Using Architectures For Research, Development, and Acquisition

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PREFACE

As the Department of Defense (DoD) moves steadily toward increasingly complex weapon systems that rely on information technology for joint operation, the need for interoperation of systems becomes more critical to the achievement of military capabilities. It also demands new methods for the acquisition of systems and the assemblage of battle forces. We can no longer afford the cost, either material or human, associated with acquiring individual systems without considering how the interoperation of these systems affects the capability of the Battleforce.

When the DoD introduced the Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) Architecture Framework in 1996, its intention was to provide the DoD community with a standard method for expressing the complex information exchange relationships that reflected the best systems engineering practices of government and industry. Since then, many advances have been made in DoD acquisition practices, the most significant of which has been the recent focus on capabilities-based acquisition. The idea of organizing the acquisition strategy around specific military capabilities delivered by a Family of Systems (FoS) is traceable to reforms in the British Ministry of Defense in the late 1990s. These reforms were a significant departure from the traditional practice of organizing the acquisition strategy around specific threats to be countered by individual systems, platforms, or military components. The revolutionary FoS concept is being explored today at the highest levels of the DoD and across the individual Services.

The goal of this book is to show how architectures can be used to enable a capabilities-based approach to the research, development, and acquisition of DoD families of systems that must interoperate with each other in the conduct of military operations. Much has been written about architectures and about capabilities-based acquisition. This book is about the pilot projects that have actually been used to explore the utility of the architecture methodology for both U.S. Navy fleet experimentation and the recent building of the Fiscal Year 2004 Program Objective Memorandum (POM 04) acquisition plan. At the time of this book's publication, the architecture methodology has been used successfully to describe and assess components of two Fleet Battle Experiments. It was also used to develop organizing exhibits at the early stages of planning for POM 04, although the exhibits were not used in the final decision-making process. The Assistant Secretary for the Navy (ASN) Research, Development, and Acquisition (RDA) Chief Engineer did use the Multi-Attribute Utility Analysis to advise ASN(RDA). Additionally, the architecture methodology has been used to influence decision-making with U.S. Coalition partners.

In order to use the architecture methodology to support these efforts, it was necessary to adapt the Framework's best practices for architecting complex information exchange relationships to a systems engineering process that addressed complex families of systems. It was critical to provide a much greater degree of integration between these practices and the military concept of operations to yield systems and weapons that could deliver required capabilities. The implications of this kind of integration are clearly illustrated by the Coalition Forces' integration of C4ISR and precision guided munitions used in military operations in Afghanistan and more recently in Iraq to achieve new time-sensitive targeting capabilities against unusual and asymmetric threats. This improved integration of information and weapon systems has allowed engagement of threats at ranges that maximize weapon effectiveness while minimizing casualties to our own forces as well as collateral damage to noncombatants. Ultimately, the increased integration of C4ISR and information technology with weapon systems should result in a new generation of warfare, which is widely referred to as Network Centric Warfare.

There has been substantial advocacy at the Office of the Secretary of Defense (OSD) level for the use of architectures in capabilities-based acquisition. Proponents include Mr. John Osterholtz, Director of Architecture and Interoperability for the DoD Chief Information Officer, and Dr. V. Garber, Director of Systems Integration, Office of the Undersecretary of Defense (OUSD) for Acquisition, Technology, and Logistics (AT&L). Both of these individuals have provided leadership across the information technology and system acquisition communities. Mr. Truman Parmele, Command Information Superiority Architectures (CISA) Program Manager for the Office of the Assistant Secretary of Defense (OASD)/Network Integration and Interoperability (NII), has led the development of the C4ISR Architecture Framework during its evolution over the past several years and is responsible for inclusion of this book into the current desktop series.

Development of the methodologies presented in this book and pursuit of the pilot projects (case studies) that provide proof of concept have been supported by the ASN(RDA) and the Assistant Secretary's Office of the Chief Engineer. The work was begun under the Honorable Dr. Lee Buchanan and the first Chief Engineer, Rear Admiral Kathleen Paige. It was finished under the Honorable Mr. John Young and the subsequent Chief Engineers, Rear Admirals Michael Mathis and Michael Sharp. The principal deputy for the Assistant Secretary, Mr. Paul Schneider, was also instrumental in the success of this work. CAPT Dennis Sorensen of the Naval Air Station, Patuxent River, was instrumental in both the overall technical review of this book and the development of the Precision Engagement example in the case studies.

Ms. Jacqueline Owens Lancaster of BAE Systems and previously of ManTech Systems Engineering Corporation is the editor of this work. It is to her credit that the technical material in this book is written in a manner intended to be understandable to all who read it. Most of the graphics in the book have been created over the last three years by Mr. Darrold Johnson of Strategic Insight and Ms. Davina Marklin of BAE Systems. The quality of their work speaks for itself. Special thanks must also go to Ms. Cynthia Smith of BAE Systems, who was my administrative assistant during my tenure in the Chief Engineer's office. Her support in compiling the editorial and graphic content of the book helped us all.

This book provides the early artifacts of an architecture-based systems engineering approach to the research, development, and acquisition of DoD systems. We hope that it will provide the DoD community with new insights into capabilities-based acquisition that will help the community chart the course for new capabilities like those promised by Network Centric Warfare.

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A large number of dedicated professionals have collaborated on this work. Citations by name and source are made in the text where appropriate. While it is impossible to summarize all of the names, the list below tries to call out organizations and individuals not otherwise directly cited. Please note that some of these individuals have moved to other organizations, but they are identified by the organization they supported at the time of their contribution to this work.

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PART I
INTRODUCTION

This part of the book introduces the challenge the Department of Defense (DoD) faces in attempting to move toward a Research, Development, and Acquisition (RDA) strategy that focuses on achievement of capabilities through a Family of Systems (FoS) systems engineering approach. While this change in approach represents a significant and critical departure from the way DoD has done business in the past, it is widely recognized that this approach is the best possible method for achieving real and measurable improvement in defense capabilities. The DoD has decided to use the FoS approach in pursuing the military advantages made possible through the concepts of Network Centric Warfare (NCW). The Army, Navy, Air Force, Marine Corps, National Security Agency/Central Security Office, Missile Defense Agency, National Imagery and Mapping Agency, and Defense Threat Reduction Agency have all adopted visions for NCW, and it is clear that all DoD elements recognize the importance of NCW capabilities to the achievement of Battlespace dominance. What remains unknown to many DoD agencies is how to move from acknowledgement that capability-based acquisition through an FoS systems engineering approach is needed to achieve NCW to an actual implementation approach. This part of the book lays the groundwork for understanding how an architecture-based process can provide the framework necessary to integrate capabilities across FoSs in order to achieve new capabilities, including NCW. The next part of the book builds upon this foundation by providing case studies that illustrate how the Architecture Framework products have actually been used.

CHAPTER 1
MOVING TOWARD ARCHITECTURE-BASED SYSTEMS ENGINEERING

Purpose

DoD currently faces a critical challenge: it must integrate multiple capabilities across both developing systems and often disparate legacy systems that support multiple warfare areas. To meet this challenge, DoD has been reorganizing in order to integrate acquisition activities in a way that leads to the achievement of capabilities through FoSs rather than just individual systems or platforms. The modification of the engineering methods needed to support capabilities-based acquisition uses architectures as the key element in the new methodology. This chapter establishes a framework within which architectures are being used for capabilities-based research, development, and acquisition within DoD. It focuses specifically on NCW as an area where the requirement for ever-increasing levels of interoperability can be met through the use of an architectural approach for acquiring the FoSs necessary to support this critical capability. Part II of the book builds on this introduction by providing five case studies that clearly illustrate how the architectural methodology is applied to the FoS systems engineering process.

The Distinction Between FoS Concepts and Classical Systems Engineering

Architects play a key role in FoS engineering. Classical systems engineering[⌖] focuses on designing a best solution (system) for a bounded, controlled problem. But the FoS systems engineering process is intended to enable the acquisition of capabilities from both the individual operation and the collective interoperation of the systems that comprise the FoS. Therefore, the FoS architects, unlike classical systems engineers, will not have control of many of the design parameters associated with the FoS. For example, in the assemblage of a Battleforce, 80 to 90 percent of the systems may be legacy systems over which the architect has no control. The critical distinction of FoS engineering is its focus on the capabilities attainable from the assemblage of systems rather than from a single system design, and it is this distinction that drives the architectural methods for FoS acquisition.

It should be obvious, then, that architects play a key role in FoS engineering. The FoS architect provides a critical link between the warfighter and the systems engineer. The architect captures the warfighter's requirements and transforms them into a language that can be understood by the systems engineer. Additionally, the architect must have a firm understanding of what the warfighter requires today and how the future may alter those needs. He or she must be able to interpret both current and future needs and lay out a preliminary sketch of an FoS that will accomplish the warfighter's requirements while remaining responsive to change. The architect must then work with the system engineer to determine the most operationally sound, technically feasible, and cost effective program investments. Reaching an acceptable balance among warfighter needs, ability to build systems that meet those needs, future flexibility, and cost should be in the domain of the FoS architect.

[⌖] For the purposes of this book, the systems engineering methods and standards like IEEE 1220 that have been historically used to design individual systems or platforms will be referred to as "classical systems engineering."

DoD Responses to the Challenge

The most exciting opportunity for which the U.S. DoD has chosen to achieve FoS capabilities is NCW, which is executed through Network Centric Operations (NCO). NCW is a collection of warfighting concepts that lead to military capabilities with which warfighters take advantage of all available information and bring all available assets to bear in a rapid and flexible manner. NCW includes the following basic tenets:

- A robustly networked force to improve information sharing
- Information sharing to enhance the quality of information
- Shared situational awareness to enable collaboration and self-synchronization and to enhance the sustainability and speed of command
- A dramatic increase in mission effectiveness enabled through the first three tenets[1]

The Army, Navy, Air Force, Marine Corps, National Security Agency/Central Security Office, Ballistic Missile Defense Office, National Imagery and Mapping Agency, and Defense Threat Reduction Agency have all adopted visions and implementation plans for NCW. The NCW strategies for four of these agencies are outlined in the following paragraphs.

In detailing its NCW vision, the Army provided a conceptual template for its transformation into a force that is strategically responsive and dominant across the full spectrum of operations and an integral member of the Joint warfighting team. The Army has stated that accomplishing its vision is strongly dependent on the potential of linking together networking, geographically dispersed combat elements. In doing so, the Army expects to achieve significant improvements to shared Battlespace understanding and increased combat effectiveness through synchronized actions. The theory behind the Army's NCW vision is that by linking sensor networks, Command and Control (C^2) networks, and shooter networks, it can achieve efficiencies in all military operations from the synergy that would be derived by simultaneously sharing information in a common operating environment. In addition, such linkages allow for the discovery of new concepts of operations both among Army forces and Joint forces in theater.[2]

The Navy's "Network Centric Operations (NCO), A Capstone Concept for Naval Operations in the Information Age" articulates the Navy's path to NCW**.** This document states that, "In developing NCW systems, a different approach to applying the principles must be taken. NCW requires that technology, tactics, and systems be developed together." The Navy document also points to three military trends: a shift toward Joint, effects-based combat; heightened reliance on knowledge superiority; and use of technology by adversaries to rapidly improve capabilities in countering U.S. strengths. It notes that these trends underline the necessity for coordinated NCW that enables substantial gains in combat power through the joining of networking and information technology with effects-based operations. "The power, survivability and effectiveness of the future force will be significantly enhanced through networking of warfighters."[3]

The Air Force's NCW vision recognizes that dominating the information spectrum is just as critical to conflict today as controlling air and space or occupying land was in the past. This vision document notes that the time available for collecting information, processing it into knowledge, and using it to support warfighting initiatives is shrinking. It also acknowledges that while possessing, exploiting, and manipulating information have always been essential parts of warfare, information has evolved beyond its traditional role. "Today, information is itself both a weapon and a target." The Air Force vision states that improved capabilities will be needed to deal with the increasing volume of information, emerging threats, and the challenges of tomorrow. It also states that the key to improving Air Force capabilities involves not just improvements to individual sensors, networking sensors, and improved C2 for sensors, but also in new ways of thinking about warfare and the integration of U.S. forces.[4]

While the Marine Corps has not historically used the term Network Centric Warfare, the Corps notes in its vision document that the principles embodied by the term have been an integral part of Marine Corps operations for years. The Corps acknowledges that their continued capability to meet these challenges will be its ability to capitalize on and expand its networked command and control structure to train and educate the future force in effects sensitive decision-making.[5]

Clearly, the concept of NCW has been embraced by all the services, and it is apparent that realizing the Services' individual visions of NCW will inherently require ever-increasing levels of interoperability. Accordingly, NCW is an ideal capability example for illustrating how architectural methods can be used to support the FoS systems engineering approach necessary for capability-based acquisition.

An Illustration of the Concept of FoS Capabilities

How will U.S. military forces be assembled and how will they interoperate to achieve new capabilities through the principles of NCW? The answer to this question may be found through understanding the interplay between military operations and military systems caused by advances in technology. Lessons learned from the German Blitzkrieg of World War II provide some insights. Blitzkrieg was an offensive revolution based on weapon technology and communications capabilities -- and the command structures designed to exploit both simultaneously. All three elements were essential to the success of this battlefield tactic. But the lynchpin of the new tactic was the radio. Radios had been available to the military in World War I, but they were bulky due to power supply limitations. By the time of World War II, early efforts at miniaturization (a word that would echo throughout the world for years to come and both drive and allow giant leaps forward in all forms of commerce) had reduced power demands, allowing reliable radios to be installed in both tanks and aircraft. Portable radio sets were provided as far down in the military echelons as the platoon. In every tank there was at least one radio. Advances in communications and information technologies in the 1980s and 1990s will enable NCW in ways that are similar to the manner in which the radio and advances in weapons technology enabled Blitzkrieg.[6]

NCW is more about the capabilities achieved through the interoperation of systems than it is about networks. The networks simply enable the interoperation.[7] Figure 1-1 illustrates the conceptual shift from a platform-centric system architecture to a network centric system architecture. Platform centric operations usually involve a sectored Battlespace as a means to control weapon systems and engagements. Platforms carry sensors, processors, and weapons (or combinations), the effectiveness of which can be increased dramatically by FoS integration enabled by a network centric architecture. Figure 1-1 is an example of the third key concept[⁜] of

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[⁜] The following bullets describe the three key concepts:

- The use of geographically dispersed forces
- The empowerment of forces by knowledge superiority
- The effective linkage of dispersed and distributed entities in the Battlespace

NCW cited by Alberts and Gartska[8], namely the effective linking of dispersed and distributed entities in the Battlespace. The importance of real-time fusing of multiple sensor outputs as a driver for the target engagement architecture cannot be overemphasized; it is fundamental to bringing network-centric operations to the point where U.S. forces meet the enemy. This change in architecture brought about by linked sensors is also illustrated in Figure 1-1.[9]

The implications for change in the nature of combat engagement as illustrated in Figure 1-1 are profound. On a single platform, it is relatively easy to close the observe, orient, decide, and act (OODA) loop. The challenge in network-centric operations is to enable OODA loops that span space and time as effectively and as rapidly for dispersed force elements as for a single platform, particularly when some sensors may be involved in multiple loops. Any sensor and processor with useful data or information will provide it for anyone who can use it, and the provider may not know who the user is nor the user who the provider is. In a larger context, however, the operation of the network will remain a closed loop in that the information will lead to action, and the mission decision maker – the one who decides what the target is – will have to know that the target was engaged and the outcome of that engagement as conditions for deciding on further action.[10]

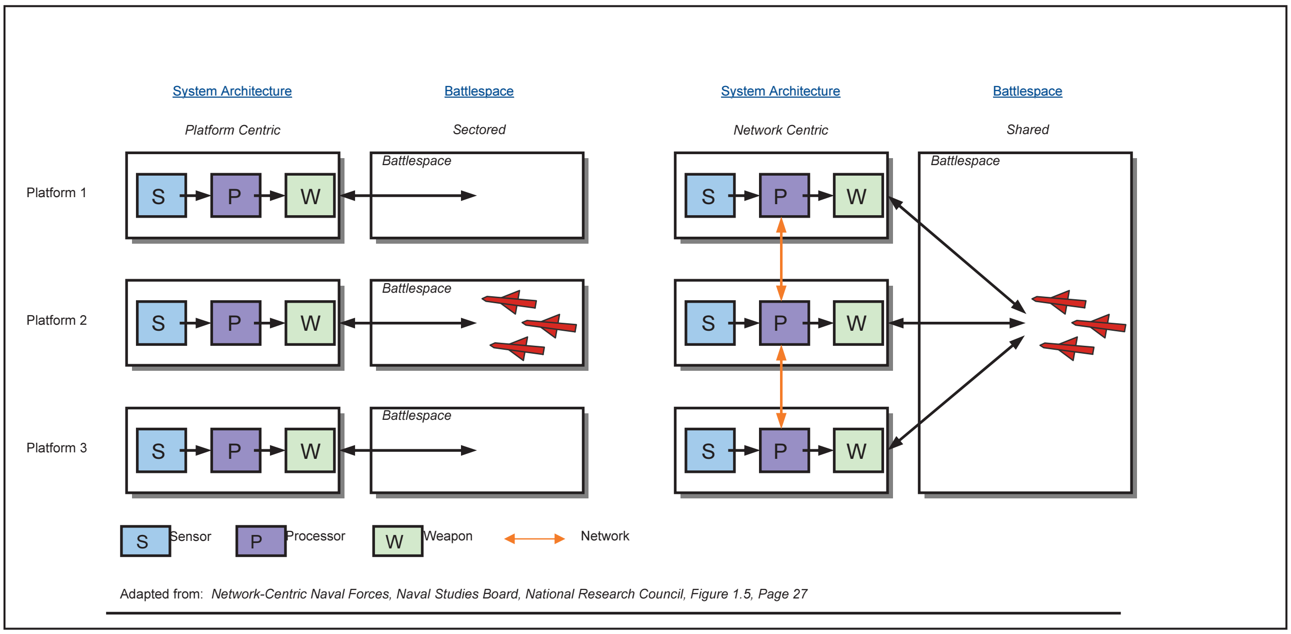

Figure 1-1. FoS Integration through Networks

The simple construct illustrated in Figure 1-1 can be applied broadly to many military FoS examples. In Figure 1-2, networks enable the sensors and weapons to be located on different platforms, as indicated by the color coding in the graphic. Thus, unarmed Guardrail aircraft are able to perform part of the targeting functions using the common data link (CDL) to pass targeting data for use by the Advanced Tactical Missile System (ATACMS), which performs engagement functions.

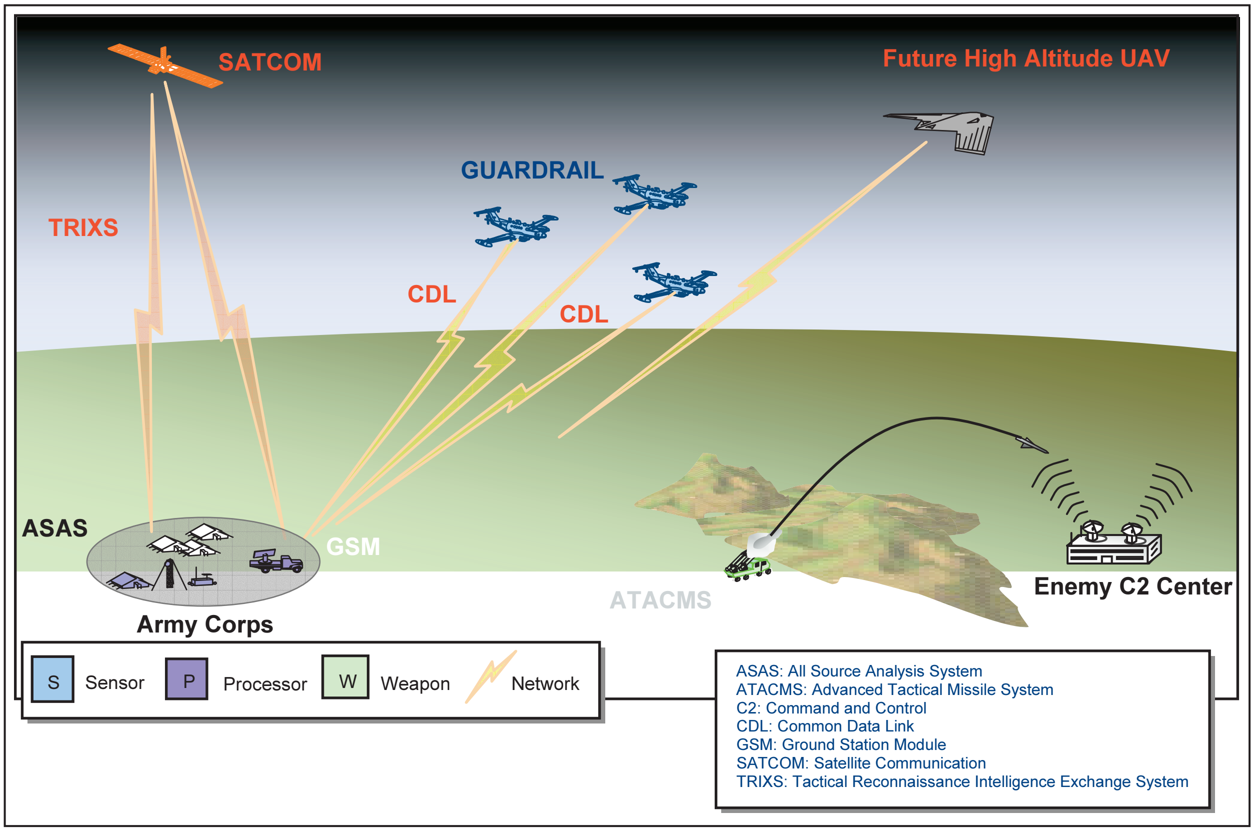

Figure 1-2. Example of Networks Enabling Targeting

One of the tenets of NCW is the dramatic (nonlinear) improvement in FoS capabilities that can be achieved through the networking of entities in the Battlespace. Metcalfe's Law, for example, has been cited as an illustration of the nonlinear kinds of improvement that are sought by networking the FoS.[11] In Metcalfe's Law, the number of connections in a network is seen to increase proportionally to N^2 (nonlinear) rather than N (linear), where N is the number of nodes in the network.

