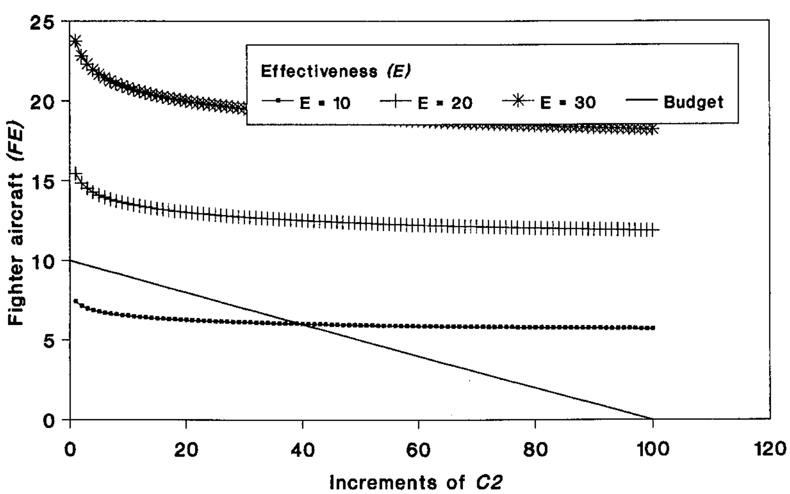
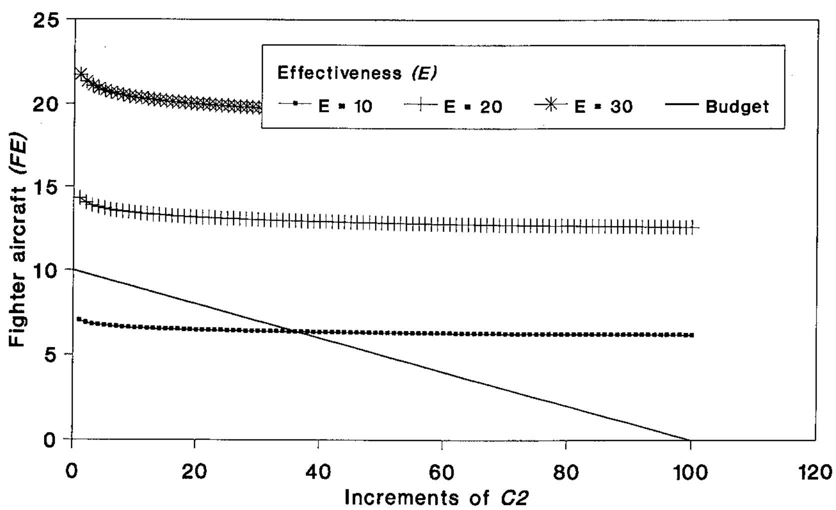


FIGURE B-7e.
Relative force effectiveness
(a=1.5, b=0.027, c=0.973)



• *Solve the force mix equation.* Knowing the number of C^2 increments (approximately 25) at the BLUE commander's point of equilibrium for a maximum-to-moderate risk scenario, we can use the \$180 million budget constraint equation to calculate the number of fighter aircraft needed to solve the deficiencies in Mission Area 223 (Close Air Support and Interdiction). Recalling the linear equation for the budget constraint:

(B15a) $180M = $1.8M (C2) + $18M (FE)

where *FE* is the number of force elements (fighters) in the proposed increase
C2 is the number (increments) of C^2 enhancements

and where $FE \geq 1$

$30 \geq C2 \geq 1$

Solving for *FE*,

$$\text{(B15b)} \quad FE = \frac{(\$180M - \$1.8M\,(25))}{\$18M} = 7.5 \text{ fighter aircraft}$$

So we have arrived at the solution to the decisionmaker's force structure problem of maximizing force effectiveness in this mission area. Given a requirement to satisfy the budget constraint and a choice between buying C^2 resources and force elements, we should plan to buy 25 increments of C^2 plus 7 fighter aircraft to cope with the commander's maximum-to-moderate risk scenario.

Referring to table B-2, we see the various price tags for the four categories of C^2 equipment—satellite communications terminals, high-speed computers, search and track radars, and a intelligence fusion facility. Within the decision to purchase 25 increments of C^2, what is the BLUE commander's preference for deploying, for instance, radars before computers or vice versa? We need to figure out which categories of C^2 equipment are more important than others in satisfying our mission area needs.