Figure 1-3 illustrates how networking of the systems in the operational example of Figure 1-2 can also lead to nonlinear improvement. In this case, networking further enables the use of geographically dispersed forces, which allows better exploitation of the laws of physics for the sensors. The results in the figure were generated by computer simulation. The contours in the figure are lines of constant targeting accuracy. The shaded areas are those regions where targeting accuracy is adequate to support weapons employment. The region of targeting accuracy for three Guardrails is illustrated in the left panel of Figure 1-3. The addition of the fourth sensor at sufficient altitude to interoperate with the Guardrail sensors exploits the laws of physics to achieve dramatic improvements in targeting. This addition might require a new air vehicle to achieve a useful altitude. A future high-altitude unmanned air vehicle (UAV), for example, might take on a mission like this. The right-hand panel shows how the targeting area is calculated to increase by a factor of five when the single high-altitude sensor is integrated into the Guardrail FoS. This is one kind of benefit that NCW propounds to offer through the proper assemblage of disparate and dispersed entities.

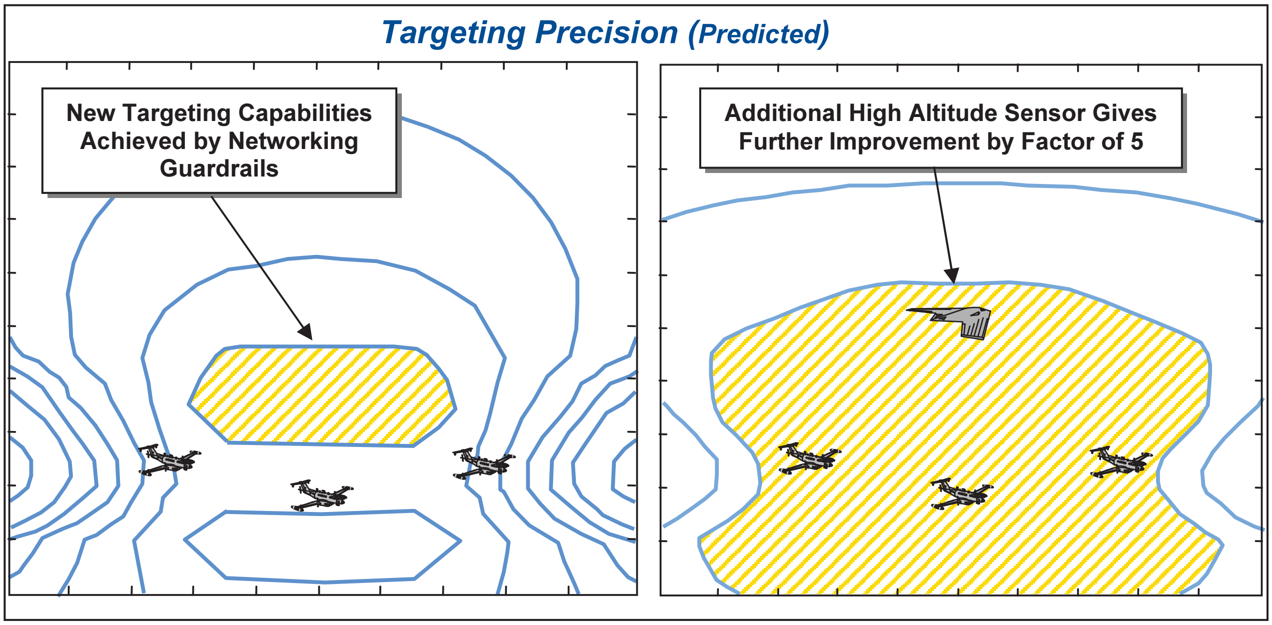

Figure 1-3. Illustration of Network Centric Warfare Benefits

Finally, it must be remembered that the capabilities enabled by networks and the architecture of the network will be determined by needs and objectives. Force coordination, force control, and sensor fusion for weapons employment will all have different requirements. Additionally, the network architectures for each of these uses should ultimately be integrated. An adaptation of the popular graphic from OSD[12] depicted in Figure 1-4 is used to illustrate these relationships.

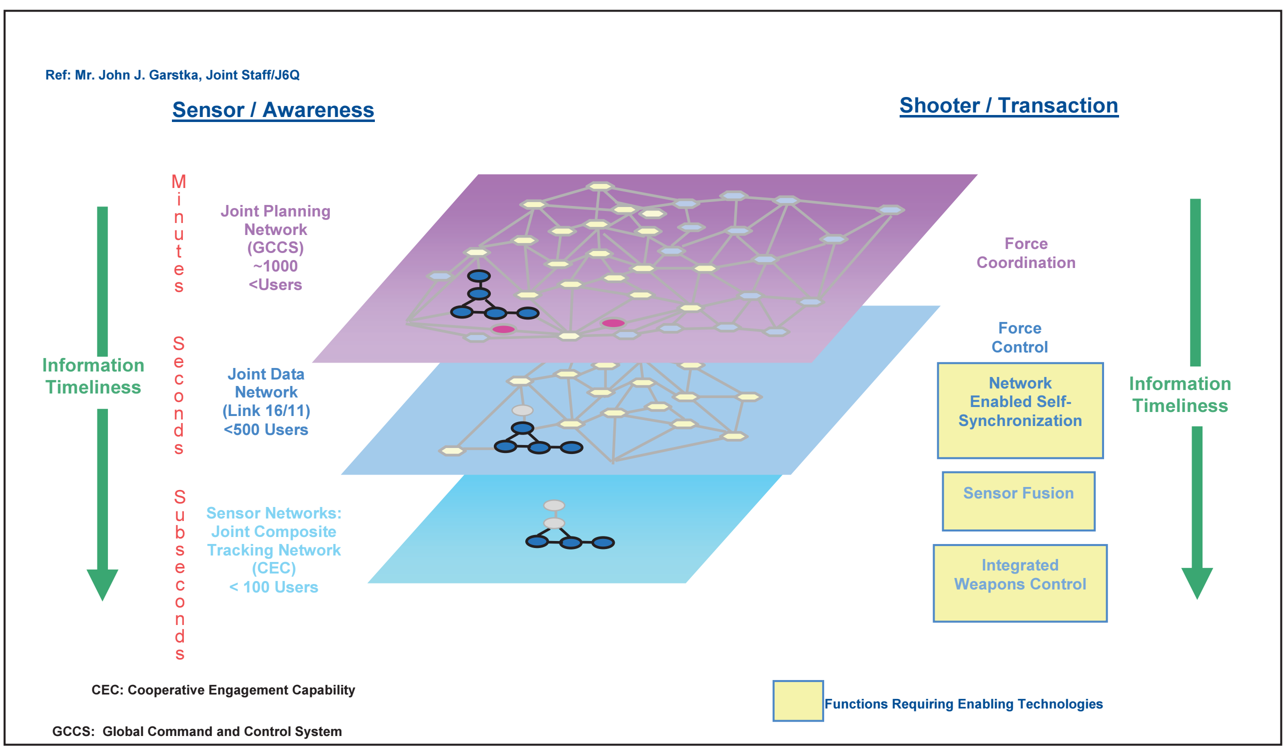

Figure 1-4. Networking the Force

The Role of Architectures

How then have architectures been used in FoS systems engineering? Figure 1-4 hints at the role of architectures by representing the force structure and command structure as a network of nodes that are associated with performance metrics at the FoS level. These metrics are achieved through the interoperation of the nodes. To use architectures to support FoS systems engineering, two types of assessments must be performed. The first is a performance assessment of systems and collections of systems conducted through traditional modeling and simulation methods. Unfortunately, these methods usually make tacit assumptions about interoperability between the nodes that are not addressed by existing modeling and simulation tools. Accordingly, the second type of assessment is an interoperability assessment. The case studies in Part II of this book devote substantial attention to the use of architectures for interoperability assessments. The most significant accomplishment that has emerged from the case studies is the development of common architectural exhibits that have been used by both system engineers to conduct performance assessments and architects to perform interoperability assessments. These common exhibits have provided a very necessary concordance between FoS performance assessments and interoperability. Without this concordance, FoS performance predictions are not supportable.

Summary

The challenge for DoD in developing methods to integrate multiple capabilities across developing and often disparate legacy systems can be met with an FoS systems engineering process that is architecture based. NCW provides an exciting opportunity for the DoD to achieve new capabilities enabled through the interoperation of systems. The architectural methodology for FoS systems engineering and acquisition is central to realizing the capabilities achievable through the interoperation of systems. Dramatic improvements in FoS capabilities, gained through the interoperation of systems which in turn is enabled by networks, have both an historic and analytical basis. The overview of the problem to be solved and the architecture-based approach to the solution presented in this introduction will be expanded in the chapters that follow and illustrated in the case studies. The case studies and architectural methodology should provide the reader with a firm understanding of how to use these methods in practice.

CHAPTER 2
USING ARCHITECTURES IN SYSTEMS ENGINEERING AND ACQUISITION

Purpose

The previous chapter introduced the concept of using an architectural approach to assemble an FoS to achieve defined mission capabilities, including a specific example of NCW. This chapter provides an overview of how the DoD Architecture Framework can be used to support a capabilities-based FoS systems engineering process. Effective planning, design, and analysis are critical throughout the development of the FoS to ensure cost-effective achievement of mission objectives. The DoD Architecture Framework products can be used as tools to develop integrated solutions for achieving desired mission capabilities. These products can be used as standardized templates to allow operators, engineers, and acquisition professionals to describe the activities, functions, and systems required to assemble the FoS. The adaptation of the DoD Architecture Framework products to support the architecture assessments critical for developing FoSs designed to achieve specific mission capabilities will provide DoD professionals with effective tools for making more informed acquisition investment decisions. Exactly how these products can be applied in order to support acquisition of FoSs designed to provide specific mission capabilities is illustrated in the case studies in Part II of this book.

Architectural Methodology

Collective mission capabilities are derived from the interrelationships and dependencies between systems. Not surprisingly, the complexity of the description of the FoS increases rapidly as it moves from high-level concepts to their instantiation by physical systems. The architectural methodology is part of a systems engineering discipline that documents "the structure of components, their relationships, and the principles and guidelines governing their design and evolution over time."[13]

The architecture is the first level of design that can be reasoned about. It provides the framework for analyzing both engineering development and operational uses of the FoS. It also provides the basis for the transformation of FoS planning and acquisition into a capabilities based strategy.[14]

To support FoS systems engineering and acquisition, the Architecture Framework products can be organized into five product groups or use cases:

- Operational Concept
- System Functional Mapping
- System Interface Mapping
- Architecture Performance and Behavior
- Acquisition Planning

In Figure 2-1, these groups are generally ordered (top to bottom) by the anticipated level of complexity associated with their use. However, this ordering of the five groups should not be confused with how the products, or views, are developed. Many of the products are developed concurrently.

The first four of the five groups of products can be generally associated with the four steps of classical systems engineering:

- Requirements Analysis
- Functional Analysis
- Synthesis
- Design Verification

While FoS systems engineering must follow the principles of classical systems engineering, the complexity of the FoS and the preponderance of legacy systems in the FoS will limit the system engineer's ability to apply these principles in practice. Performing requirements analysis to achieve specific FoS capabilities and developing a functional design for the FoS are, however, both manageable tasks. The architecture products that emerge from requirements and functional analyses become stable views of the FoS that are much simpler to understand than the underlying and constantly changing physical architecture. The FoS synthesis provides the critical mapping of legacy systems into the functional view of the architecture for the FoS and enables determination of how the remaining trade space might be used for new systems and system improvements. Performing FoS design verification is reduced in complexity by focusing on threads of systems that provide the supporting functionality for specific mission capabilities.

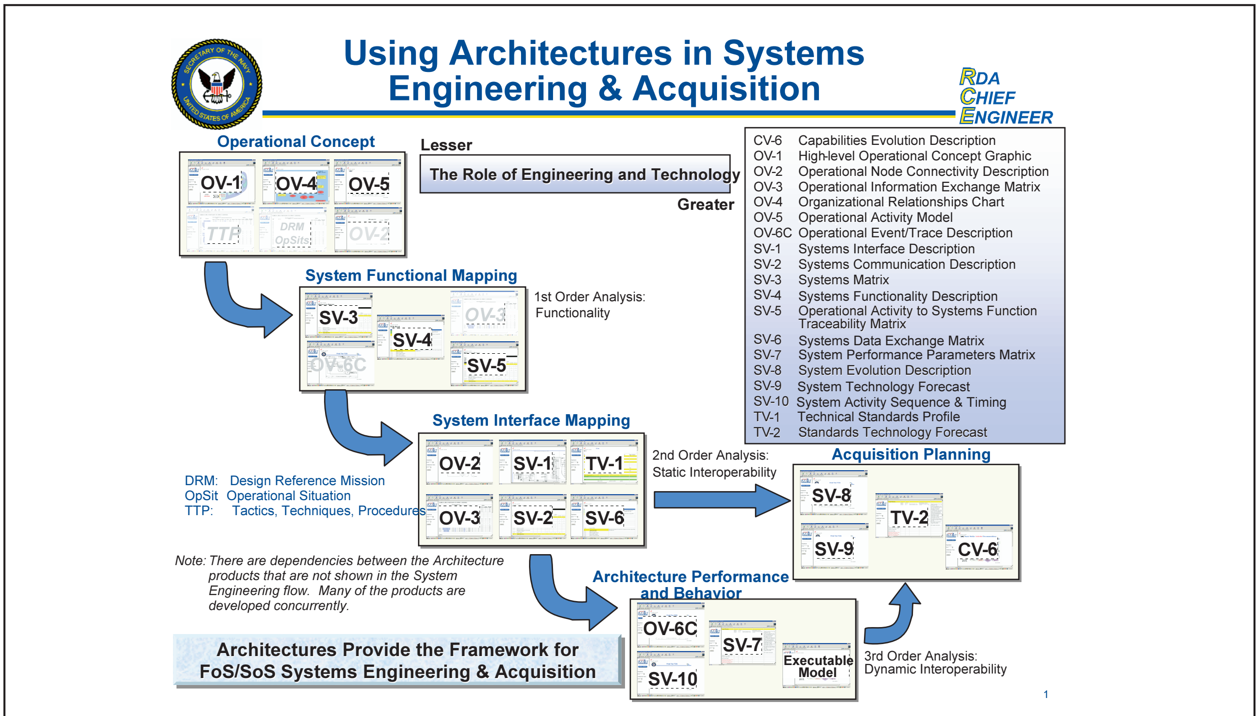

Figure 2-1. Using the Architecture Framework in FoS Systems Engineering and Acquisition

The following paragraphs describe each of the five Architecture Framework product groups and introduce the Framework products that are used to support them. This basic overview of the architectural methodology is intended to provide the reader with a foundation that will be expanded through a demonstration of how the products are used in practice in the case studies that comprise Part II of the book.

Operational Concept

The operational concept should be a high level abstraction of the problem to be solved and the proposed approach to solve the problem. It can also include boundary conditions and invariants (i.e., things not in the trade space of the solution). Description of the operational concept can be supported through the use of three Architecture Framework products or Operational Views (OVs) while keeping a fourth product mind:

- OV-1, High-Level Operational Concept Graphic: provides a high level description of what the military force is and its intended effects on the defined threat
- OV-5, Operational Activity Model: provides the first descriptions of how the military force will achieve its intended effects
- OV-4, Organizational Relationships Chart: documents the control relations over the operational activities, establishing by what authority or mechanisms activities are directed to execute or remain idle
- OV-2, Operational Node Connectivity Description: offers an enterprise view of the architecture and provides meaningful groupings of the activities in the Operational Activity Model; these groupings can be thought of as task-oriented cells where work is accomplished

These products lay the foundation for systems development and facilitate communication by providing context, orientation, and focus. They also serve as the entry point for requirements flow down into the architecture. These architecture products are the first artifacts that support the feasibility of the concept. They will help answer the following questions: What is the problem to be solved, what is the proposed approach for solving that problem, and is that approach feasible? The case studies in Part II of this book discuss the use of the architecture products in supporting concept and requirements development and address the specific architecture views used to gather and collect data to build an analytical framework.

System Functional Mapping

Because most FoSs are highly complex, simply keeping track of the data describing the systems, their relationships, and their evolution is an overwhelming task. The System Functional Mapping of the solution provides a stable model that facilitates the management of this information as well as the mapping of systems to functions. The system functional mapping is supported by three Architecture Framework products or System Views (SVs):

- SV-4, Systems Functionality Description: provides a list of system functions that will be used to enable or execute operational activities
- SV-5, Operational Activity to Systems Function Traceability Matrix: aligns individual system functions with the individual operational activities they enable or execute
- SV-3, Systems^2 Matrix: aligns systems to functions, operational activities, and to other systems

Together, these products provide the linkage and traceability of capabilities and requirements flow-down between the operational and physical views. The functional view is also the first level of the architecture that is appropriate for systems assessments. The products provide the basis to answer the following question: Does the FoS system architecture provide the functionality to support the desired mission capabilities? Assessments using this functional group of products provide the basis for a first order analysis of combinations of systems proposed to comprise the FoS. Chapters 3 and 4 in Part II provide greater detail on System Functional Mapping and

Assessment and specifically discuss the use of each Framework product in conducting this step in the process. In the systems engineering process, attention will be focused on an FoS that is intended to solve the problems laid out in the High Level Operational Concept (OV-1). For example, an analysis of gaps and overlaps will reduce the size of the system trade space. The result of this first order architecture analysis is the starting point for systems engineering trade-off analysis, and it is discussed in detail in Chapter 5 of this book.

System Interface Mapping

The system interface mapping builds all views -- operational, system, and technical -- of the connectivity between the FoS systems. System interface mapping can be supported through the use of six Architecture Framework products, which are a mixture of OVs, SVs, and Technical Views (TVs):

- OV-2, Operational Node Connectivity Description: provides meaningful groupings of the activities in the Operational Activity Model; these groupings can be thought of as task-oriented cells where work is accomplished
- OV-3, Operational Information Exchange Matrix: defines the Information Exchange Requirements (IERs) across the three basic entities of the operational view (activities, operational nodes, and information flow)
- SV-1, Systems Interface Description: links the operational nodes and system views of the architecture
- SV-2, Systems Communications Description: represents the specific communications systems pathways or networks and the details of their configurations through which the physical nodes and systems interface
- TV-1, Technical Standards Profile: provides the set of rules that govern system implementation and operation
- SV-6, System Data Exchange Matrix: creates end-to-end views of system information and service exchanges

From the point of view of systems engineering trades, these views provide the basis to answer the following question: Have the appropriate standards been applied and the levels of interoperability been properly aligned so that the individual systems in the FoS can be expected to interoperate with each other successfully to enable the functionality sought for the FoS? The architecture views from the framework used to capture this data and the process used to conduct the analysis are discussed in detail in Chapters 3 and 4 of Part II.

Architecture Performance and Behavior

The system functional mapping and the system interface mapping provide key insights into the functionality and connectivity of the architecture with traceability to operational capability. As such, these uses of Framework Architecture products provide an early validation of the architecture and serve to answer the following question: What can the architecture enable the FoS to actually do? Yet the architecture cannot be validated until it can be executed as a flow of events, a task that can be accomplished only through review of the products of its performance and behavior. The group of architecture products proposed to support the use case of performance and behavior can serve to answer the following questions: How well does the architecture perform (to deliver mission capabilities), and does it behave in ways acceptable to the users? This use case can be supported with three existing Architecture Framework products and the addition of one new product:

- OV-6c, Operational Event/Trace Description: enables the traceability of actions in a scenario or critical sequence of events to address the executability (or dynamic validity) of the operational view of the architecture
- SV-10, System Activity Sequence and Timing Description: includes a Systems Rules Model, a Systems State Transition Description, and a Systems/Event Trace Description
- SV-7, Systems Performance Parameters Matrix: builds on the Systems Interface Description (SV-1) to depict the current performance characteristics of each system and the expected or required performance characteristics at specified times in the future
- Executable Model (new product): required for both validation and analysis

While these products are necessary to support system selection decisions that reside in the domain of FoS systems engineering trade studies (i.e., performance and capabilities versus cost and risk), they are the most labor intensive of the five groups (use cases) to generate. Further detail on this set of architecture views is provided in Chapters 5 and 7 of Part II.

Acquisition Planning

To support capabilities-based acquisition planning, it is critical to align the evolution of systems, technologies, and standards with the evolving mission capability requirements of the FoS. Describing the acquisition strategy requires three existing Architecture Framework products and a proposed new product called a Capability View (CV):

- SV-9, Systems Technology Forecast: provides a detailed description of emerging technologies and specific hardware and software products
- TV-2, Technical Standards Forecast: provides a detailed description of emerging technology standards relevant to the systems and business processes covered by the architecture
- SV-8, Systems Evolution Description: describes plans for "modernizing" a system or suite of systems over time
- CV-6, Capability Evolution Description: provides a high-level graphic for managers and executives to use in providing oversight of FoS alignment during acquisition

Together, these products provide a description of the evolution and acquisition of the system improvements for the FoS that are traceable to mission capability requirements. They help answer the following question: what changes in systems, standards, and capabilities will affect the ability of the FoS to deliver the desired mission capability? Chapter 5 provides additional information on using the Architecture Framework products to support acquisition planning.

Capabilities-Based FoS Systems Engineering

In FoS systems engineering, the operational concept must clearly be tied to capabilities. The Joint Requirements Oversight Council (JROC) has defined an operational concept to be an end-to-end stream of activities that defines how Force elements, systems, organizations, and tactics combine to accomplish a military task.[15] This must be distinguished from a concept of operations (CONOPS), which is a statement of the Commander's assumptions or intent with regard to an operation. The CONOPS is frequently embodied in campaign plans and operations plans and especially in operations plans that cover a series of operations to be carried out simultaneously or in succession.[16]

Joint doctrine has defined the term "capability" with a simple and authoritative definition: a capability is the ability to execute a specified Course of Action (COA)[17]. A COA is just a possible plan available to an individual or commander that would accomplish (or is related to the accomplishment) of a mission. These definitions are easily adapted to the architectural methodology. In this sense, COAs are simply sequences of operations that can be executed to support or accomplish a mission. The term "capability," then, has a rigorous meaning in both its military and engineering usage. The next part of this book will illustrate how architectures can be used in FoS engineering to support delivery of mission capability.

Summary

The DoD Architecture Framework products serve as tools for supporting a capabilities-based FoS systems engineering process. The Framework views provide a common language that can be used among operators, engineers, and acquisition professionals in performing architectural analysis to support better acquisition decisions focused on achieving desired mission capabilities within an FoS. Part II of this book illustrates how these tools can be put into practice in pursuing NCW capabilities for FoSs.

PART II
ARCHITECTURAL CASE STUDIES

The case studies presented in this part of the book use the previously introduced architectural methodology to develop more fully the NCW concept introduced in Chapter 1. The presentation of these case studies is intended to serve two purposes:

- To provide an abstraction of NCW that will support Joint Vision 2020[18]
- To show how the architecture methodology provides traceability of operational capabilities to the functionality and connectivity of the FoS

This part of the book begins with an overview of how the architecture products introduced in Chapter 2 can be used to support the development of NCW concepts. Chapter 3 demonstrates at an abstract level how these products provide a framework to describe a mission warfare area and to demonstrate the logical validity of the mission and system architecture. It discusses the methods used in building a warfare mission architecture with traceability of FoS functionality and connectivity to capability objectives. In other words, it shows how the methodology provides an engineering framework to describe the way in which mission capabilities are achieved through the interoperation of systems. Part II continues with four more case studies that further illustrate the architectural methodology for FoS systems engineering. Each of these case studies focuses on a different aspect of the architectural methodology and its application. The detailed case study presented in Chapter 4 illustrates the use of the three basic groups of products in addressing a specific warfare application, Precision Engagement. The next case study, presented in Chapter 5, discusses the use of the architecture products in support of Fleet Battle Experiment India (FBE-I). This chapter focuses on how alternative systems that could instantiate the architecture can be assessed in order to build an acquisition plan. It also provides the reader with a better understanding of the need for alignment of systems in their procurement schedules to provide the resources necessary to support the FoS systems engineering and integration that enable the interoperation of systems in the family. Chapter 6, a case study on Joint Maritime Command and Control Capability, takes a more detailed look at command and control, primarily from an operational view. The final case study, a Coalition Partner Integrated Air Picture, is presented in Chapter 7. It demonstrates how a capability such as an integrated air picture for coalition partners can be used as an operational node within a mission warfare architecture. It also initiates the discussion of how executable architectures can be used to assess architecture performance and behavior. Taken in total, these case studies provide the reader with an illustration of how the Architecture Framework products can be implemented to support the achievement of mission capability based acquisition.

CHAPTER 3
INTRODUCTION TO NCW CASE STUDIES

Purpose

This introductory chapter to the case studies offers the reader foundational information on NCW and the mission effects it offers through the interoperation of systems. To provide this foundation, it guides the reader through an abstraction of a simple example of NCW Precision Engagement motivated by the Guardrail example provided in Figure 1-2 in Chapter 1. The discussion in this chapter is designed to be similar to the manner in which an architect would work with a system developer and a military operator in that it starts with a conceptual illustration of the proposed solution to the problem. It then shows how the first three basic groups of architecture products introduced in Chapter 2 (the operational concept, the system functional mapping, and the system interface mapping) support the development of NCW concepts. It discusses how these basic architecture products provide a framework to describe a mission warfare area and demonstrate the logical validity of the mission and system architecture. Establishing the logical validity of the architecture is the first step toward demonstrating that the FoS architecture has the requisite interoperability to support the mission. Without this interoperability, the performance claims made in Figure 1-3 would be unsupportable. The information presented in this chapter will be helpful to readers as they review the case studies contained in Chapters 4, 5, 6, and 7.

Translating the NCW Mission into Architectural Views

As noted earlier in this book, NCW relies on information sharing, information quality, shared situational awareness, collaboration, and self-synchronization to deliver a dramatic increase in mission effectiveness. In short, it is focused on leveraging knowledge superiority enabled by technology to conduct effects-based military operations. In this context, it is the mission effects achieved through the interoperation of systems enabled by networks – not the networks themselves – that are the focus and substance of NCW. It is easy to understand how achieving the increased mission effects enabled through NCW would be beneficial to the warfighter. The acquisition challenge is to identify specifically what must occur to make those increased mission effects a reality. What systems and information are needed to bring about this increase, and how can they be integrated to make it happen? The complexity associated with answering these questions led to the organization of the architectural views into the five groups of views presented in Chapter 2 (Figure 2-1). These architectural views enable systems architects, engineers, and acquisition specialists to move from defining the operational concept to identifying and analyzing the actual systems and interfaces that will be needed to perform the required activities and functions, to provide the necessary communication and information exchanges, and to execute the NCW mission.

The acquisition challenge is usually met by working with military operators to establish a conceptual solution like the one illustrated in Figure 3-1. The architect must work with military operators, systems engineers, and other stakeholders to develop architectural views leading to a solution that is operationally sound, technically feasible, and cost effective. The first element of the graphic, Figure 3-1a, was first introduced in Chapter 1 and illustrates an instance of the specific NCW mission of Precision Engagement. While the illustration in Figure 3-1a provides information on the force elements and the mission objective and context, it fails to show information that will be critical to achieving the technical solution. The lightning bolts in the graphic, for example, show that information will be exchanged, but no information is provided on how the information will flow, what systems make this information exchange possible, or what the information needs are. This information is essential to making the NCW vision for this mission a reality. The second element of the graphic, Figure 3-1b, goes a bit further by providing a very high-level systems architecture. The physical systems identified in the conceptual solution are abstracted as sensors, processors, and weapons that interoperate through networks. A high-level paradigm of Detect, Control (of the weapon), and Engage can be used to organize the concept. Under this paradigm, the operational concept for Precision Engagement of a C^2 target in the Battlespace can be described using a combination of these basic operational activities. Specifically, the target in the Battlespace is first detected, and then the weapon used to engage the target is controlled (i.e., the fire control solution is developed) using these detections. The systems in the conceptual solution presented in Figure 3-1a can be allocated in a geographically distributed way that can then be abstracted and captured with an architectural diagram (Figure 3-1b). The use of this basic diagram allows operational capabilities to be traced to systems and system interoperation. With the architectural formalism of this diagram, it becomes obvious that a network between the data processor and the weapon may have been overlooked in the conceptual solution. The architect must then work with the military operator to identify what connection was intended. While the alignment of systems to operational capabilities offers a helpful first step in identifying the missing pieces of the architecture, it still fails to provide the information exchange elements that are missing from Figure 3-1a.

The architecture products discussed and illustrated in the remainder of this chapter show how the operational concept in Figure 3-1a and the notional architecture presented in Figure 3-1b are validated through development and analysis of operational and functional views and the implied interfaces. These views will establish the logical validity of the high-level systems architecture presented in Figure 3-1b, which is the first step in determining if the mission illustrated in Figure 3-1a can actually be accomplished.

NCW Operational Concept

The first step in developing architecture products for an NCW mission is to develop operational concept views. As noted in Chapter 2, the operational concept is a high-level abstraction of the problem to be solved and the proposed approach for solving it. These products lay the foundation for systems development and facilitate communication by providing context, orientation, and focus. They also serve as the entry point for requirements flow down into the architecture. They also provide the further refinement of definitions that is necessary to make these views more useable as engineering products. These operational concept architecture products are the first artifacts that support the feasibility of the concept. The NCW Operational Concept can be described using four architecture products:

- High-Level Operational Concept Graphic (OV-1)
- Operational Activity Model (OV-5)
- Operational Node Connectivity Description (OV-2)
- Organizational Relationships Chart (OV-4)

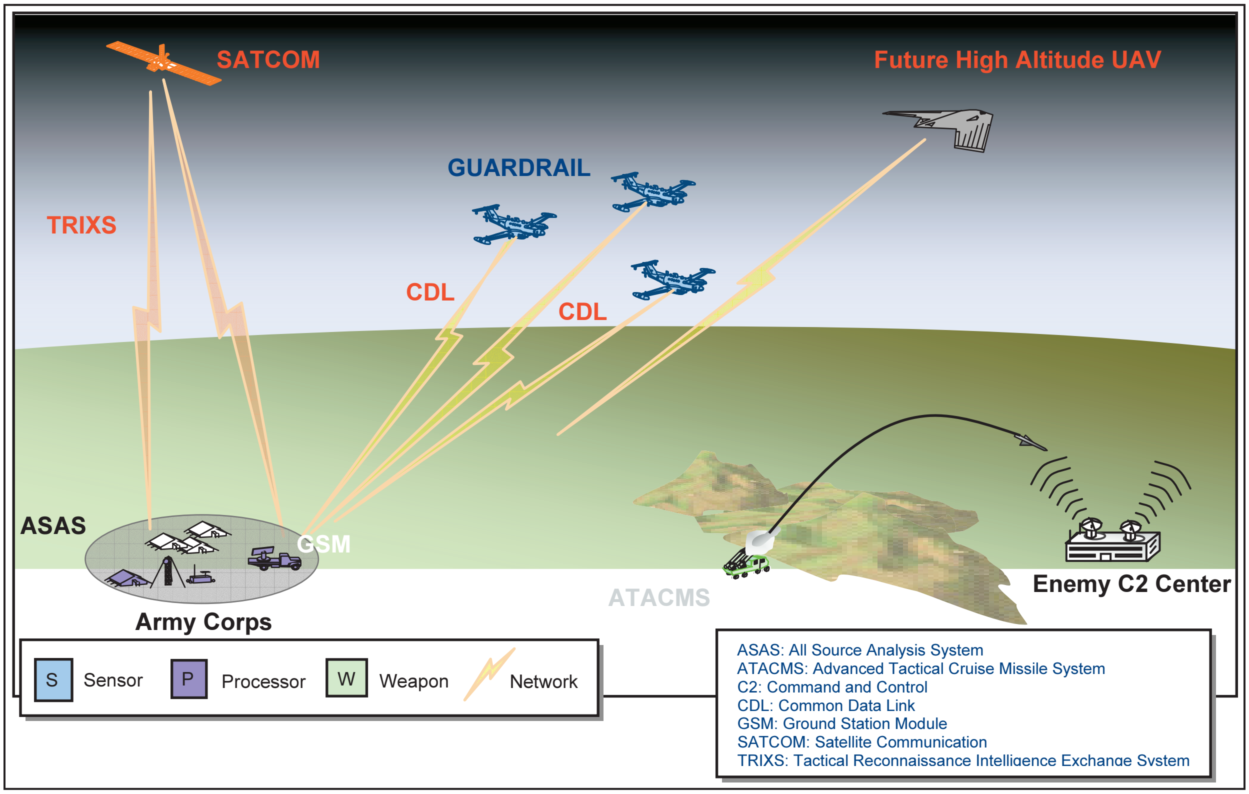

Figure 3-1a. Example of Networks Enabling Precision Engagement

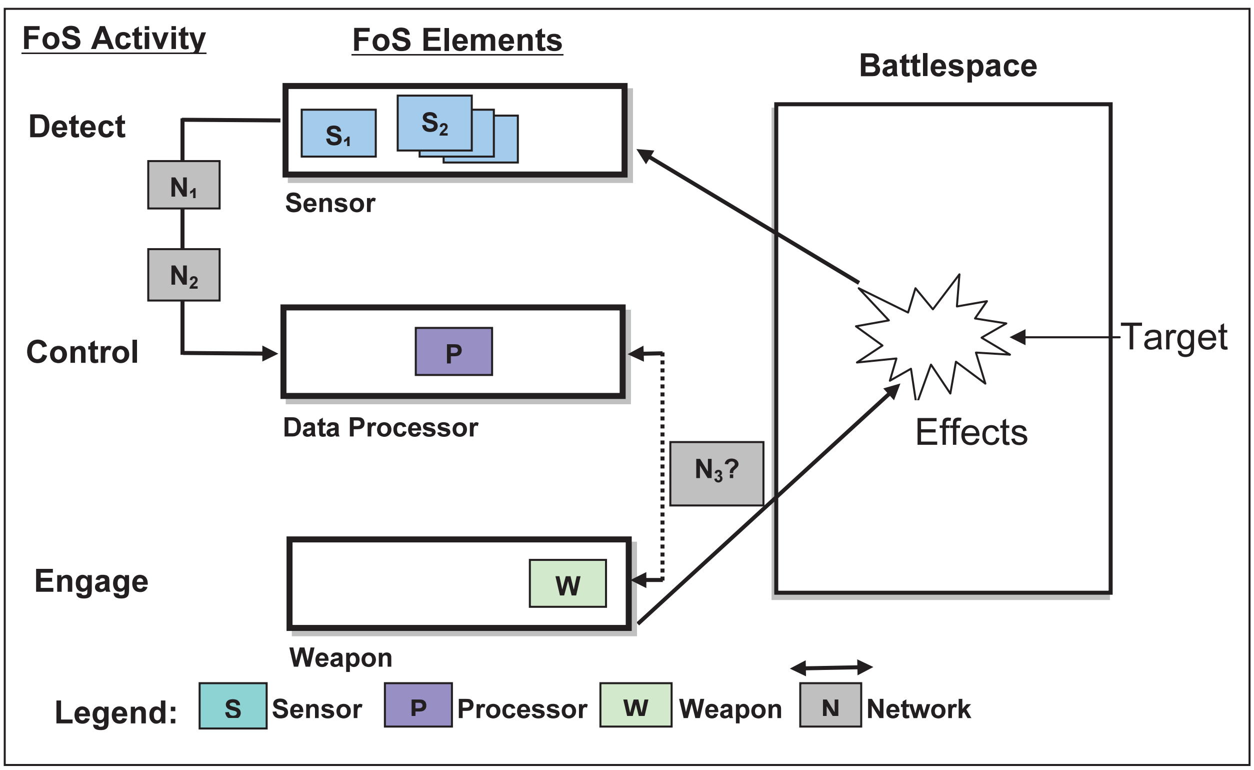

Figure 3-1b. Abstraction of Targeting Example

Figure 3-1. Architectural Abstraction for NCW Precision Engagement Example

These products will help provide the groundwork for answering the following questions: What is the problem to be solved, what is the proposed approach for solving it, and is that approach feasible?

The Precision Engagement targeting example illustrated in Figure 3-1 can be easily related to these four basic operational views of the architecture. The conceptual solution (Figure 3-1a) corresponds to the High-Level Operational Concept Graphic (OV-1). The Detect-Control-Engage paradigm illustrated in Figure 3-1b corresponds to the Operational Activity Model (OV-5). The use of the Detect-Control-Engage paradigm to organize assets that perform specific tasks and interoperate with each other corresponds to the Operational Node Connectivity Description Diagram (OV-2), which is discussed in detail later in this chapter. The final product, Organizational Relationships Chart (OV-4), is not addressed in the conceptual solution in Figure 3-1. Even so, it is apparent that the way command authority is allocated to individual weapon system (System of Systems (SoS)) commanders significantly affects how the military force fights and its ability to achieve speed of effects in the Battlespace.

The central architectural views can then be used to build an organizing operational view (the Operational Event/Trace Nodal Description) that is based on two additional architecture products:

- Operational Event/Trace Description (OV-6c)
- Operational Information Exchange Matrix (OV-3)

To provide a better understanding of how the operational concept products are used in an NCW context, each product is described in the following paragraphs.

NCW High-Level Operational Concept Graphic (OV-1)

Figure 3-2a illustrates a high-level operational concept that can be used to describe the high-level warfare areas. This operational concept has five key elements:

- Command authority
- Military force
- Threat
- Battlespace
- Effects

The overarching concept is that the command authority controls the military force, which can be directed to affect a threat within a Battlespace. Understanding this concept is critical to understanding mission capability, which is defined as the means to use military force to achieve an intended and measurable effect within the Batttlespace.[19] At the highest level of abstraction, the five elements that define the High-Level Operational Concept are undefined terms that will be more fully defined as the architecture is developed. Four of these five elements are accounted for in the conceptual solution (Figure 3-1a). The command relationship (which corresponds to the Organizational Relationships Chart (OV-4)) is the one element that is not accounted for in the conceptual solution. Figure 3-2a addresses the command relationship. In order to discuss the network-centric aspects of this concept, the military force must be decomposed into an FoS, which is illustrated in Figure 3-2b as an integrated family of SoSs. This is a boundary condition in the NCW operational concept.

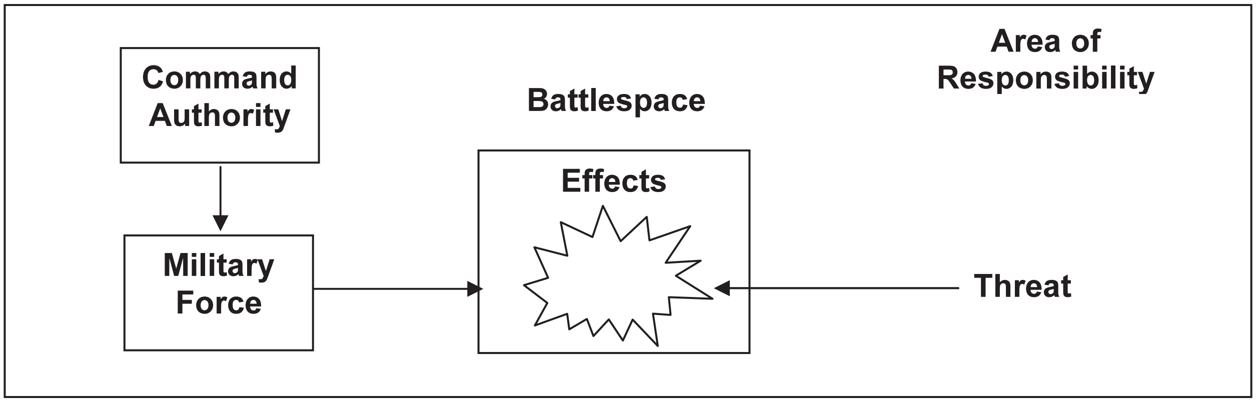

Figure 3-2a. Key Elements of the Operational Concept for Warfare Areas

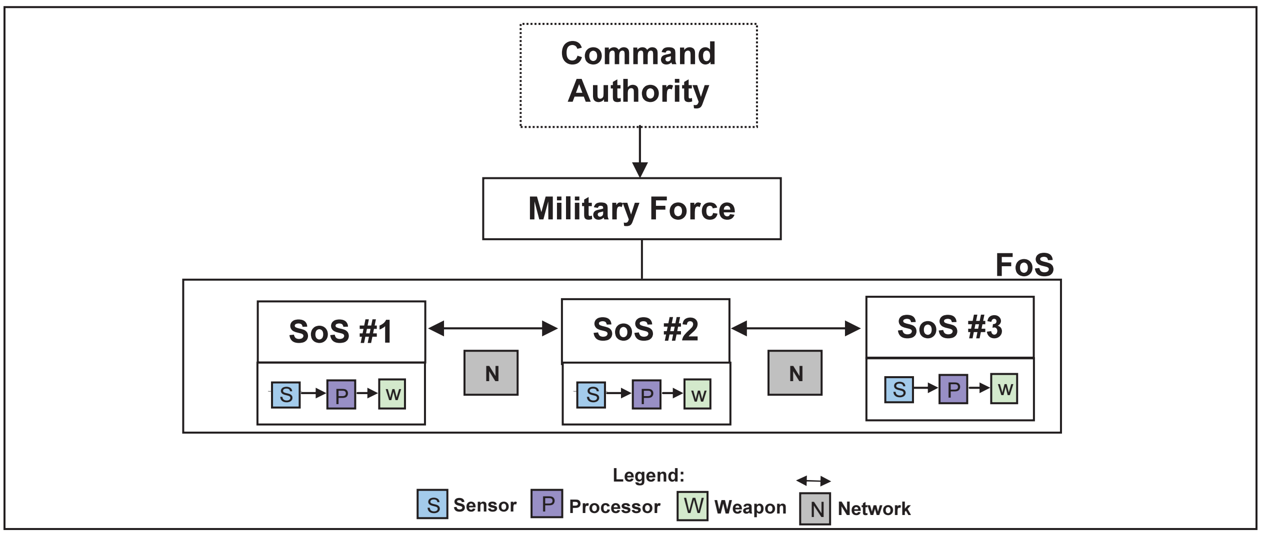

Figure 3-2b. Network Centric Aspect of the Military Force

Figure 3-2. High-Level Operational Concept Graphic for NCW (OV-1)

The NCW concept is part of an evolution that military systems have been undergoing as modern computers and communications have evolved. Twenty-first century NCW concepts are the basis for the operational construct and architectural framework for the full spectrum of warfare in the Information Age, which involves the integration of warriors, sensors, networks, command and control, platforms, and weapons into a networked, distributed combat force, scalable across the spectrum of conflict from seabed to space and from sea to land. NCW provides for the development of interoperable and horizontally integrated concepts and technologies into a highly adaptive, human-centric, comprehensive family of systems to provide near-real-time executable decision-making information throughout the Battlespace. NCW capabilities will be built to conform to joint architectural frameworks that will link current and future sensors, command and control elements, and weapons systems in a robust, secure, and scalable way. Information will be converted to actionable knowledge and disseminated to a dispersed combat force, enabling the rapid concentration of the full power of the sea, air, land, and space components while greatly reducing the quantity of required forces and assets. Information Age warfare also emphasizes the human factor in the development of advanced technologies. This philosophy acknowledges that the warrior is a premier element of all operational systems.

Today, NCW is moving from concept to reality. Initial efforts will focus on integrating existing networks, sensors, and command and control systems. In the years ahead, NCW will enable the Joint Services to employ a fully netted force, engage with distributed combat power, and command with increased awareness and speed.

Network centricity is obviously a key element of the concept, but it must be remembered that network centricity is a warfare enabler that must always be discussed in the context of the warfare mission. To do otherwise would be to leave the "W" out of NCW. NCW principles and architectures can be applied to any and all of the five Joint Warfare Architecture (JWAR) high-level areas:

- Power projection
- Sea dominance
- Air dominance
- Space dominance
- Information superiority

These warfare areas can be used to organize and focus the meaning of the increased mission effectiveness to be enabled by the tenets of NCW. This suggests that warfare mission capabilities can be divided into components related to the Battlespace. There are five physical components (undersea, sea, land, air, and space) and one information component (cyberspace). The area of operation (AO) for the military forces provides a second dimension for describing components of mission capabilities. Joint doctrine defines the AO as an operational area identified by the JFC for land and sea forces and differentiated from the operational area in that it does not typically encompass the entire operational area.[20] It is therefore reasonable to introduce an AO component based on the same localities used in the JWAR decomposition.