In appendix A, we rated the categories of equipment. Of the four categories, high-speed computers ranked the highest in meeting the desired C^2 system characteristics for Mission Area 223. The second highest ranking category was the satellite communications terminal, followed by the intelligence fusion facility and the search and track radar. So we should pick items from the equipment list to assemble an optimum suite of equipment within the 25-increment constraint.[25] Because the search and track radar ranked so low with respect to the other three categories, we will simply decide to not purchase five of the six proposed radars, but purchase all the rest of the proposed C^2 equipment.

To review this example, we decisionmakers and the BLUE commander see a maximum-to-moderate risk in the future, in view of how we perceive enemy intentions, the quantitative and qualitative force ratios, and other factors relating to how well we think BLUE forces will perform under the scenarios in the specified mission area. On the basis of those perceptions—which show up in BLUE's preference for information—we believe the BLUE commander needs as much in the way of C^2 resources as would otherwise be needed if the scenario was riskier or a higher level of force effectiveness was desired. Table B-4 is the final schedule of purchases for the Close Air Support and Interdiction force structure challenge. Recall that we determined the amount of *FE* needed was 7.5 aircraft. We ignored the "one-half" aircraft, which freed up another $9 million. This is where the "final spin" or judgment should be applied in a force structure decision. We could label the remaining funds as discretionary for use in operations and support functions. Or we could cut back on our C^2 equipment purchases to free up an additional $9 million to buy one more improved fighter. There are several viable options, but the final choice is the senior decisionmaker's.

Table B-5 summarizes the BLUE commander's force structure solutions for different relative effectiveness levels, based on his perceptions of risk. Note that if the BLUE commander had desired a higher *E* level for the maximum-to-moderate risk scenario, there would have been a need for more C^2 equipment than was available on the proposed procurement schedule (table B-2) and we decisionmakers may have spent the remaining budget on fighters. If we saw a maximum risk scenario at any of the relative force effectiveness levels, this analytical tool would have also advised us to purchase more C^2 equipment than was originally planned. Of course, if satisfying validated requirements for force structure improvement doesn't add up to $180 million, the senior decisionmaker may decide he has no reason to spend more on resources than is needed to meet the threat.

We can now summarize the mathematics of this economic analysis. When the commander perceives his/her preferences for C^2 resources and force elements are balanced within a certain risk environment and a given budget constraint, that is, when

$$\text{(B16a)} \qquad \frac{dFE}{dC2} = -\frac{pC2}{pFE},$$

an optimized force structure mix increase of *C2* and *FE* would then have

$$\text{(B16b)} \qquad \left[\left(\frac{pFE}{pC2}\right)(s)\left(E^{\frac{1}{c}}\right)\right]^{\left(\frac{1}{s+1}\right)} \text{ increments of C2}$$

and

$$\text{(B16c)} \qquad \frac{(TC - pC2\ (C2))}{pFE} \text{ units of FE}$$

where

dFE/dC2	is the derivative of *FE* relative to *C2*
pC2	is the price of an increment of the C^2 enhancements
pFE	is the price of a force element
E	is the desired level of relative force effectiveness
C2	is the number of C^2 increments needed to achieve the desired force effectiveness
FE	is the number of force elements needed to achieve the desired force effectiveness
b	is a coefficient relating to the influence of *C2* on *E*
c	is a coefficient relating to the influence of *FE* on *E*
$b + c = 1$	
$s = b/c$	
TC	is the total change in the budget (increase or reduction)

TABLE B-3. BLUE's marginal rates of substitution preference for C2 with respect to risk level

Risk level	Desired relative force effectiveness	Constant	C2 exponent
Maximum risk	10	-170.08	-2.16
	20	-762.47	-2.16
	30	-1833.89	-2.16
Max-to-mod risk	10	-7.60	-1.34
	20	-19.29	-1.34
	30	-33.27	-1.34
Moderate risk	10	-1.98	-1.14
	20	-4.38	-1.14
	30	-6.97	-1.14
Mod-to-min risk	10	-0.65	-1.06
	20	-1.35	-1.06
	30	-2.08	-1.06
Minimum risk	10	-0.30	-1.03
	20	-0.60	-1.03
	30	-0.91	-1.03