Figure 3-3 summarizes the mission capability components for the Precision Engagement example shown in Figure 3-1a. This warfare mission capability will be discussed in detail in the case study in Chapter 4. As shown in the matrix, Precision Engagement causes effects in the Battlespace against targets on land or against the cyberspace through which they operate. Precision destruction of the target and/or disruption of the target's operations through focused effects on the target or the target's cyberspace are the Battlespace effects of the Precision Engagement example.

Battlespace Components

Area of Operation	Area of Battlespace Effects					
	Undersea	Sea	Land	Air	Space	Cyberspace
Undersea						
Sea						
Land			✓			
Air			✓			✓
Space						
Cyberspace						✓

Figure 3-3. Mission Capability Components for Precision Engagement Example[ǂ]

[ǂ] A mission capability component is a Battlespace component affected from an area of operation.

Network centricity can enable several warfare capabilities:

- Speed of effects
- Massing of effects
- Coordinated operations from dispersed assets

The activity model must be at a sufficient level of detail to show how the activities lead to effects (and capabilities) in the execution model. Moving from the operational concept into operational activities is the subject of the next section in this chapter.

Moving from the Operational Concept to Activities

Establishing the high-level operational concept for the NCW mission is critical to moving forward in developing and ensuring the validity of an architecture that can support a mission. But once the concept is established, the systems architect or engineer must drill down from the concept to determine how the conceptual mission will be executed. In any NCW mission, the critical enabling factor is the ability to exchange the right information and services at the right time and place. To deliver this enabling capability, the systems architect must identify the information needs, types of exchange, and exchange abilities associated with the NCW mission. The operational concept introduced in Figure 3-1a illustrates this point. As shown in the graphic, both TRIXS and CDL are being used for information transfer, but there is no way to know that CDL is taking raw data from its sources, while TRIXS is using processed data. Obviously, this information is crucial to successful mission execution. Understanding what the systems are doing at the engineering level is part of understanding the operational concept. The key point is that the information needs, types, and functional flow drive the feasibility of the architecture. Determining these critical information exchange requirements begins with an analysis of the operational activities that support mission execution.

Operational Activity Model (OV-5)

The Architecture Framework describes the Operational Activity Model (OV-5) as the applicable activities associated with the architecture; the data and/or information exchanged between activities; and the data and/or information exchanged with other activities that are outside the scope of the model (i.e., external exchanges). The Activity Model captures the activities performed in a business process or mission and their Inputs, Controls, Outputs, and Mechanisms (ICOMs). Mechanisms are the resources that are involved in the performance of an activity. The objective behind the Operational Activity Model is development of several small, quick-to-develop models rather than a large, many-layered model that may be cumbersome to use and time-consuming to develop. The Activity Model generally includes a chart of the hierarchy of activities covered in the model.

In Figure 3-1b, the Detect/Control/Engage paradigm was introduced. This is a first-level decomposition of the conceptual solution shown in Figure 3-1a and allows organization of the standard operational activities associated with the mission into a second-level hierarchy. The standard operational activities are taken from the Universal Joint Task List (UJTL) and the Services-derived task lists. The Detect/Control/Engage paradigm is not part of the UJTL; it is an organizing principle related to the mission. Table 3-1 illustrates a reasonable grouping of activities against the Detect/Control/Engage model. For illustrative purposes, a minimal set of operational activities was chosen. These activities provide the next level of detail regarding what must be done, but they do not provide any design details except one: it is envisioned that a missile will fly into the Battlespace to engage the target.

Table 3-1
NCW Operational Activity Model (OV-5) Using Detect/Control/Engage Hierarchy

Detect	Control	Engage
• Search • Detect target • Detect environment	• Identify target • Geolocate target • Nominate target • Issue fire order	• Execute fire order • Weapon fly out

Referring once again to the conceptual solution shown in Figure 3-1a, it should be clear that the use of the Detect/Control/Engage paradigm provides the ability to align most of the activities associated with the mission depicted in that graphic. What should also be clear, though, is that the command authority for many of the mission participants is not illustrated. Understanding the Organizational Relationships for the mission is critical to determining if the architecture can support mission execution. Accordingly, the Detect/Control/Engage paradigm should be expanded to include Command as well. Table 3-2 adds Command to this paradigm and identifies the activities associated with that element of the paradigm.

Table 3-2
NCW Operational Activity Model (OV-5) Using
Detect/Control/Engage/Command Hierarchy

Detect	Control	Engage	Command
• Search • Detect target • Detect environment	• Identify target • Geolocate target • Nominate target • Issue fire order	• Execute fire order • Weapon fly out	• Update mission plan • Deconflict airspace • Grant permission to fire

Once the activities of the NCW mission operational concept have been grouped in accordance with the Activity Model, the key Information Elements (IEs) that support those activities can be identified. This is a critical step in determining whether or not the information exchange requirements associated with the NCW operational concept can be supported by the architecture. Table 3-3 shows the IE outputs for the NCW mission previously introduced in Figure 3-1a at each level of the hierarchy addressed in the Activity Model.

It should be noted that choosing a different operational and system solution for the mission will not generally change the operational activities and key IE outputs identified in Tables 3-2 and 3-3. For example, suppose the customer chose to use an Electromagnetic Countermeasures (ECM) solution rather than using a missile. In that case, electromagnetic waves would penetrate the Battlespace instead of a missile. The operational activities would not be changed by choosing an ECM solution, but meanings or interpretations of activities could be changed. For example, employing active ECM might cause "Deconflict airspace" to mean "Deconflict EMI with friendly electronic equipment." The ECM solution provides an example of attacking the target's cyberspace rather than the target itself.

Table 3-3
Key IE Outputs to Activities

Operational Activity	IE Outputs	
Operational Command	▪ Collection plan ▪ Weapon Target Plan	▪ Permission to fire
Detect	▪ Sensor reports - Target detections and features - Environment detections and features	
Control	▪ Target nomination	▪ Fire order - Fire control solution
Engage	▪ Weapon launch report	▪ *Effects on target**

**While effects on the target are an important output of the Engage activity, they are not an information element.*

While grouping the activities from the Figure 3-1a operational concept into the Detect/Control/Engage/Command hierarchy does offer some level of organization of the operational activities, it fails to provide a sense of activity flow. The activity flow will be discussed later in this chapter, but it should be noted here that the flow is rooted in the logical relations between the activities. The logical relations between activities provide a starting point for understanding activity flow. Figure 3-4a illustrates the simple logical relations between the three high-level activities; in other words, it shows the input/output relationships. In contrast to the simple one-to-one relation shown in Figure 3-4a, Figure 3-4b illustrates how activities (in the second level relations) can exist in a one-to-many relationship. The dashed line in the graphic indicates that relations between activities can occur that were not envisioned in the activity model. An example of this type of dotted-line relationship would be the detection of a target in the presence of clutter or other interfering signals.

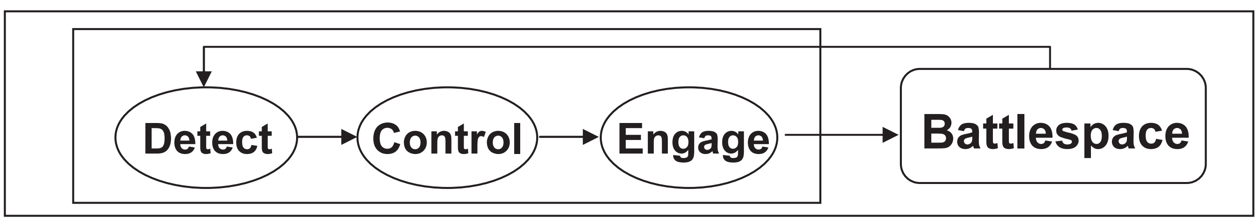

Figure 3-4a. Example of First-Level Relations

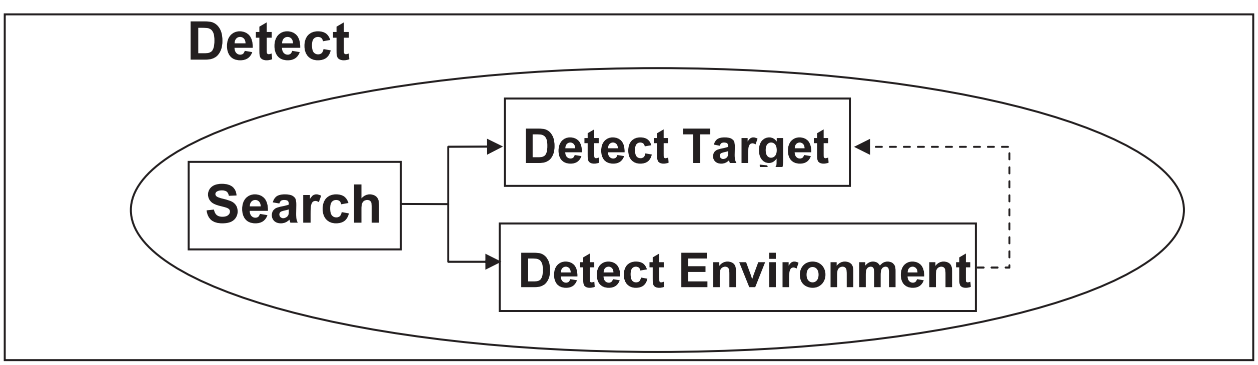

Figure 3-4b. Example of Second-Level Relations

Figure 3-4. Logical Relations among Activities

The logical relations of the activity model can be illustrated through the use of an Operational Node Connectivity Description (OV-2) view, which is described next in this chapter.

Operational Node Connectivity Description (OV-2)

Before Operational Node Connectivity Description can be addressed, it is important to recall what an Operational Node actually is. An Operational Node is a collection of one or more activities that operates under a single authority, produces one or more outputs, and interacts with other Operational Nodes. Figure 3-5 provides an illustration of an Operational Node Connectivity Description Diagram that shows the logical relations of a high-level activity model in which each first-level activity is treated as a node. The nodal relations are established by exchange of IEs and do not necessarily imply Organizational Relationships.

In order for the Operational Node Connectivity Description view to be useful in showing how activities under the control of a single authority are integrated with each other and how the node itself interacts with other nodes, it is critical to adopt a uniform nodal activity model. While the Detect/Control/Engage model calls out three distinct nodes of the conceptual solution in Figure 3-1a, it does not provide a model of what is happening *inside* the node. Each of the nodes in Table 3-2 clearly has a different purpose and different activities to be performed. A uniform nodal model would provide an organization of the operational activities in ways that allow easy assemblage of OV-2 nodes into an architecture. The significance of this subtle point may not be obvious when there are only three nodes (e.g., Detect/Control/Engage) to be instantiated. When there are dozens, or hundreds, or even thousands of nodes in a complex FoS, however, the uniform internal organization of the nodes will dramatically affect whether the nodes can be easily "assembled" (i.e., be integrated together and be made interoperable).

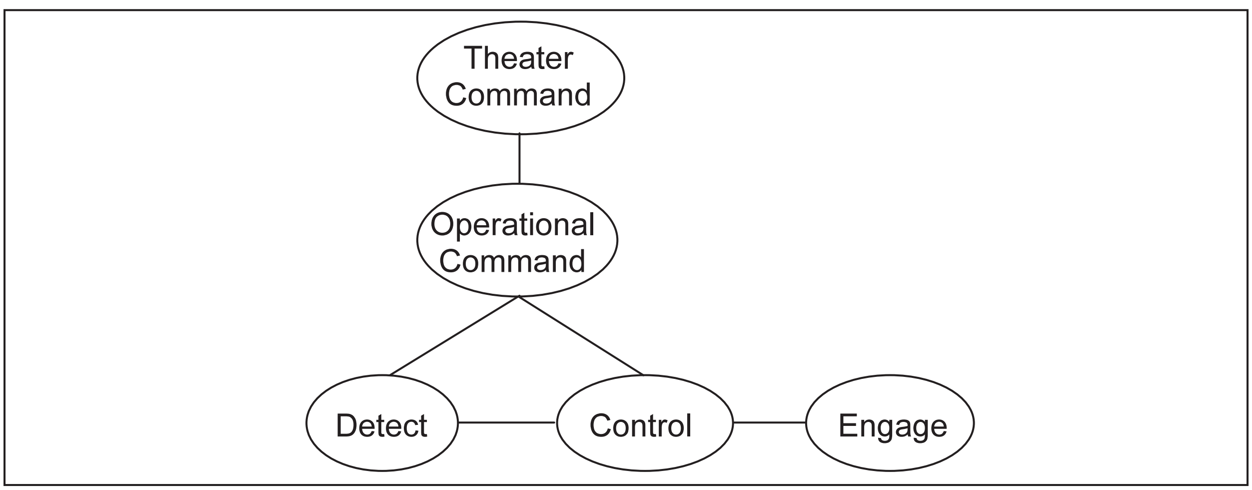

Figure 3-5. Operational Node Connectivity Description Diagram (OV-2) for Precision Engagement Example

Figure 3-6 illustrates a nodal model that can be used uniformly across the architecture. The specific nodal capability identified in the graphic will determine the activities performed for the node. The DoD Architecture Framework views the OV-2 nodes as bundles of activities; in other words, the nodal activity model for "Detect" would include all of the activities associated with that overarching activity. Mission capabilities can also be treated as overarching nodes. Figure 3-6 adds to this concept by providing the layers, including services and physical assets, through which the node is instantiated. In this case, the model for the specific warfare capability of Precision Engagement would be the center (the Operational Activity Model). The Precision Engagement node would then decompose into the four nodes shown in the hierarchy in Table 3-2.

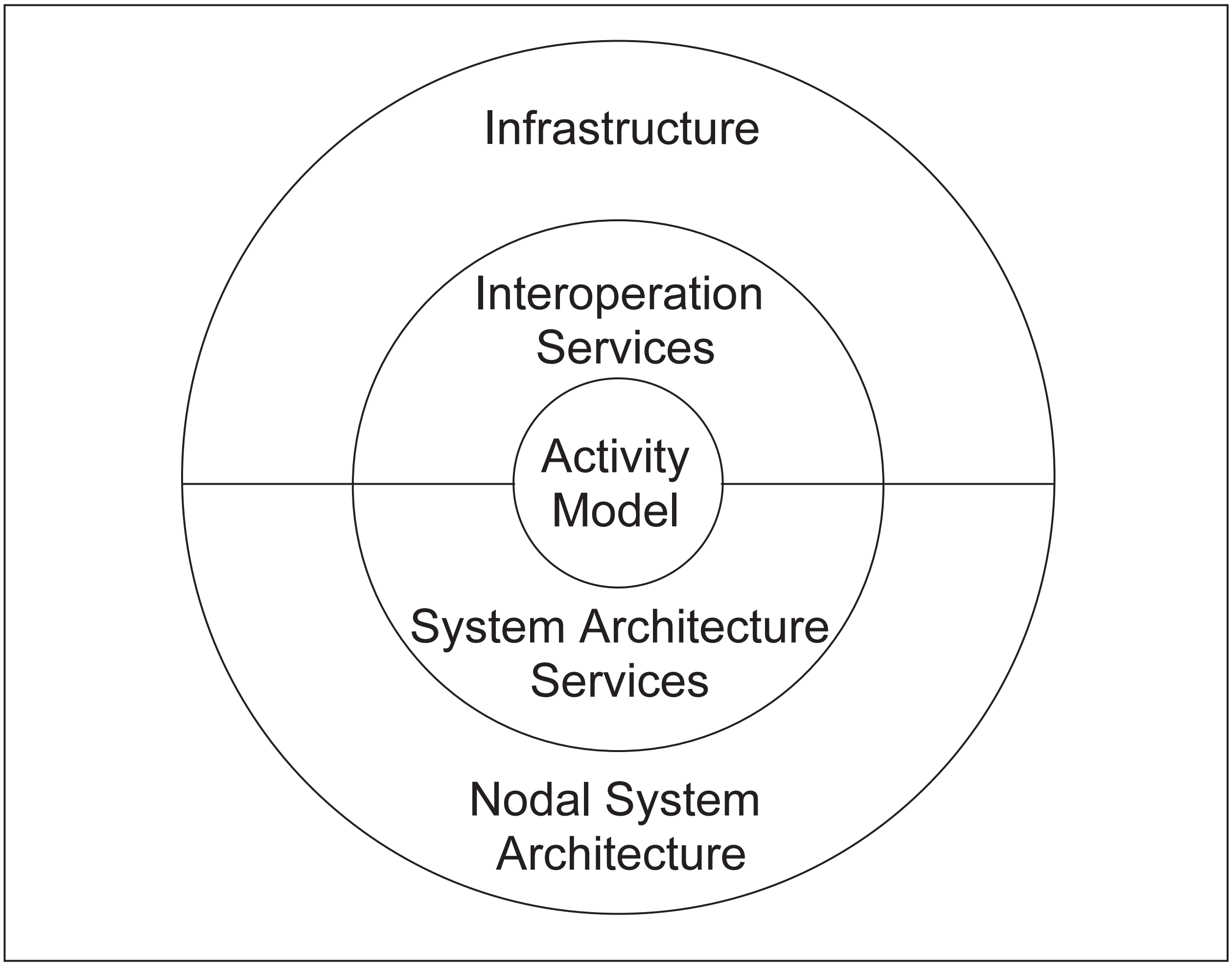

Figure 3-6. Uniform Nodal Model

The logical relations of the Nodal Activity Model depend in large part on the Organizational Relationships established for the mission. These relationships are described in the Organizational Relationships Chart (OV-4) view.

Organizational Relationships Chart (OV-4)

The Organizational Relationships Chart (OV-4) illustrates the relationships among organizations or resources in an architecture. These relationships can include command, control, and coordination relationships (which influence what connectivity is needed) as well as many others, depending upon the purpose of the architecture. It is important to include these relationships in an operational view of an architecture because they illustrate fundamental roles and management relationships.

NCW can achieve mission effectiveness through the innovative use of command and control (C^2). Figure 3-7 shows that the military force in this architectural description will operate at the tactical level and be under ultimate control of the Theater Commander. How the Theater Commander allocates command authority to the individual systems or SoS commanders will significantly affect how the military force fights and its ability to achieve speed of effects in the Battlespace. Figure 3-7 illustrates a possible C^2 concept that could be used for this NCW mission.

Command relationships for NCW missions can vary from highly centralized control to command by negation. The operational situation will determine the appropriate command structure. For example, in a conflict with heightened political consequences, it may be more appropriate to have centralized command. From the perspective of developing an architecture to support the mission, it is critical to identify the organizational relationships, because each command structure will have differing needs for information and communications support. These needs must be understood in order to develop an architecture that will be effective in accomplishing the mission. Figure 3-7a shows the hierarchy of command relations for this case study.

The matrix of command relations provided in Figure 3-7b is the first architectural artifiact that illustrates the nodal model of the OV-2 node as having command relationships in a structured control construct (i.e., each node has a single point of entry for control). For example, the command and control (through the Theater Commander) that enters through the Operational Command node and exits through the Control and Engage node shows that the Operational Commander is under the control of only *one* superior node. These entry and exit points are also the first high-level descriptions of the lines of communication.

The architectural products introduced thus far to describe the Operational Concept (the High-Level Operational Concept Graphic, the Operational Activity Model, the Operational Node Connectivity Description Diagram, and the Organizational Relationships Chart) enable the systems architect or engineer to move from an operational mission concept to a structured, controlled construct for meeting the mission objectives. Essentially, during the construction of the Operational Concept views, the systems architect develops a collection of Operational Nodes through which the mission will be executed. What none of the previously introduced products provide is a means for determining the executability or dynamic validity of this operational view of the architecture. The Operational Event/Trace Description (OV-6c) provides this capability.

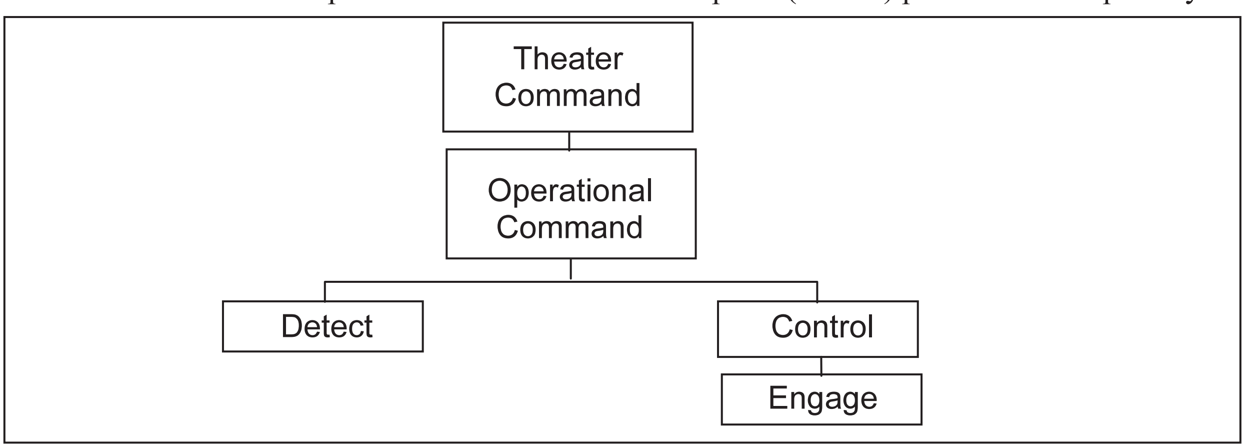

Figure 3-7a Hierarchy of Command Relations

Node n

Node m	Theater Command	Operational Command	Detect	Control	Engage
Theater Command		Sp	—	—	—
Operational Command	Sb		Sp	Sp	—
Detect	—	Sb		P	—
Control	—	Sb	P		Sp
Engage	—	—	—	Sb	

Legend:
Node m is ____ to Node n (m = row, n = column)
Sp = Superior
P = Peer
Sb = Subordinate
- = No direct relationship (i.e., no nodal connectivity)

Figure 3-7b. Matrix of Command Relations

Figure 3-7. Organizational Relationships Chart (OV-4) for Precision Engagement Example

Operational Event/Trace Description (OV-6c)

Operational activities should result in accomplishment of the mission objective, or causation of the desired effect in the Battlespace. The Operational Event/Trace Description enables traceability of actions in a scenario or critical sequence of events so the architect can determine if the activities will, in fact, deliver the desired result. Basically, it introduces timing and sequence into the Operational Activity Model. An Operational Event/Trace Description (OV-6c) is provided in Figure 3-8.

The Operational Event/Trace Description can also be organized into Nodal Model activities using the Operational Node Connectivity Description (OV-2) and the Organizational Relationships Chart for control (or triggering) of architecture responses to scenario events. This organization of the Operational Event/Trace Description is shown in Figure 3-9. Note that the "Update Mission Plan" activity must be visited twice, first when the "trigger" from the "Issue Task Order and Guidance" starts the execution sequence and again when a target is nominated. If Battle Damage Assessment were included in the execution sequence, "Update Mission Plan" would in fact be revisited a third time.

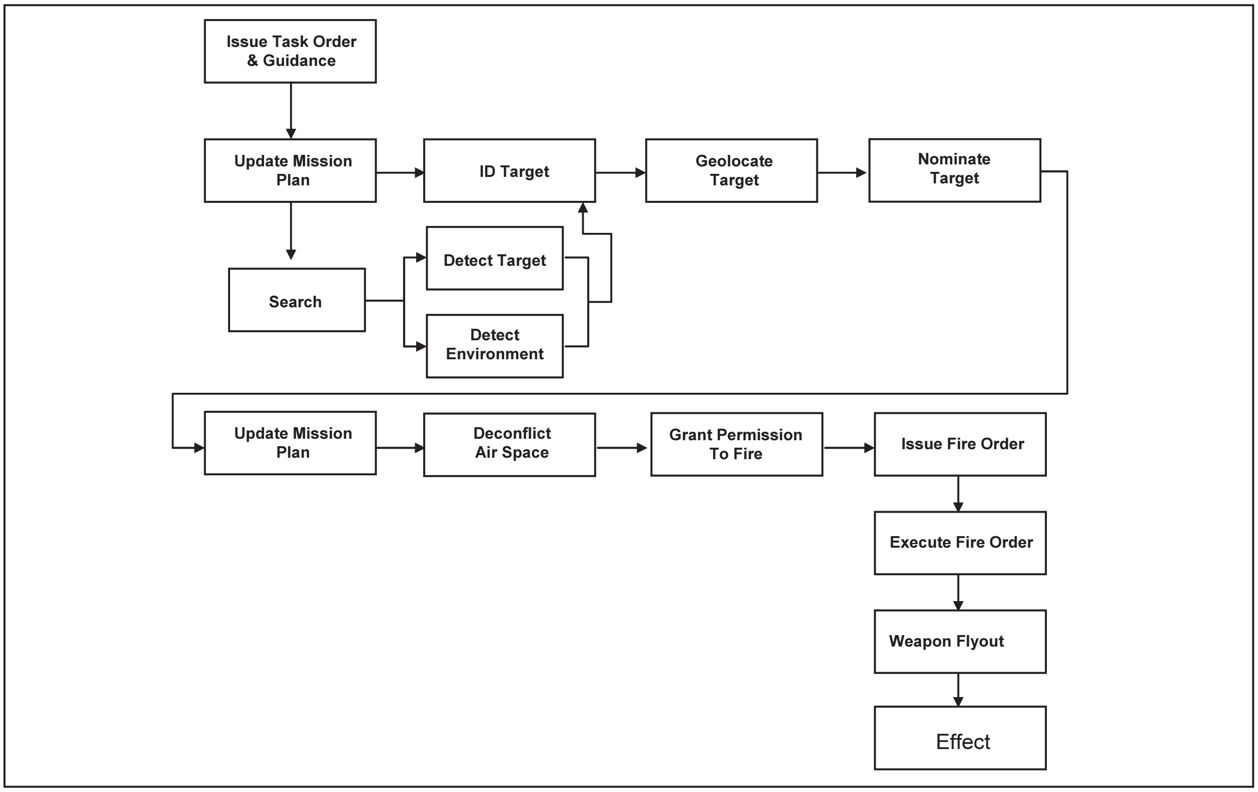

Figure 3-8. Operational Event/Trace Description (OV-6c) for Precision Engagement Example

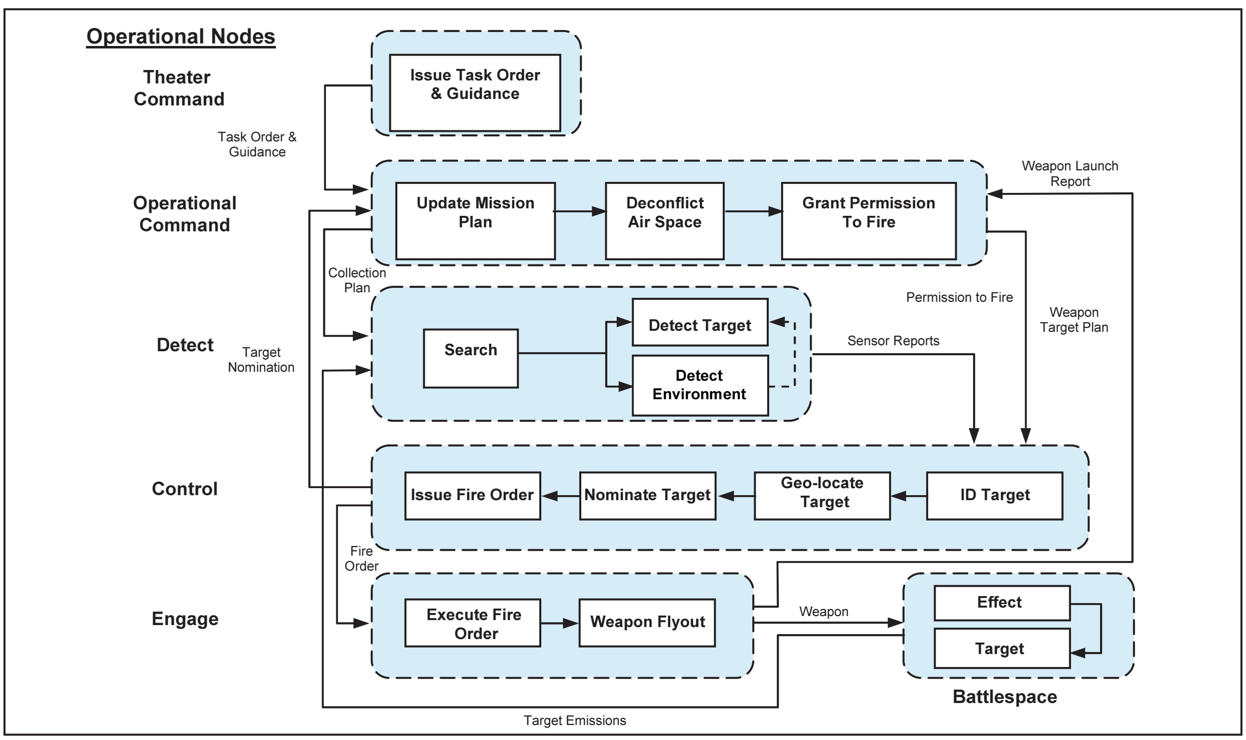

Figure 3-9. Operational Event/Trace Nodal Description (OV-6c)

Operational Information Exchange Matrix (OV-3)

The Operational Node Connectivity Description Diagram (OV-2) can be used to create a nodal version of the Operational Event/Trace Description (OV-6c) using an Operational Information Exchange Matrix (OV-3). This view traces the operational activities to operational nodes along with their associated IEs. The Architecture Framework defines the IERs of the Operational Information Exchange Matrix (OV-3) view as the relationship among three basic entities (activities, operational nodes, and information flow) of the operational view of the architecture. Using the sample architecture for NCW engagement illustrated in Figure 3-8 and the information elements for the Operational Activity Model provided in Table 3-3, it is possible to build a sample IER matrix, which is displayed in Table 3-4. Because the Operational Information Exchange Matrix displays exchanges between the operational nodes of the Operational Node Connectivity Description (OV-2), the groupings and connections of the OV-2 cause a reorganization of the outputs of the Operational Activity Model (OV-5) that were previously illustrated in Table 3-3. In the representation of the OV-3 provided in Table 3-4, each need line of the OV-2 is represented by a line (or table entry).

Table 3-4
Operational Information Exchange Matrix (OV-3) for Precision Engagement Example

Source OV-2 Node	Nodal Activity	Information Element	Receiving OV-2 Node
Theater Command	Issue Task Order and Guidance	Task Order and Guidance	Operational Command
Operational Command	Update Mission Plan	Collection Plan	Detect
	Update Mission Plan	Weapon Target Plan	Control
	Grant Permission to Fire	Permission to Fire	Control
Detect	Detect Target	Sensor Reports	Control
	Detect Environment	Sensor Reports	Control
Control	Nominate Target	Target Nomination	Operational Command
	Issue Fire Order	Fire Order	Engage
Engage	Execute Fire Order	Weapon Launch Report	Operational Command

Operational Concept Summary

Once the OV-6c nodal description is developed, the systems architect will for the first time have both the activities and the information flow identified so that the high-level operational concept introduced in the OV-1 can actually be understood from an architectural perspective. This product connects the end-to-end execution of activities to mission capability, so it automatically provides a mission capability tracking function. It must be noted, however, that at this time, no physical solution has been assumed. Physically instantiating the operational concept comprises the next steps in the process.

System Functional Mapping

With the completion of the Operational Concept views, the systems architect or engineer is now in a position to do the actual systems engineering against a more rigorously defined operational concept. This systems engineering begins with System Functional Mapping. Due to the complexity of the FoSs of interest, simply keeping track of the data describing the systems, their relationships, and their evolution is an overwhelming task. System Functional Mapping of the solution provides a stable model that facilitates the management of the data describing the systems, their relationships, and their evolution as well as the mapping of systems to functions. The NCW System Functional Mapping can be described using three architecture product series:

- Systems Functionality Description (SV-4) series
- Operational Activity to Systems Function Traceability Matrix (SV-5)
- Systems-to-Systems Matrix (SV-3) series, which includes the Systems to Systems Functions Mapping (SV-3a), the Operational Activities to Systems Traceability Matrix (SV-3b), and the Systems^2 Matrix (SV-3c)

Each product series and its use in an abstract NCW context are described in the following paragraphs.

Systems Functionality Description (SV-4) Series

The functions and primary data flow between functions required to support operational concepts are presented in the System Functionality Description (SV-4), which is applicable to a broad spectrum of mission capability architectures including Theater Air Missile Defense (TAMD), Strike, Undersea Warfare, Information Operations, Counter Terrorism, Expeditionary Warfare, Navigation, Battle Force Command and Control, and Intelligence, Surveillance, and Reconnaissance. The System Functionality Description (SV-4) series includes the High-Level Systems Functions List (SV-4a), Systems Functional View (SV-4b), and Logical Interface View (SV-4c). The High-Level Systems Functions List is presented in the following paragraph, but it is followed by a description of the Operational Activity to Systems Function Traceability Matrix (SV-5). While the SV-5 is not part of the SV-4 series, it is presented in the middle of the SV-4 series because this order reveals the logical flow of the products. Following the discussion of the SV-5, the Systems Functional View (SV-4b) and Logical Interface View (SV-4c) are presented.

In discussing the High-Level Systems Functions List (SV-4a), it is important to note that each of the nodal activities of the Precision Engagement model will involve performance of four high-level system functions:

- Sense
- Command
- Act
- Interoperate

The first three directly enable operational activities, but the last one is primarily related to the exchange of information and services between operational nodes. Table 3-5 provides definitions for the first-level system functions. The second level functions will also be needed to describe how the systems will support the activity models shown for the Operational Event/Trace Description (OV-6c, shown previously in Figures 3-8 and 3-9).

Table 3-5
High-Level Systems Functions List (SV-4a)

First-Level Functions	Definitions
Sense	Functions that perform detection and identification of objects in the area of interest and develop imagery, track, and parametric data on these objects; involves receipt of data from objects outside the system that provide the system with knowledge/data regarding these objects outside the system; includes fusion of data from multiple sources to create a common sensor picture of the area of interest; could be receipt of a signal or receipt of an emission
Command	Functions that support and perform decision-making processes that effectively and efficiently direct the force(s) under command and that support the employment of offensive and defensive weapons; involves communication of an executable order; requires output of Process (to create the order) and use of Interoperate (to transmit the order)
Act	Functions necessary to deploy, maneuver, sustain, and/or configure platforms, troops, cargo, sensors, and weapons and to execute engagements; a physical response to a command (e.g., change the state of a switch; launch a weapon; transmit data); can be thought of as "actuation"
Interoperate	Functions that support data dissemination, including formatting, access, and routing of data to and between all other functions; also includes the development and dissemination of common reference time, navigation, and METOC data; additionally, includes all communication functions

Operational Activity to Systems Function Traceability Matrix (SV-5)

Figure 3-10 provides a high-level operational activity to system function traceability matrix (SV-5). It traces the enabling of operational activities by system functions. The Sense function enables the Detect activity. It should be noted that the Sense function in the Precision Engagement example is done at the FoS level and requires the use of multiple sensors. The Act function is related to physical response, and the Command function is related to decision-making and planning. The Interoperation function connects the high-level activity nodes and supports the issuance of orders. Figure 3-10 illustrates the case for the Precision Engagement example in which each of the three high-level activities is treated as a separate node based on the specific nodes of the Operational Node Connectivity Description (OV-2) illustrated previously in Figure 3-5.

Enabling System Function	Operational Activity		
	Detect	Control	Engage
Sense	✓	✓	
Command		✓	
Act			✓
Interoperate*	✓	✓	✓

Figure 3-10. Operational Activity to Systems Function Traceability Matrix (SV-5)
** The interoperation in this model is based on the OV-2 description that makes each element of the Detect-Control-Engage hierarchy a separate node.*

The SV-5 must be expanded to the next level of decomposition in order to understand why the Sense function supports both the Detect and Control activities. Table 3-6 shows the System Functionality Description (SV-4) and Operational Activity to System Function Traceability Matrix (SV-5) level of detail necessary to relate the systems functions to the second-level operational activities presented in the Operational Event/Trace Description (OV-6c). Additionally, Chapter 7 provides an example of a more detailed SV-4 and SV-5.

Table 3-6
Lower-Level Operational Activities and System Functions for the Operational Activity to Systems Function Traceability Matrix (SV-5)

OV-2 Node	Operational Activity	System Function		Nodal IE
Operational Command	Update mission plan	Command	Weapon target association	Weapon target plan
			Collection options	Collection plan
	Deconflict airspace		Air picture integration	Collection plan*
	Grant permission to fire		Decision support	Permission to fire
			Communication of order	
Detect	Search	Sense	Passive search	Sensor reports
	Detect • Target • Environment		Single sensor sense	
Control	Geolocate target	Sense	Multi-sensor sense (data alignment & association)	Fire Control Solution
	ID target		Feature extraction	
	Nominate target	Command	Decision support	Target nomination
	Issue Fire Order		Generate order	Fire Order
Engage	Execute Fire Order	Act	Weapon initialization and launch	Weapon launch report
	Weapon Fly Out		Weapon Guidance	Battlespace Effect**

**Collection plan is updated for deconfliction.*
***While Battlespace effects are an important output of the Engage node, they are not an IE.*

Systems Functionality Description (SV-4) Series (Continued)

Returning to the Systems Functionality Description (SV-4) series, the next product is the Systems Functional View (SV-4b), which depicts the logical relations of the first-level functional decomposition. These functions were previously defined in Table 3-5. The first level includes the highest order functions: Sense (blue), Command (red), Act (green), and Interoperate (gold). Figure 3-11 can be derived from the Operational Node Connectivity Description Diagram (OV-2) shown previously in Figure 3-5 by applying the Operational Activity to System Function Traceability Matrix (SV-5, shown in Figure 3-10) to the activities.

The final Systems Functional Description product is the Logical Interface View (SV-4c), presented in Figure 3-12. The Logical Interface View presents the information elements for the logical interfaces between the system functions. This view is used primarily in the second order analysis to assess completeness as well as deficiencies in integration and interoperability. This view is derived from the logical relations of the Systems Functional View (SV-4b, Figure 3-11) and the Operational Event/Trace Nodal Description (OV-6C, Figure 3-9) using the Operational Activity to System Function Traceability Matrix (SV-5, Figure 3-10).

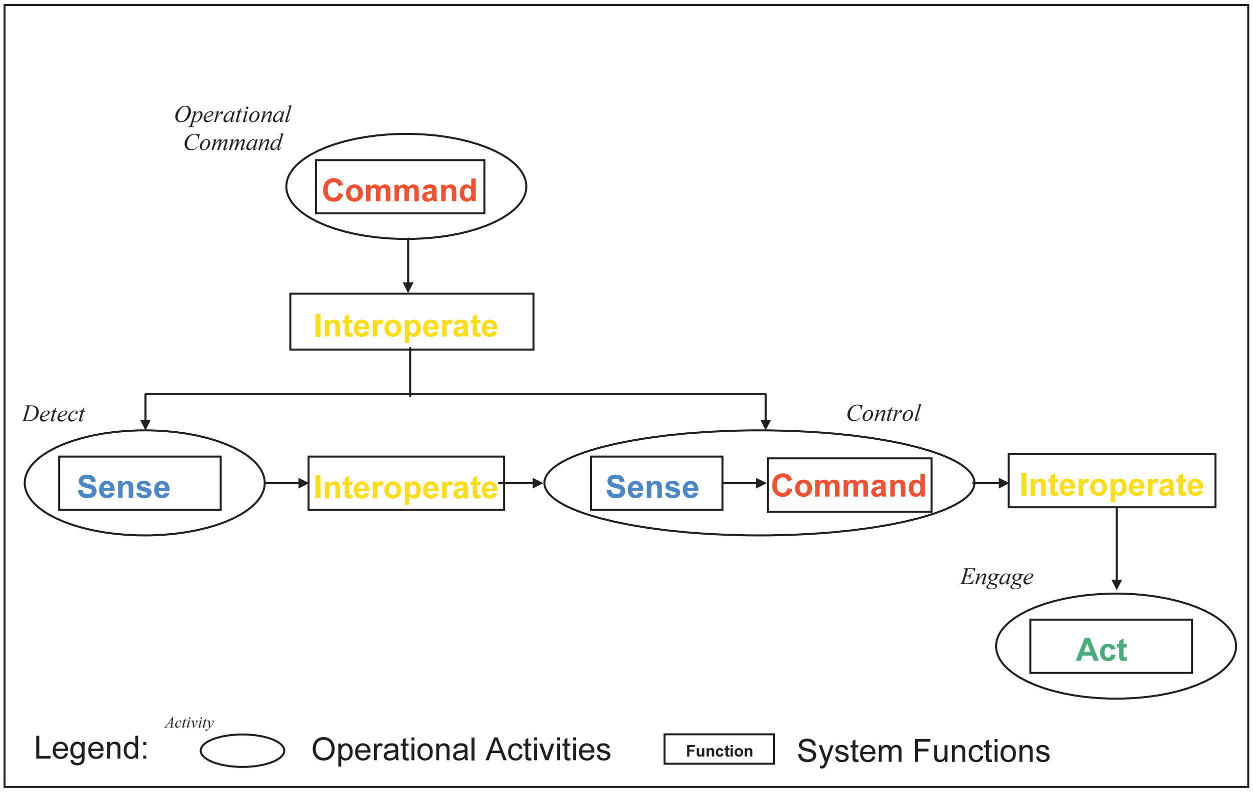

Figure 3-11. Systems Functional View (SV-4b) for the Precision Engagement Example

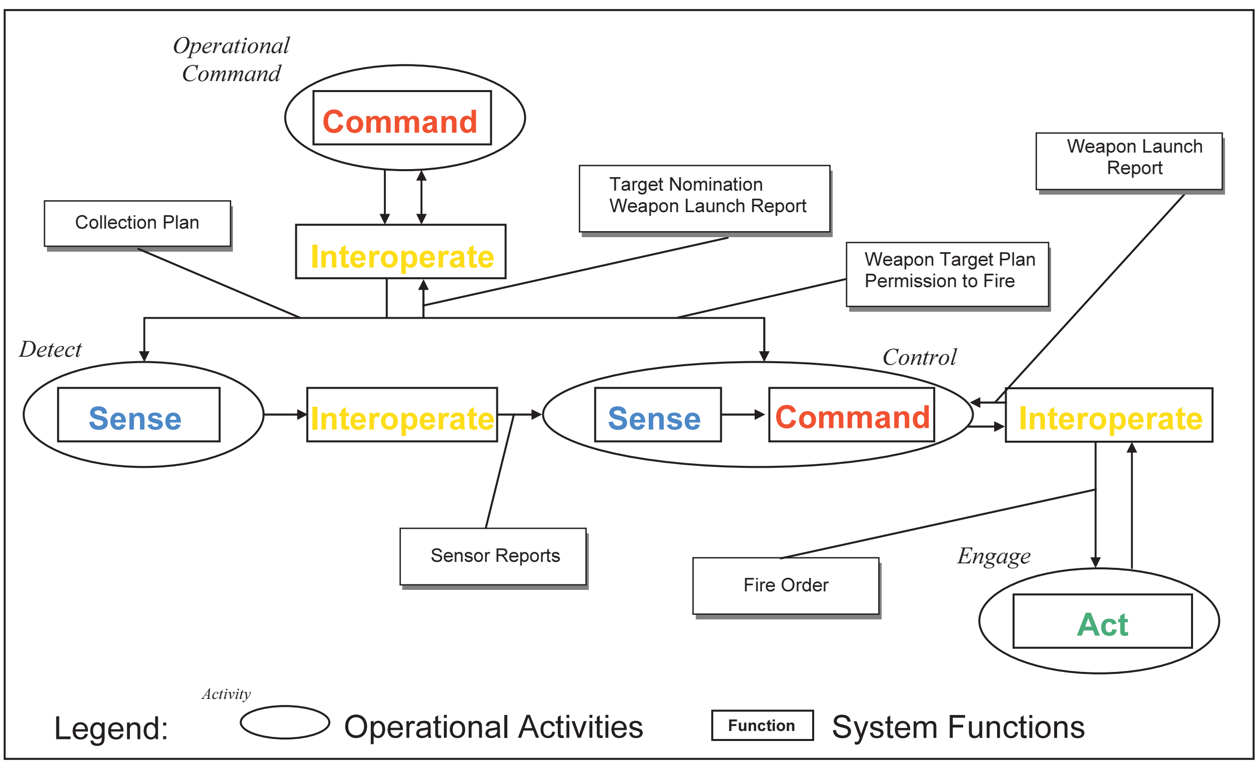

Figure 3-12. Logical Interface View (SV-4c) for the Precision Engagement Example

Systems-to-Systems Matrix (SV-3)

The Systems-to-Systems Matrix (SV-3) is more useful for FoS systems engineering when the Architecture Framework is revised to include three views:

- SV-3a: Systems to Functions Matrix
- SV-3b: Operational Activity to Systems Traceability Matrix
- SV-3c: Systems^2 Matrix

The SV-3a is a matrix that summarizes which individual physical systems are used to enable which individual system functions. Each cell of the matrix points to a functional use case of the physical systems. Using the systems functions along with the Operational Activity to Systems Function Traceability Matrix (SV-5), the Systems to Functions Matrix provides the direct traceability of operational capabilities into the physical systems of the FoS. This results in a matrix (the Operational Activity to Systems Traceability Matrix (SV-3b)) that is analogous to the Operational Activity to Systems Function Traceability Matrix but at the physical level. Each cell of the Operational Activity to Systems Traceability Matrix points to an operational use case of the physical systems. The Systems^2 Matrix is in the form of the Framework's Systems^2 Matrix, but in this methodology, it is built using the relations between system functions provided by the Systems Functional View (SV-4b). The logical interfaces of the Logical Interface View (SV-4c) taken with the Systems^2 Matrix can be used to begin building a physical instantiation of the Operational Information Exchange Matrix. Each of the three Systems Matrix views is described in the following paragraphs.