TABLE B-4. BLUE's final force structure purchase schedule

$180 M proposed increase to BLUE's budget

Quantity	Item	Unit cost	Total	
	Programmed improvement in forces			
7	Improved fighter aircraft	$18M	$126M	
			$126M	
	Programmed improved in C2 system			Units
3	Advanced high-speed computers	$ 3.6M	$ 10.8M	6
8	Satellite comm terminals	1.8	14.4	8
1	Intelligence fusion facility	18	18	10
1	New search and track radar	1.8	1.8	1
			$ 45 M	25
	Grand total		$171 M	
	Discretionary funds		$ 9M	

(Notational data: $ are constant dollars)

TABLE B-5. Force structure changes based on BLUE's perception of risk and information value

Risk level	Desired relative force effectiveness	C2 increments	Fighter aircraft
Maximum risk	10	31	6
	20	62	3
	30	93	0
Max-to-mod risk	10	25	7
	20	50	4
	30	75	2
Moderate risk	10	13	8
	20	27	7
	30	40	5
Mod-to-min risk	10	5	9
	20	11	8
	30	17	8
Minimum risk	10	2	9
	20	5	9
	30	8	9

Notes: (a) integer values only
(b) shaded areas show out-of-range values

§ § §

Notes

1. Charles J. Hitch and Roland N. McKean, *The Economics of Defense in the Nuclear Age* (Cambridge, MA: Harvard University Press, 1960; reprint, New York: Atheneum, 1966), chapter 7 and appendix. Alain C. Enthoven, then of The RAND Corporation, prepared the appendix. Enthoven apologizes for skirting the issues of risk, uncertainty, and criterion selection and not accounting for how the enemy might react. In the example to be explained in this appendix, we account for risk, uncertainty, and criterion selection using the analytical hierarchy process described in appendix A. We similarly incorporate how the enemy might react in conflict by measuring how the decisionmaker or commander *perceives* risk. Principles of economic theory, including production and utility theory, come from David E. James and C.D. Throsby, *Introduction to Quantitative Methods in Economics* (New York: John Wiley and Sons Australasia Pty Ltd, 1973), 125-160, 170-186; from C.E. Ferguson and S. Charles Maurice, *Economic Analysis: Theory and Application* 3rd ed., (Homewood, IL: Richard C. Irwin, Inc., 1978), 75-105; and from William J. Baumol and Alan S. Blinder, *Economics: Principles and Policy,* 4th ed., (Washington, DC: Harcourt, Brace, Jovanovich Inc., 1988), 469-476.

2. Captain Thomas W. Manacapilli USAF, Robert F. Allen, and Lieutenant Colonel Palmer F. Smith USAF, "A Methodology for Identifying Cost-effective Strategic Force Mixes," *Proceedings of the 53rd Military Operations Research Society Symposium* (Washington, DC: DoD, June 1985), 65-76.

3. Alain C. Enthoven, "The Simple Mathematics of Maximization," the appendix in Hitch and McKean, 396.

4. Professor Frank Snyder of the Naval War College suggests this useful, although challenging, approach. Interview held at the Naval War College, Newport, RI, 25 January 1990.

5. See Ferguson and Maurice, 78-81, for a more detailed discussion of these assumptions.

6. The "rate of technical satisfaction" is a term stemming from economic analysis and meaning the degree to which a consumer will

trade one type of good for another and still remain a satisfied consumer.

7. This more detailed example differs from the one in chapter 7, where decisionmakers deal with a $180 million cut in the proposed budget for the Close Air Support and Interdiction mission area at a perceived moderate-to-minimum risk level. Here the decisionmakers deal with the opposite kind of challenge—the economic problem of how to spend a budget increase to meet a higher risk (threat) environment.

8. United States, Department of Defense, *USDDR&E FY 87-91 Mission Assignments,* unpublished materials, 26 February 1986, A-31. The USD(DDR&E) maintains and distributes about 150 standard mission area definitions for warfighting missions, "garrison" missions, and research and development activities.

9. I extrapolated the relative force ratios from benchmark data summarized by Army researcher Robert McQuie in *Historical Characteristics of Combat for Wargames (Benchmarks)* CAA-RP-87-2 (Bethesda, MD: US Army Concepts Analysis Agency, July 1988), 16-17. The two extreme scenarios I suggest parrot the upper and lower bounds of central tendencies in McQuie's 50-year data base. Data with regard to the Korean Peninsula taken from Frank C. Carlucci, *Report of the Secretary of Defense to the Congress* (Washington, DC: GPO, 17 January 1989), 23-24.