The Systems to Systems Functions Mapping must be introduced at this point to describe an FoS that can enable the system functions. An abstract approach following the concepts of Figure 3-2 can be used as a high-level description based on five principal types of systems:

- Networks
- Sensors
- Processors
- Weapons
- Platforms

This organization of the systems does have some overlap, especially at the SoS level. For example, most networks, sensors, and weapons have some form of an embedded processor. Also, many weapons have sensors. However, at the FoS level, the decomposition of the FoS into the five types is useful.

The Systems to Systems Function Matrix (SV-3a), depicted at a high level, would take the form illustrated in Figure 3-13. In this context, platforms are systems with the function of carrying and positioning networks, sensors, processors, and weapons.

Enabling System	System Function			
	Sense	Command	Act	Interoperate
Networks		✓		✓
Sensors	✓			
Processors		✓		
Weapons			✓	
Platforms			✓	

Figure 3-13. High-Level Systems-to-Systems Function Matrix (SV-3a)

Using the Systems-to-Systems Function Matrix (SV-3a, shown in Figure 3-13) and the Operational Activity to Systems Function Traceability Matrix (SV-5, shown previously in Figure 3-12), it is a straightforward exercise to derive the Operational Activity to System Traceability Matrix (the SV-3b, shown in Figure 3-14). In order to fully understand how the enabling systems interoperate with each other and are used as an FoS to enable mission capabilities, the activities (from the Operational Activity Model (OV-5)) need to be grouped into nodes that will establish natural lines of communication between physical locations. Creating these groupings is one of the purposes of the Operational Node Connectivity Description (OV-2).

Enabling System	Operational Activity		
	Detect	Control	Engage
Sensor	✓		
Processor		✓	
Weapon			✓

Figure 3-14. Operational Activity to Systems Traceability Matrix (SV-3b)

The Architecture Framework represents the SV-3 as the Systems^2 Matrix, which is a description of the system-to-system relationships identified in the internodal and intranodal perspectives of the System Interface Description. The Systems^2 Matrix, which has been denoted in this book as the SV-3c, is the first high-level exhibit of FoS systems interoperation. Specifically, it displays which systems interoperate with each other. This information cannot be derived directly from the previous architecture views. Strictly speaking, the Systems^2 Matrix needs to be derived from use cases or threads in the Operational Concept that show execution sequences enabled by systems, connectivity, and operational command relations. This need can be clearly seen if a high-level Systems^2 Matrix is constructed for the system types used in the Systems to Systems Functions Mapping (SV-3a). Figure 3-15 illustrates the Systems^2 Matrix at a high level.

		Sensors		Processors		Weapons
		S_1	S_2	P_1	P_2	W
Sensors	S_1		-	-	✓	-
	S_2			-	✓	-
Processors	P_1				✓	-
	P_2					✓
Weapons	W					

Figure 3-15. Systems^2 Matrix (SV-3c) for Precision Engagement Example

System Interface Mapping

System interface mapping can be supported through the use of six Framework products:

- Operational Node Connectivity Description (OV-2)
- Operational Information Exchange Matrix (OV-3)
- Systems Interface Description (SV-1)
- System Communications Description (SV-2)
- Technical Standards Profile (TV-1)
- System Data Exchange Matrix (SV-6)

It may be helpful to think of each of the system interface mapping Architecture Framework products as circuit cards that can be inserted into an operational context to provide ever-increasing levels of clarity regarding the mission capability achievable considering the activities, functions, systems, and connectivity either currently achievable or planned for the future. As these "circuit cards" are inserted, the architect, engineer, or acquisition specialist can acquire a snapshot of the mission capability of the FoS that includes consideration and reflection of multiple layers of interoperability and offers a more realistic perspective of the capabilities of an FoS as well as facilitated identification of critical gaps in that capability. The system use case section that follows this paragraph illustrates instantiations of the System Interface Mapping Architecture Framework products.

System Use Cases: the Instantiated Operational Nodes (OV-2)

The logical activity model depicted by the Operational Node Connectivity Description (shown previously in Figure 3-5) can be instantiated (abstractly) using the Operational Activity to System Traceability Matrix shown previously in Figure 3-14. Networks must also be allocated to the need lines of the Operational Node Connectivity Description. These instantiations of the nodes and the need lines are essentially the development of the System Interface Description (SV-1) and the System Communications Description (SV-2). Using the Sensor, Processor, Weapon, and Network symbology introduced in Chapter 1, the logical model illustrated in Figure 3-16 emerges. This is the earliest architectural graphic that describes how systems are used to enable operational activities.

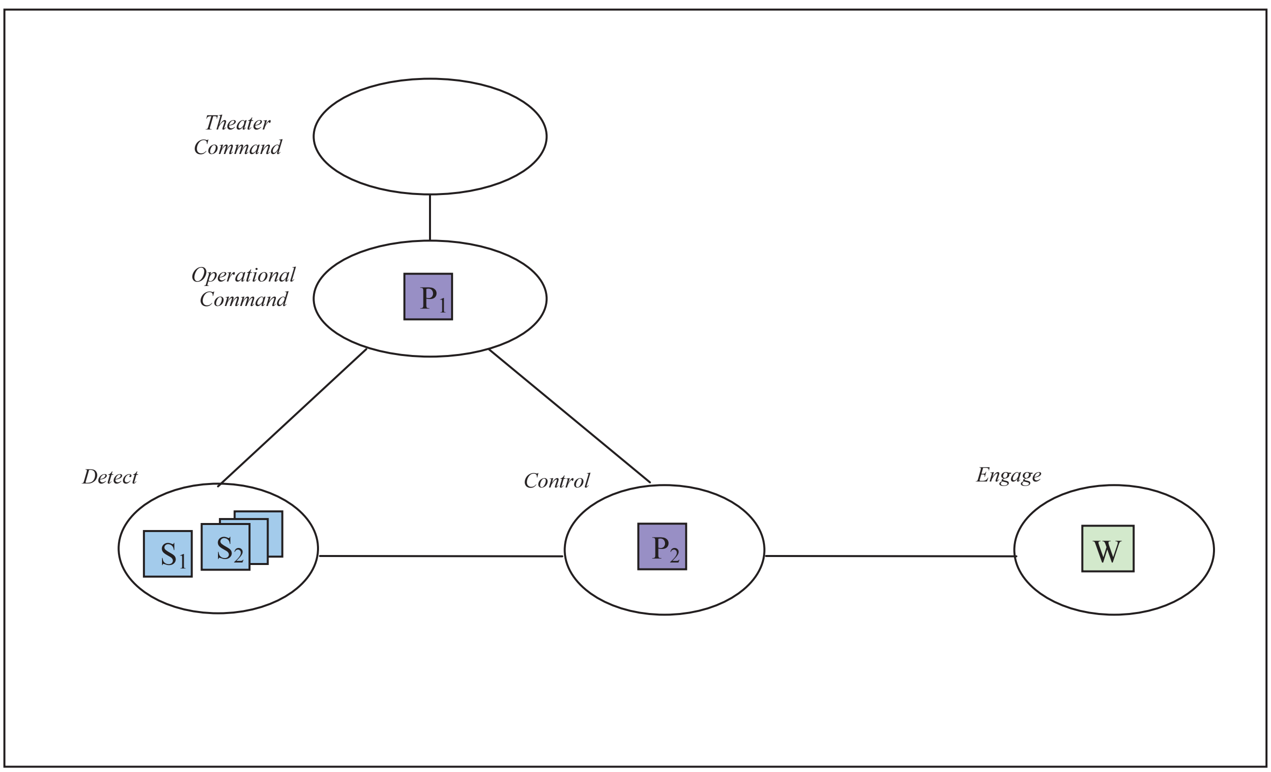

Figure 3-16a. Systems Interface Description (SV-1)

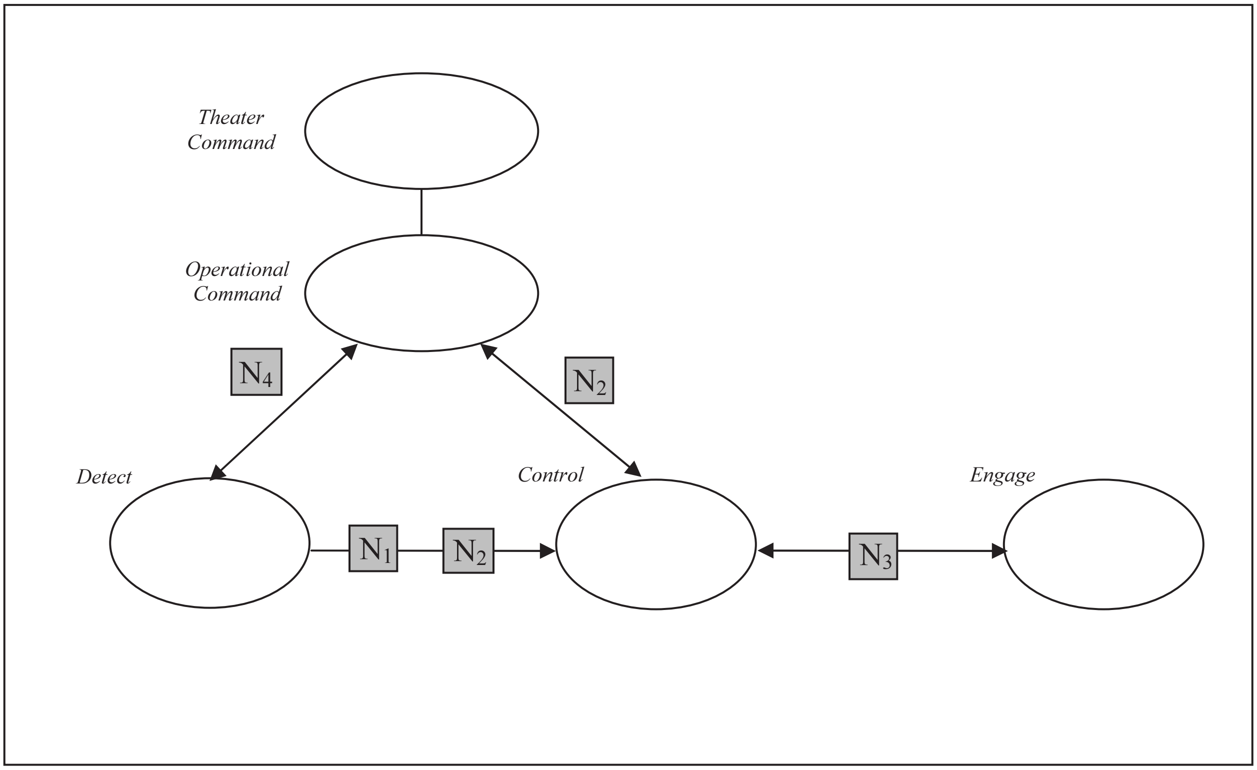

Figure 3-16b. System Communications Description (SV-2)

Figure 3-16. Abstract Instantiation of the Operational Nodes for Precision Engagement Example

Systems Interface Description (SV-1)

The System Interface Description (SV-1) associates physical systems with the operational nodes, as illustrated at a high level in Figure 3-16a. This view is derived from the Operational Node Connectivity Description (OV-2) and the Operational Activity to System Traceability Matrix (SV-3b). Following the hierarchy of Figure 1-4, two different levels of processing have been introduced. The first level (indicated as P_1) is used for command and control. The second level (indicated as P_2) is used for the processing of sensor data for tactical purposes (i.e., for directly establishing the fire control solution from sensor data). The command and control processor and network could be expected to have less stressing throughput and latency requirements than the processor and network that supports sensing and targeting directly.

This instantiation is the Nodal System Architecture of the Uniform Nodal Model presented previously in Figure 3-6. The System Architecture Services presented in the Uniform Nodal Model are the System Functions, which are linked to the Operational Activity Model by the Operational Activity to System Function Traceability Matrix (SV-5) and to the Nodal System Architecture by the Systems Matrix (SV-3) series.

Systems Communication Description (SV-2)

This view represents the specific communications systems pathways or networks through which the physical nodes and systems interface. These pathways are illustrated at a high level in Figure

3-16b. Just as it was for the Systems Interface Description (SV-1), the Operational Node Connectivity Description (OV-2) is the starting point. The Operational Information Exchange Matrix (OV-3) must also be considered, but no previous views presented from the Architecture Framework provide the communication systems or pathways to instantiate the need lines between nodes. This instantiation is the Infrastructure layer of the Uniform Nodal Model presented previously in Figure 3-6. The Interoperation Services layer would be described using standards like the Open System Interface (OSI) model.

The System Communications Description (SV-2) can also be used to revise the Systems^2 Matrix (SV-3c) to reflect the communications systems pathways that provide nodal connectivity between systems. Figure 3-17 modifies the uninstantiated version of the SV-3c presented previously in Figure 3-15 to illustrate the nodal connectivity at a high level for the Precision Engagement example.

		Sensors*		Processors		Weapons
		S_1	S_2	P_1	P_2	W
Sensors	S_1		-	-	$N_1 – N_2$	-
	S_2			-	$N_1 – N_2$	-
Processors	P_1				N_2	-
	P_2					N_3
Weapons	W					

Legend: N_1 – CDL N_2 – SATCOM N_3 – Fiber Optic? N_4 – UHF/VHF Comms

**Sensor S1 and S2 platforms are connected to Operational Command through N_4.*

Figure 3-17. Nodal version of Systems^2 Matrix (SV-3c)

The diagram in Figure 3-16 can be redrawn in the format used in Figure 1-1, which would yield the diagram shown in Figure 3-18. Diagrams like Figures 3-16 and 3-18, created using the supporting architectural exhibits in this chapter, provide the first artifacts that demonstrate the logical validity of the architecture. In practice, when architects work with users (in this case, the operators of the military systems), these users can go directly to a diagram like Figure 3-18, in a manner similar to that used in the beginning of this chapter. It is, however, the rigor of the tedious details that lays the foundation for architectural assessments, modeling and simulation, and the disciplined system engineering trades that make architectures an engineering tool. All of the previous "tedious details" must be rolled up into a database that can be used for interoperability assessments. This is the purpose of our expanded view of the Systems Data Exchange Matrix (SV-6), which is presented later in this chapter.

Technical Standards Profile (TV-1)

The Technical Standards Profile represents the technical component of the architecture in providing a set of rules that governs system implementation and operation. In this sense, the Technical Standards Profile should include more than just interface standards and protocols. In practice, however, the profile frequently provides only the list of standards and protocols associated with the transport layer of interfacing and communications between systems. This weakness is addressed in the Framework 2.0, which includes a notional example of a Technical Standards Profile that addresses service areas, services, and standards that go beyond interfaces. It may therefore be appropriate to decompose the profile into standards that align with overarching accepted standards like the Open System Interface (OSI) standard.

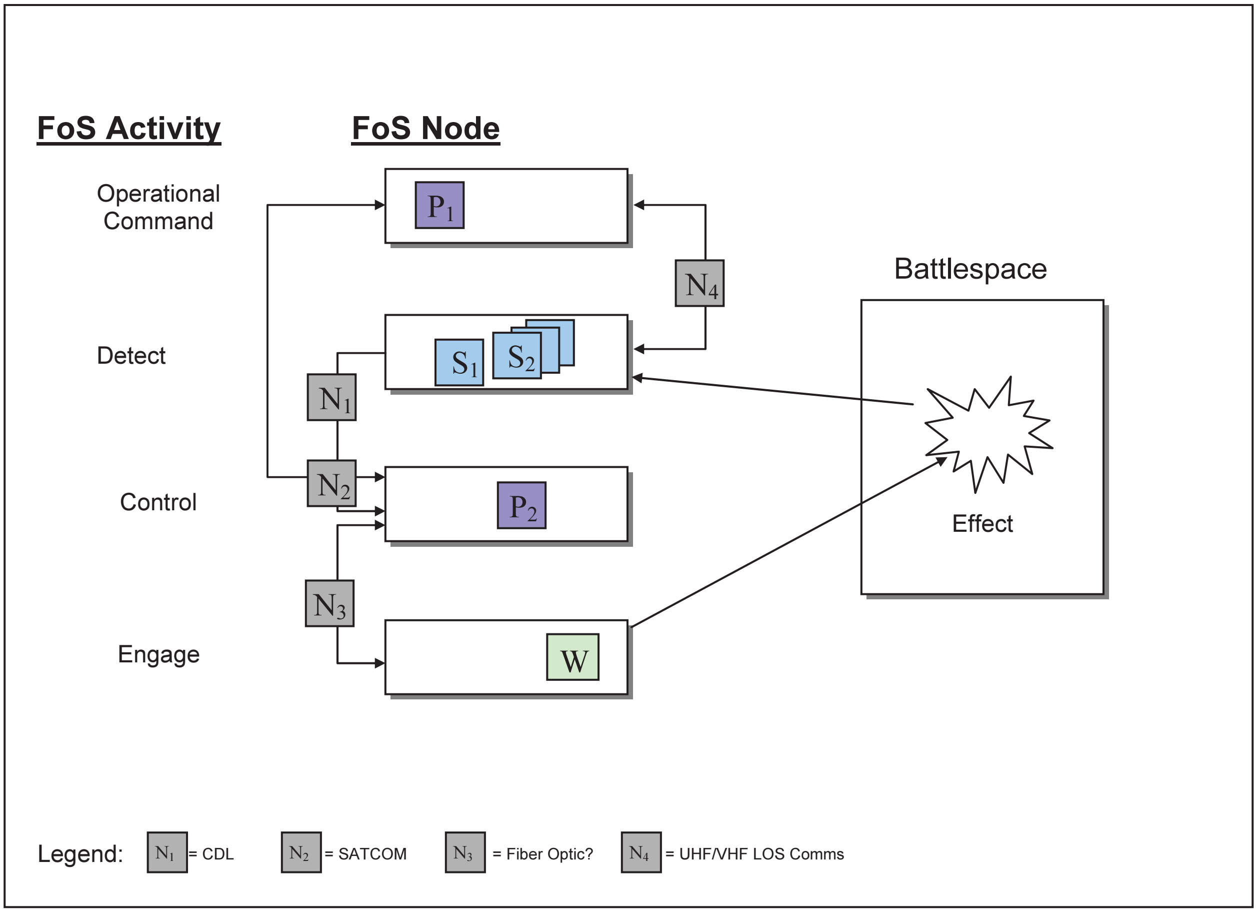

Figure 3-18. Combined Systems Interface Description (SV-1) and System Communications Description (SV-2) for Precision Targeting Example Using Centralized C^2 and Distributed Execution (Instantiated OV-2)

At the level of abstraction in Figure 3-16, it is difficult to provide abstractions of the rule sets; however, it is possible to give examples of the types of standards currently being used. Within the Technical Standards Profile, logical standards are associated with the information elements being exchanged (data) and the system function (application) processing the data. Information element standards govern the format of the data being exchanged. Examples of standards for information elements include MIL-STD-6016 for J-series bit-oriented messages; MIL-STD-6011 for M-series bit-oriented messages; Joint Publication 604 for U.S. Message Text Format (USMTF) character-oriented messages; and Imagery formats such as GIF or JPEG. System functions are enabled by applications defined at an appropriate level of abstraction or decomposition necessary for the architect to solve the problem. Some examples of system function standards include Defense Information Infrastructure Common Operating Environment (DII COE) correlation services, Simple Mail Transport Protocol (email), and Simple Network Management Protocol. Chapter 4 will provide further details on the Technical Standards Profile.

Systems Data Exchange Matrix (SV-6)

While the Architecture Framework primarily uses this view to describe in tabular format the information exchanges between systems, within a node, and to systems at other nodes, it is more useful to use this view to create end-to-end views of the system information and service exchanges. In this way, the expanded SV-6 can be used to create the first artifacts of the interoperability of the FoS/SoS. The creation of these artifacts is referred to as the static interoperability assessment. This assessment will enable the architect to determine if the architecture has the functionality and connectivity needed to support the mission capability.

The IEs and the Operational Event/Trace Nodal Description (provided previously in Figure 3-9) provide the means to identify the nodal connections and associated operational activities. These nodal connections with their associated system functions are summarized in the Logical Interface View (provided previously as Figure 3-12). As shown in the graphic, there are seven connections to be made, and each of these connections is presented in an end-to-end form in the Systems Data Exchange Matrix (SV-6) presented in Table 3-7. This example is used because of its simplicity, but in practice, this matrix can be very large. For the Navy's POM 04 Mission Capability Package (MCP) for Strike Warfare, the SV-6 matrix included 2,857 lines (connections). When these lines have been identified, it is possible to use standardized databases to determine the certification of each of the interfaces. In the Navy, for example, the Naval Command for Testing System Interoperability (NCTSI) maintains this kind of data.

Table 3-7
Systems Data Exchange Nodal Matrix for Precision Engagement Example

Source OV-2 Node	IE	Operational Activity	System Function	Interface Medium	Interface Standard	Destination OV-2 Node
Operational Command	Collection Plan	Update Mission Plan	Collection Planning	N_4	Voice	Detect
	Weapon Target Plan	Update Mission Plan	Weapon Target Association	N_2	MIL-STD-6016	Control
	Collection Plan*	Deconflict Airspace	Air Picture Integration, Dynamic Deconfliction	N_4	Voice	Detect
	Permission to Fire	Grant Permission to Fire	Decision, Target Prioritization	N_2	USMTF	Control
Detect	Sensor Reports	Detect • Target • Environment	Single Sensor Sense	N_1 - N_2	USMTF, Binary	Control
Control	Target Nomination	Geolocate, ID target	Multi-Sensor Sense, Feature Extraction	N_2	USMTF	Operational Command
	Fire Order**	Issue Fire Order	-	N_3	USMTF	Engage
Engage	Weapon Launch Report	Weapon Fly-Out	Weapon Initialization and Launch	N_3 - N_2	USMTF	Control – Operational Command

**Collection Plan is updated for deconfliction.*
***Fire Order includes Fire Control Solution.*

Architecture Assessments

As indicated in Figure 2-1 in Chapter 2, architecture assessments can be performed on two levels: static and dynamic. As indicated earlier in this chapter, the static assessment is performed using the Systems Data Exchange Matrix (SV-6) and provides the first artifacts of FoS interoperability. Dynamic assessments will provide insights into the architecture performance and behavior. At the time of the writing of this book, no mature executable models have been implemented to support dynamic assessments, although prototypes have been investigated in the mission areas of Time Sensitive Targeting and Theater Air Missile Defense.

For the Navy's POM 04 work for Time Sensitive Targeting, a logically consistent approach has been used to support static and dynamic assessments. The central exhibits for this work were the Operational Event/Trace Description (OV-6c) and its Nodal representation. The same diagrams were used by system engineers to provide performance predictions in the context of standard scenarios[‡] and by architects to provide static interoperability assessments using the Systems Data Exchange Matrix (SV-6)[‡‡]. Performance predictions by system engineers included results like the Precision Engagement Targeting capabilities improvement illustrated in Figure 1-3, as well as predictions of lethality and survivability. The POM 04 Time Sensitive Targeting work was the first substantial demonstration of the architecture-based systems engineering methodology presented in this book. It is hoped that future work will lead to executable models that simultaneously predict performance while enabling dynamic assessment of interoperability.

FoS/SoS Concepts versus Classical Systems Engineering

It is worthwhile at this point to revisit the distinction between classical systems engineering and architecture based on FoS engineering. This discussion will also serve to demonstrate the power and utility of the abstractions created in this chapter.

This chapter has focused on an architectural abstraction of a simple example of NCW Precision Engagement motivated by the Guardrail example provided in Figure 1-2 in Chapter 1. Another way to describe this example is to view it as a case in which combat systems at an SoS single platform level are being abstracted to an FoS force level implementation using network centric concepts. Figure 3-19 illustrates this point. The Aegis Combat system illustrated in Figure 3-19a is based on an activity model that uses the Detect-Control-Engage paradigm for Air Defense missions. When this combat system was designed (at the SoS level) nearly 30 years ago, the systems engineer made classical tradeoff decisions such as electing a use a new phased array radar in order to integrate detection and fire control functions. Decisions were also made to converge the multiple surface-to-air missiles used by the Navy at that time into a single product line, which was named the Standard Missile. The systems engineer for Aegis did have boundary conditions, but clearly, that engineer also had significant latitude in the design of the SoS.

[‡] The POM 04 Time Sensitive Targeting performance predictions were performed at Naval Air Warfare Center Weapons Division, China Lake, CA, by Dr. Bob Smith et al.

[‡‡] The POM 04 Time Sensitive Targeting interoperability assessments were performed at Space and Naval Warfare Systems Command Systems Center Charleston, SC, by Phil Charles et al.

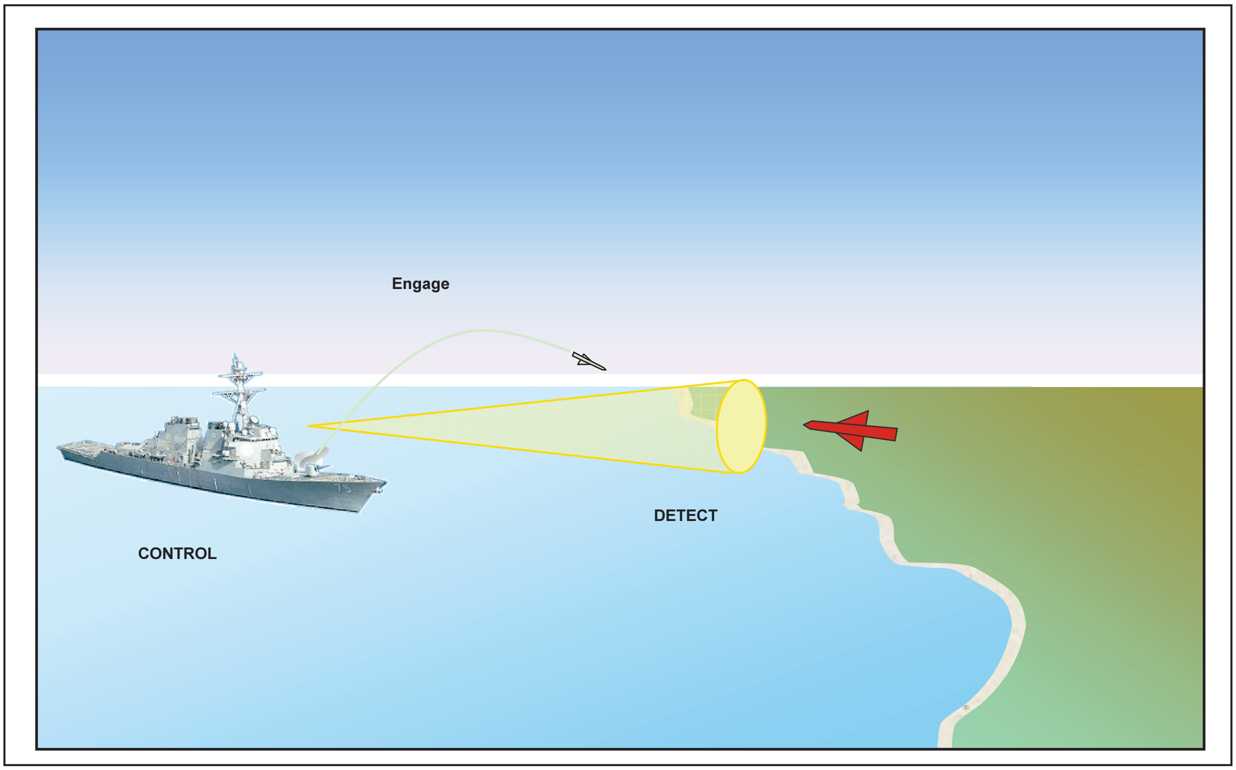

Figure 3-19a. Combat System Concept

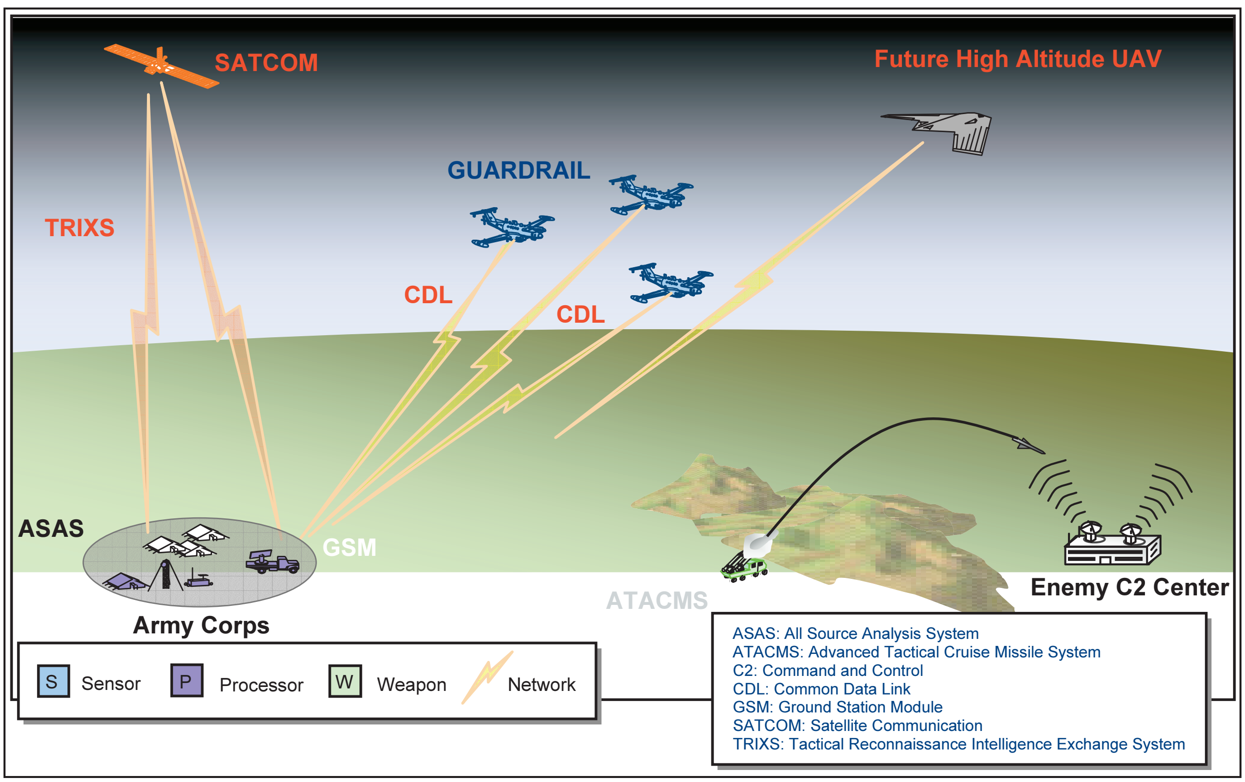

Figure 3-19b. Network centric Precision Engagement

Figure 3-19. Comparison of SoS and FoS Concepts for a Combat System

In contrast to the Aegis example, the Precision Engagement example includes substantial system boundary conditions. In the Precision Engagement case, the greatest latitude for the architect exists in how the given systems in the FoS are or can be interoperated in order to achieve mission capabilities. What is significant about the architectural abstractions of this chapter is that they can be used to describe both the SoS-level combat system (Figure 3-19a) and the network centric FoS-level "combat system" (Figure 3-19b). It is also significant that these abstractions can be used to cross warfare mission boundaries, as shown by the fact that the Aegis example addresses Air Defense while the network-centric Precision Engagement example addresses targeting of ground targets. This applicability of a single "enterprise model" (i.e, Detect-Control-Engage) to both missions was accomplished despite the fact that neither the Army nor the Air Force uses the Detect-Control-Engage model.

This kind of abstraction is enabled by the Architecture Framework and standardized lists of operational activities and systems functions. Figure 3-20 illustrates the architectural foundations for the NCW concept introduced in Figure 1-4 of Chapter 1. The key exhibit is the Operational Event/Trace Nodal Description (Figure 3-20a). It is supplemented by the concept described in Figure 3-20b, which illustrates the network centric vision that John Gartska popularized through a widely distributed graphic entitled Networking the Force (Figure 1-4). In Mr. Gartska's graphic, the Sensor Fusion level corresponds to the Detect and Control nodes in the Precision Engagement example. The Force Control Level corresponds to the Operational Command node, and the Force Coordination Level corresponds to the Theater Command node.

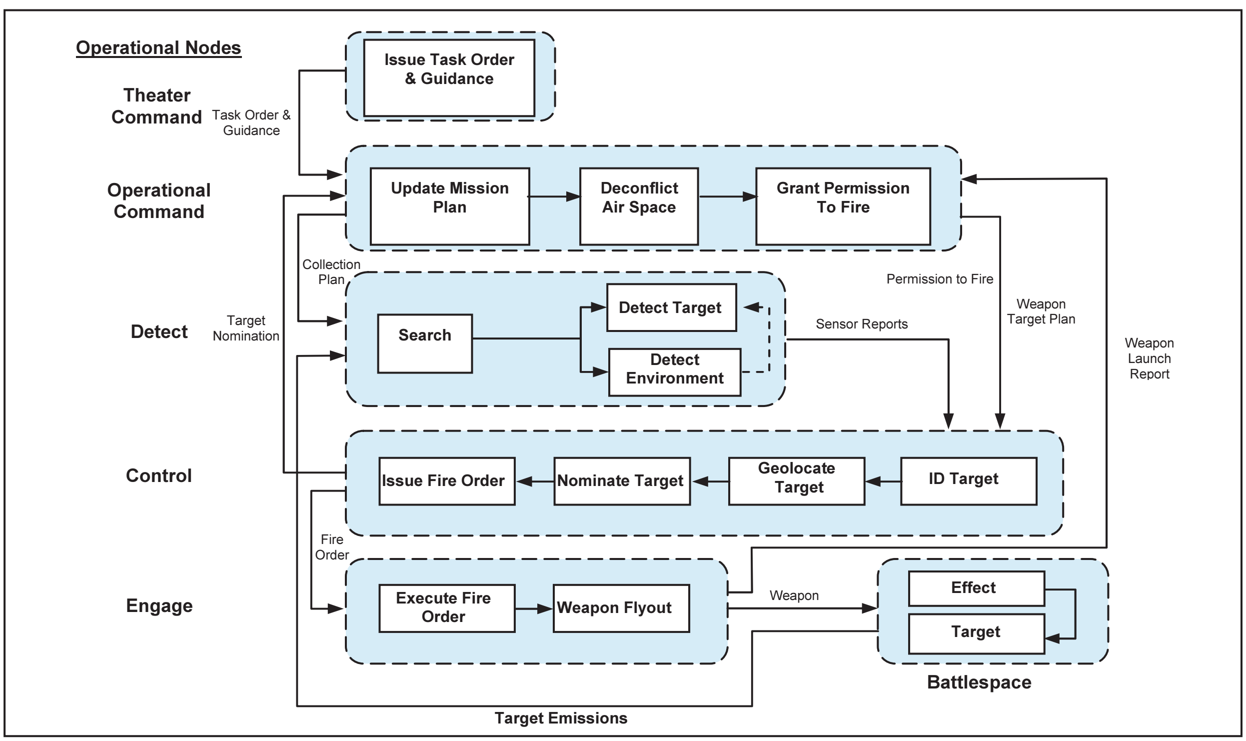

Figure 3-20a. Operational Event/Trace Nodal Description

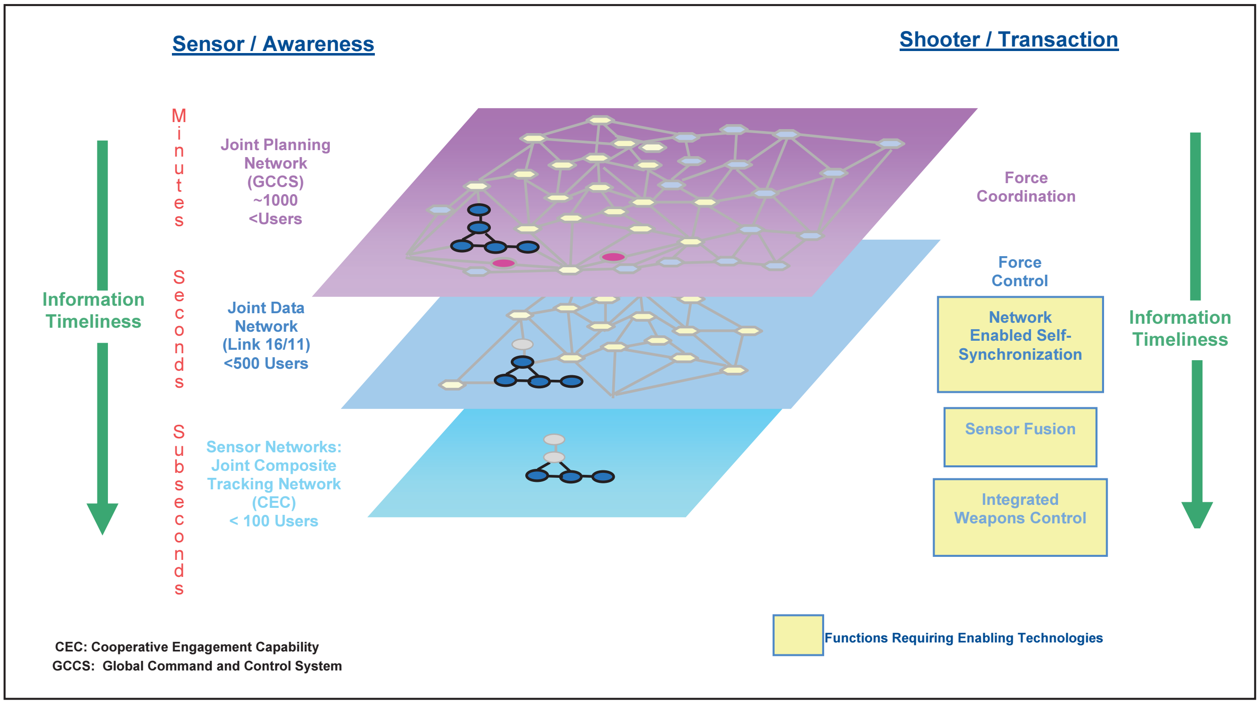

Figure 3-20b. Networking the Force

Figure 3-20. Architectural Foundations for NCW Concepts

Summary

The goal of this chapter was to show how three of the basic groups of architecture products introduced in Chapter 2 provide a framework to describe a mission warfare area and demonstrate the logical validity of the mission and system architecture. Table 3-8 summarizes the architecture products in the order they were developed to support the abstract NCW architecture. The summary exhibit, Figure 3-18 (the combined System Interface Description (SV-1) and System Communications Description (SV-2) presented earlier in this chapter), shows abstractly an example of the linkage between the operational, system, and technical views of the architecture for NCW. The Operational Event/Trace Nodal Description (the version of the OV-6c presented in Figure 3-9) is the foundational exhibit that allows abstraction of the architecture.

Table 3-8
Summary of Architecture Products

Nomenclature	Name	Figure Number
Operational Concept		
OV-1	High-Level Operational Concept Graphic	Figure 3-2
OV-5	Operational Activity Model	Tables 3-1, 3-2
OV-2	Operational Node Connectivity Description	Figure 3-5
OV-4	Organizational Relationships	Figure 3-7
OV-6c	Operational Event/Trace Description	Figure 3-8
OV-6c Nodal	Operational Event/Trace Nodal Description	Figure 3-9
OV-3	Operational Information Exchange Matrix	Table 3-4

System Functional		
SV-4a	High-Level Systems Functions List	Table 3-5
SV-5	Operational Activity to System Function Traceability Matrix	Figure 3-10 Table 3-6
SV-4b	Systems Functional View	Figure 3-11
SV-4c	Logical Interface View	Figure 3-12
SV-3a	Systems to Functions Matrix	Figure 3-13
SV-3b	Operational Activity to System Traceability Matrix	Figure 3-14
SV-3c	$Systems^2$ Matrix	Figure 3-15
System Interface		
SV-1	Systems Interface Description	Figure 3-16a
SV-2	System Communications Description	Figure 3-16b
SV-3c Nodal	Nodal Version of the $Systems^2$ Matrix	Figure 3-17
OV-2 Instantiated	Instantiated Version of Operational Node Connectivity Description	Figure 3-18
TV-1	Technical Standards Profile	Page 3-25, 26
SV-6	Systems Data Exchange Nodal Matrix	Table 3-7

CHAPTER 4
PRECISION ENGAGEMENT

Purpose

The previous chapter provided background on NCW and presented an abstraction of the role of network centricity as a warfare enabler. This case study focuses on a specific warfare mission capability, Precision Engagement, and provides a discussion of the instantiation of the NCW abstraction using the example carried through Chapters 1 and 3. This Precision Engagement case study provides a concrete example of how the Architecture Framework products can be used to describe the ability of an FoS to deliver mission capabilities. It illustrates the methods used in building a warfare mission architecture with traceability of FoS functionality and connectivity to capability objectives. This chapter provides an architectural assessment of how mission capabilities are achieved through the interoperation of systems. It offers the first artifact that validates the interoperability of the FoS architecture for the Precision Engagement example of NCW.

Precision Engagement Operational Concept

It is critical to remember that NCW is a warfare enabler and is focused on leveraging network centricity as a means for improving specific warfare missions. One such mission is Precision Engagement. The first step in developing architecture products for the Precision Engagement mission is to develop operational concept views. The five architecture products that support the Precision Engagement operational concept include the following views:

- High-Level Operational Concept (OV-1)
- Command Relationships Chart (OV-4)
- Activity Model (OV-5)
- Operational Node Connectivity Description (OV-2)
- Operational Event/Trace Description (OV-6c)

Each is described at a high level in the following paragraphs. The NCW concepts of Chapter 3 provide the basis for these products.

High Level Operational Concept Graphic (OV-1)

The warfare mission capability discussed in this case study is Precision Engagement and, more specifically, coordinated operations from dispersed assets in support of Precision Engagements. Figure 4-1 repeats the illustration of the Precision Engagement Operational Concept introduced in Chapters 1 and 3. This graphic is based on the network centric engagement concept. The NCW Precision Engagement example introduced in Chapter 3 showed how the Theater Commander could use network centricity to engage a C2 target. Figure 4-1 illustrates how three command levels (force coordination, force control, and sensor fusion, as introduced in Figure 1-4 of Chapter 1) are networked and how they use Tasking, Collection, Processing, Exploitation, and Dissemination (TCPED) and Precision Navigation and Timing (PNT) to engage a precision target. PNT must be shared across all nodes of the architecture. The TCPED of data from National Technical Means (NTM) in this concept is shared with the theater commander and fused with sensor data by the tactical commander.