10. Comprehensive US estimates of the quantitative and qualitative force balance in any one theater are not available in open source literature. At one time, the JCS defined "minimum-risk forces" for major mission area categories. Now in the early 1990s, the JCS instead defines "unconstrained forces" for certain planning scenarios. An analyst with access to this information could develop a corresponding family of risk levels appropriate to this economic analysis. To some, these risk level assessments may seem like the lead-in to an attrition-oriented analysis. Such statistics are often, however, the simplest way to measure force differences. Besides, the magnitude of an opposing force can sometimes overwhelm its enemy more than firepower alone. And the deterrent characteristic of a large force can win a battle without firing a shot.

11. While the judgments leading to these values were made with the BLUE commander's perspective in mind, they are not based on any empirical data and are therefore notional.

12. We might say this information preference function is also characteristic of what some theorists call the nonlinearity of combat.

13. A typical US Air Force tactical fighter squadron has a Primary Aircraft Authorization (PAA) of 24 fighters.

14. At this point, no particular preference exists for procuring or deploying any class of the proposed C2 improvements. We will discuss these priorities later.

15. I acknowledge that, for some, this correlation is a leap of faith. Traditional force structure planners may not agree with the logic in basing force effectiveness on these two factors. While they would agree with counting force elements, they may choose to attribute all other contributions to force effectiveness as a composite of qualitative advantages (training, morale, luck, and so forth). I would contend, however, that selecting C2 as one of the two factors is fair because C2 generally improves the ability of the leader to manage forces. A leader who manages his forces better usually has more chance for success in a conflict. I hope the reader would agree, especially after reading other chapters in this book.

16. Because no model displaces the final responsibility of the decisionmaker, it may be possible to "put spin" on the results to account for the decisionmaker's intuition.

17. Forces or force elements need not be attrition-oriented firepower. A radio frequency jammer, used in C2 countermeasures against RED forces, is a force element contributing to BLUE's force effectiveness.

18. While the objective function (B6) is not based on empirical data, it does reflect accepted notions and can be used in a relative sense to establish the economics of C^2 systems. Other types of mathematical functions, such as constant elasticity of substitution (CES) and polynomial expressions, have been used in force mix analyses by Manacapilli and others. Those functions are not as straightforward as the Cobb-Douglas and usually require some empirical data for curve fitting. As we know, quantitative data are hard to come by in the realm of C^2. The late 1980s work using response surface methodology evaluates potential tradeoffs between types of forces. In this appendix, the tradeoff is between forces and C^2 because C^2 systems have become elements in the force structure in their own right. If the reader yet questions the correlation, he should investigate the origins

of the Cobb-Douglas function. Early uses of the Cobb-Douglas function compared various combinations of labor and capital to achieve a certain level of production. The dissimilarity between labor and capital, as elements constructively interrelating to achieve a certain goal, is analogous to the dissimilarity between force elements and C^2 systems.

19. This idea is akin to the "willingness to pay" measurement in a classic cost-benefit analysis.

20. Recall that the risk levels relate to BLUE-RED force ratios in our example.

21. The derivatives of each of the two curves are negative.

22. The value of the constant *a* (nominally set to 1.5) is not meaningful at this juncture because it has no bearing on the slope of the curve, that is, no bearing on the relative tradeoff between the two factors *(C^2 and FE)* comprising the function.

23. A summary of the history of these theories is found in Ferguson and Maurice, 81-83.

24. Traditional microeconomics describes this point of tangency in two ways: (a) where the marginal benefit of the increase equals the marginal cost of the increase and (b) where the slope of the indifference curve is equal to the negative ratio of the marginal products.

25. There are many ways to approach this problem. For example, we could establish and evaluate different architectures, in the context of mission area needs. One configuration might be communications heavy, another might be computer oriented, and so forth.

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Index

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*U.S. G.P.O.:1995-387-330:20001

The Dollars and Sense of Command and Control

Text composed in Helvetica typeface,
titles in Caslon Open Face

Book and cover design by Mary Sommerville
Cover art by Juan Medrano

NDU Press editor: Mary Sommerville