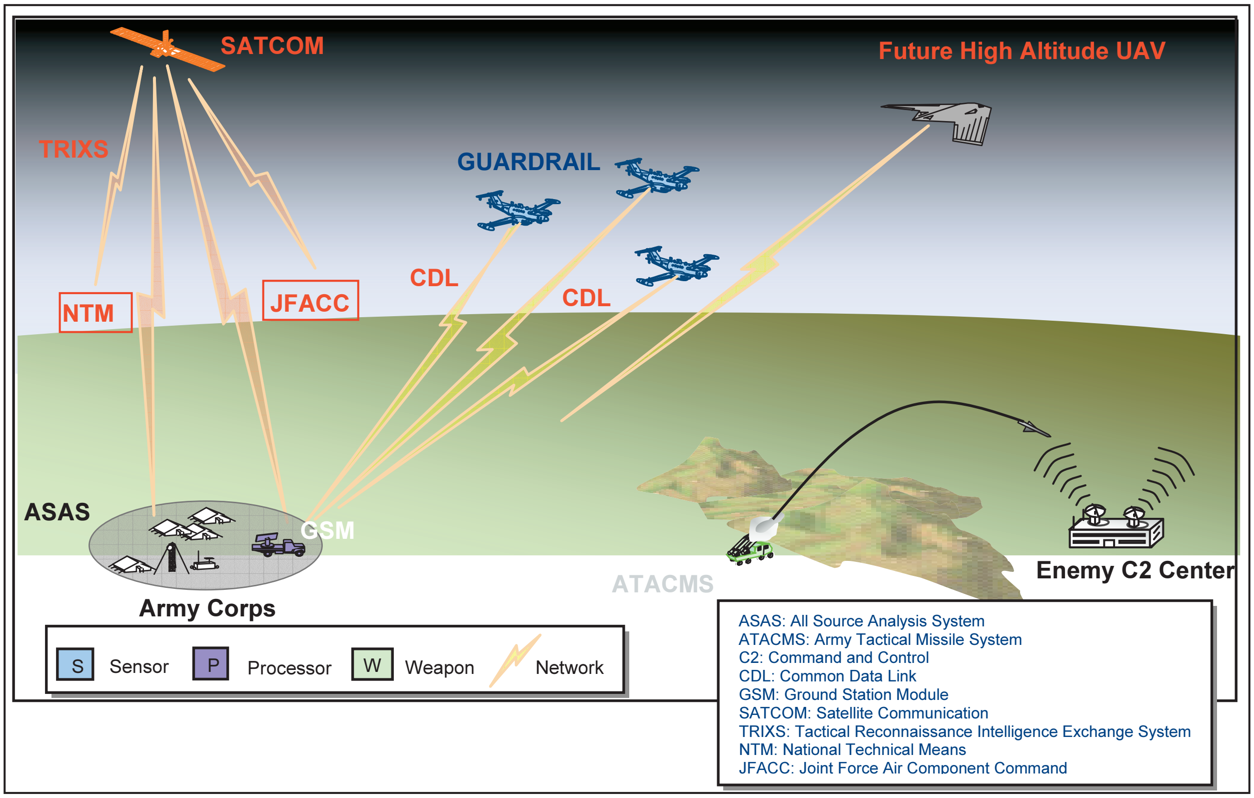

Figure 4-1. Precision Engagement High-Level Notional Operational Concept Graphic (OV-1)

In this example, the Battlespace includes various threat targets on land that are attacked using assets from land, space, or air. The Battlespace is defined in the Joint doctrine to be the environment, factors, and conditions that must be understood to apply combat power, project the force, or complete the mission successfully.[21] It is the environment where the military force will affect the threat (or vice versa), and thus will have relationships with both elements. The physical environment of the Battlespace provides a good example of the various dimensions that impact the key elements of the operational concept and their relationships. Such dimensions could include weather, radio frequency (RF) or infrared (IR) clutter, or even electromagnetic interference (EMI) that is not threat related. Battlespace effects are defined in the Joint doctrine lexicon as the degree of control over the dimensions of the Battlespace that enhance freedom of action for friendly forces or deny the enemy freedom of action. These dimensions exist within the operational areas and the areas of interest and include the air, land, sea, and space; the included enemy and friendly forces; facilities; weather; terrain; the electromagnetic spectrum; and the information environment.[22]

The effect sought in the Battlespace is to achieve lethality against the targets while maintaining a minimal targeting error, thus reducing the need for repeated weapons expenditures and the risk of collateral damage. This could be a complicated Joint theater, requiring significant coordination and deconfliction. The precision attack in this concept represents a use case that could be instantiated through the use of many different types of military force. Thus the simple graphic of the key elements of the operational concept shown in Chapter 3 (Figure 3-1) will give rise to a more complicated graphic that remains organized around the simpler concept of Figure 3-1.

Command Relationships (OV-4)

The Precision Engagement Operational Concept illustrated in Figure 4-1 achieves mission effectiveness through the sharing of data through a geographically dispersed FoS. Figure 4-2 illustrates the command relationships at the highest levels. This graphic shows command relationships down to the operational level, which is where the precision engagement concept begins in Figure 3-1.

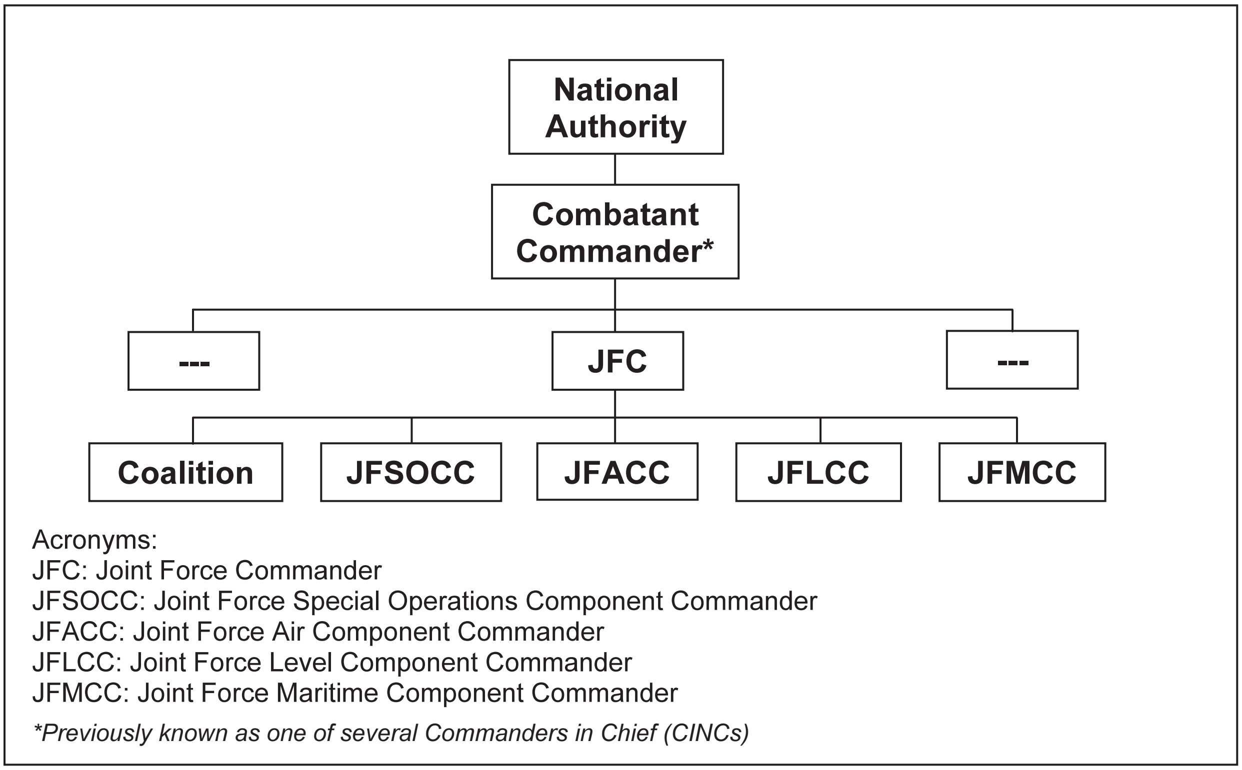

Figure 4-2. Precision Engagement Command Relationships

Activity Model (OV-5)

The Precision Engagement operational concept used in this case study is based on the Joint Targeting Doctrine illustrated in Figure 4-3. This doctrine is referred to as illustrative because the architecture development in this book predates the current Precision Engagement operational concept developed by the Joint Staff. Because this book is intended to illustrate the methodology and not current doctrine, the illustrative doctrine will be sufficient for the purposes of this book.

While the Activity Model implied by Figure 4-3 may appear to be substantially different than the Detect-Control-Engage paradigm used in Chapter 3, it will become apparent that the two views are intimately related. The primary difference is that the doctrine-based activity hierarchy augments the Joint Targeting model with TPCED activities.

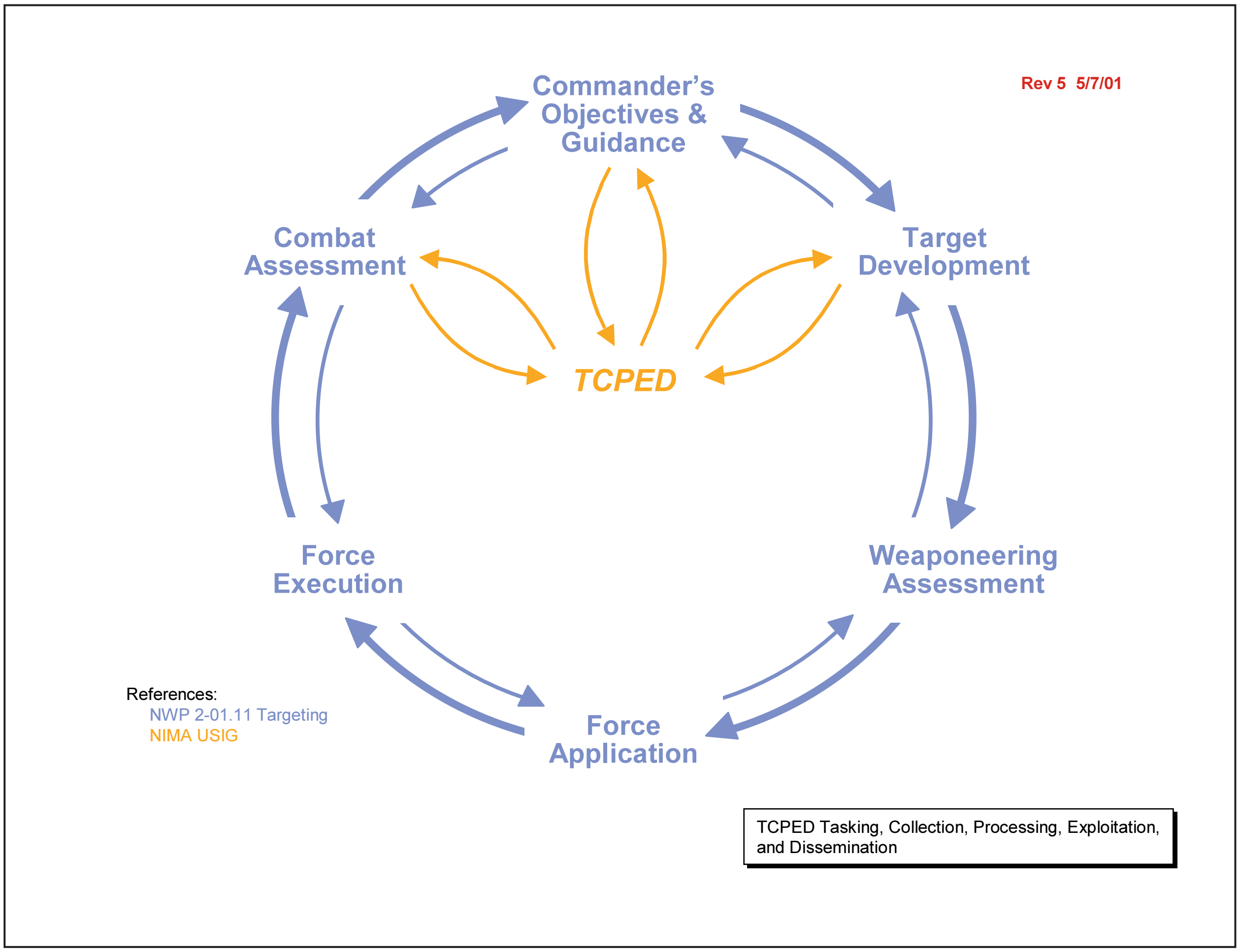

Figure 4-3. Illustrative Precision Engagement Doctrine*
**The Joint Doctrine has been revised; this example is historical and has been used for illustrative purposes.*

Figure 4-4 provides the historical doctrine-based hierarchy decomposed to a second-level hierarchy that specifically addresses the Precision Engagement warfare capability. The Command and Control activity model includes the Common Ground Picture (CGP) and the Single Integrated Air Picture (SIAP). Theater sensors can be monitored directly or through the CGP and SIAP. The hierarchy is based on Commander's Guidance, Target Development, the Weaponeering Assessment, and the other doctrine-based activities of Figure 4-3. Target Development includes activities such as determining target location and identification. It also includes assessment of the candidate target(s) against the Air Tasking Order (ATO). The Weaponeering Assessment will include a determination of whether or not the required effects and time on target (provided by the Commander's objectives and guidance) can be achieved. Additionally, this assessment will include determination (using the CGP or theater sensors) of the accuracy of the target location and guidance on collateral damage. The resulting output is a list of weapon target pairings (WTPs) from which final selection will be made. During Target Development, changes in the target status must also be assessed. These changes could be the result of target activity reported through the sensors or a change in the Commander's objectives.

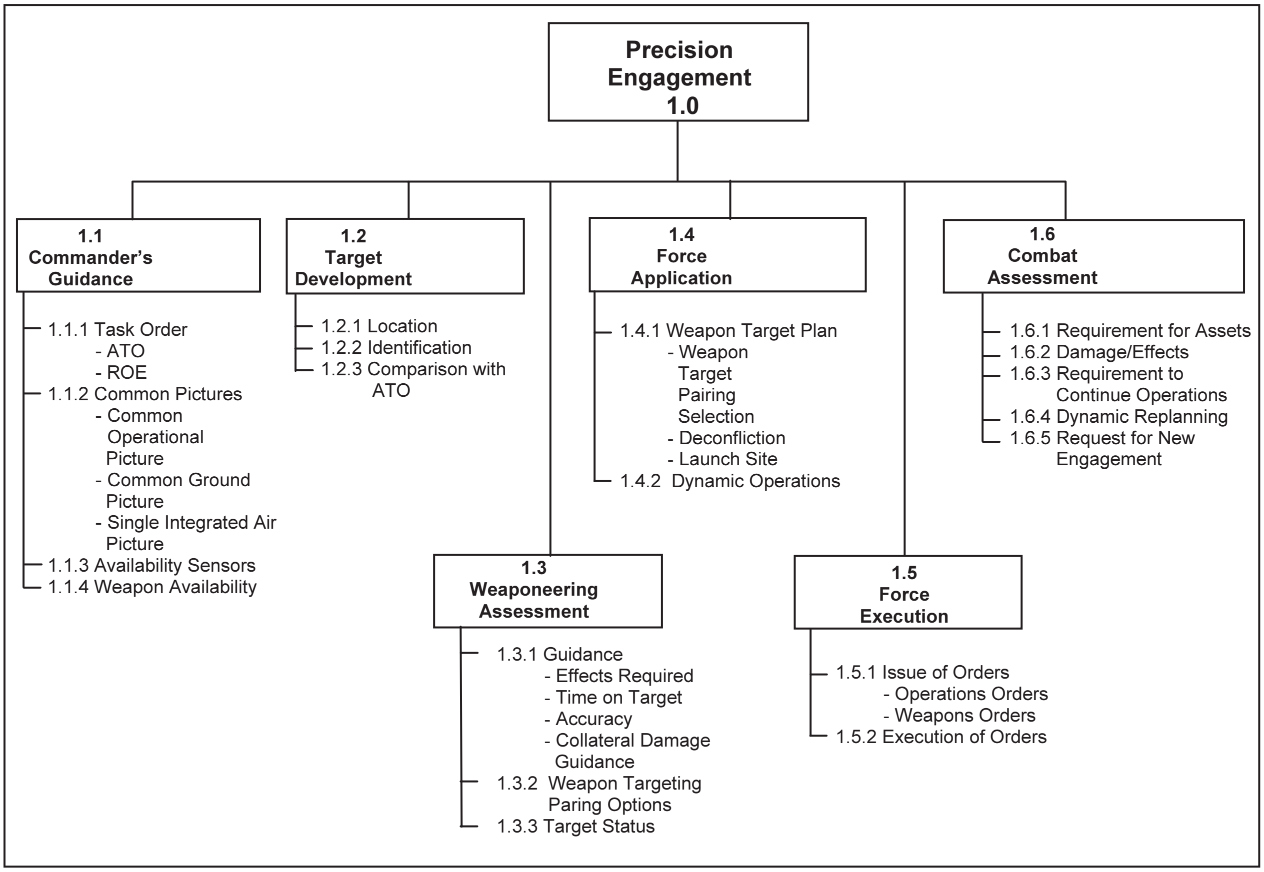

Figure 4-4. NCW Operational Activity Model (OV-5) for Precision Engagement

Force Application includes Damage Assessments and planning of Dynamic Operations. During Force Application planning, a final WTP selection will be made, and the launch time for the weapon will be established. Deconfliction is also part of Force Application planning. Force Execution includes issuing orders for both launch of the weapon and other operations that may be related to the engagement or affected by it. Requests for assets are made through the theater commander (the JFACC), who in turn provides the assets. The Force Application activity triggers execution of Deliberate Operations by the military force. Dynamic Operations activities differ from Deliberate Operations activities in that Dynamic Operations include adjustments that are made *concurrently* with the conduct of the mission execution, while Deliberate Operations are based only upon planning that occurs *before* the execution of the mission. Finally, to conduct the Combat Assessment activity, it first must be determined if the assets involved in the engagement should continue their mission. Requests to continue and for the requisite assets are made through the planning activities.

The historical hierarchy shown in Figure 4-4 was presented to show what a reasonable operational activity model based on military doctrine might look like. Figure 4-5 shows how this compares with the Activity Model developed in Chapter 3. The doctrine-based hierarchy model shown in Figure 4-4 has a clear correlation with the Activity Model shown in Chapter 3, although several of the top-level doctrinal activities are performed across more than one of the Detect-Control-Engage activities.

Doctrine-Based Activities	Detect-Control-Engage Paradigm Activities				
	Theater Command	Operational Command	Detect	Control	Engage
1.1 Commander's Guidance	✓				
1.2 Target Development			✓	✓	
1.3 Weaponeering Assessment		✓			
1.4 Force Application		✓			
1.5 Force Execution					✓
1.6 Combat Assessment		✓	✓	✓	

Figure 4-5. Relationship between Doctrine-Based Hierarchy and Detect-Control-Engage Paradigm

Operational Node Connectivity Description (OV-2)

Using the correlations developed in Figure 4-5, the Operational Node Connectivity Description (OV-2) for the Activity Model described in Chapter 3 can be used to support the doctrine-based activities. It is necessary, however, to amend the previously presented Operational Node Connectivity Description to include the use of NTM. No changes will be required to the list of IEs, because NTM simply becomes another source for sensor reports. The revised Operational Node Connectivity Description is shown in Figure 4-6. The Theater Command in this example would be the JFACC, and the Operational Commander would be the Army Corps Commander.

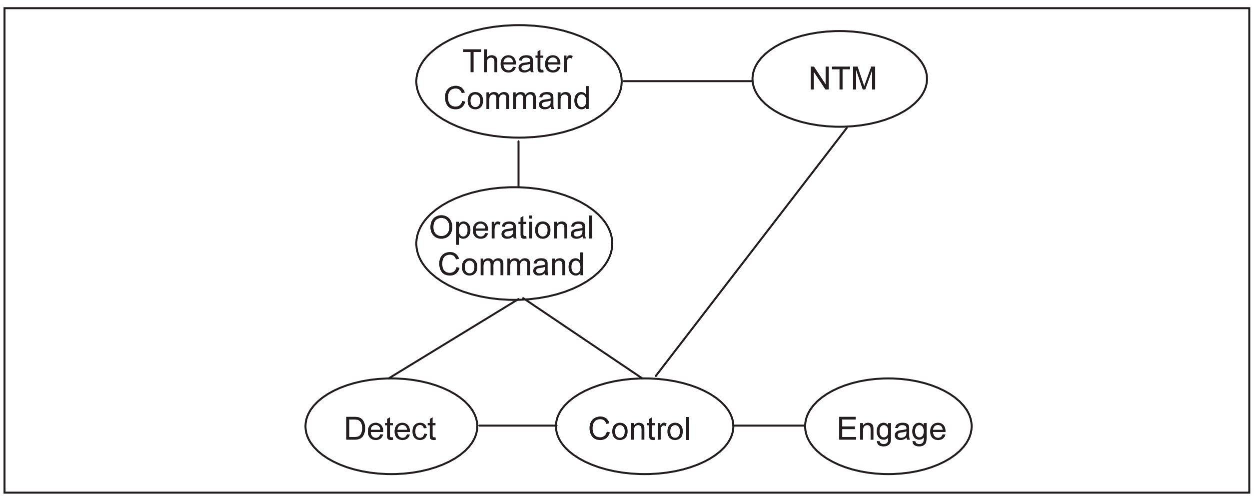

Figure 4-6. Operational Node Connectivity Description (OV-2) for Precision Engagement Example

Comparing the relationship between the doctrine-based and Detect-Control-Engage paradigm-based activities (provided in Figure 4-5) and the Nodal Description (shown in Figure 4-6) reveals an important point: high-level doctrine-based activities are not necessarily operational nodes. In this Precision Engagement example, only one such activity, the Commander's Guidance (1.1), is a node; specifically, it is the Theater Command node. The remaining doctrine-based activities are either aggregated into a single node (e.g., Weaponeering Assessment (1.3), Force Application (1.4), and Combat Assessment (1.6) are aggregated into the Operational Command node), or they are allocated across multiple nodes (e.g., Target Development (1.2) is allocated across the

Detect and Control nodes). It must be remembered that operational activities are things to be done (actions to be taken), whereas operational nodes are meaningful groupings of operational activities that will be supported by communications and other related physical instantiations.

Operational Event/Trace Description (OV-6c)

Figure 4-7 provides the revised version of the Operational Event/Trace Nodal Description (OV-6c Nodal) based on the one previously presented in Chapter 3 (Figure 3-9) and the more detailed descriptions of the operational concept (Figure 4-1) and the nodal description (Figure 4-6) presented in this chapter. One new node has been added for NTM, and this node includes the TCPED activities associated with gathering Intelligence, Surveillance, and Reconnaissance (ISR) data. This node provides additional sensor reports to the Control node. For example, NTM may provide imaging data to complement the passive data of the Detect node to give additional capabilities for target identification and geolocation. With the exception of the addition of the new node, the model is identical to the one presented in Chapter 3.

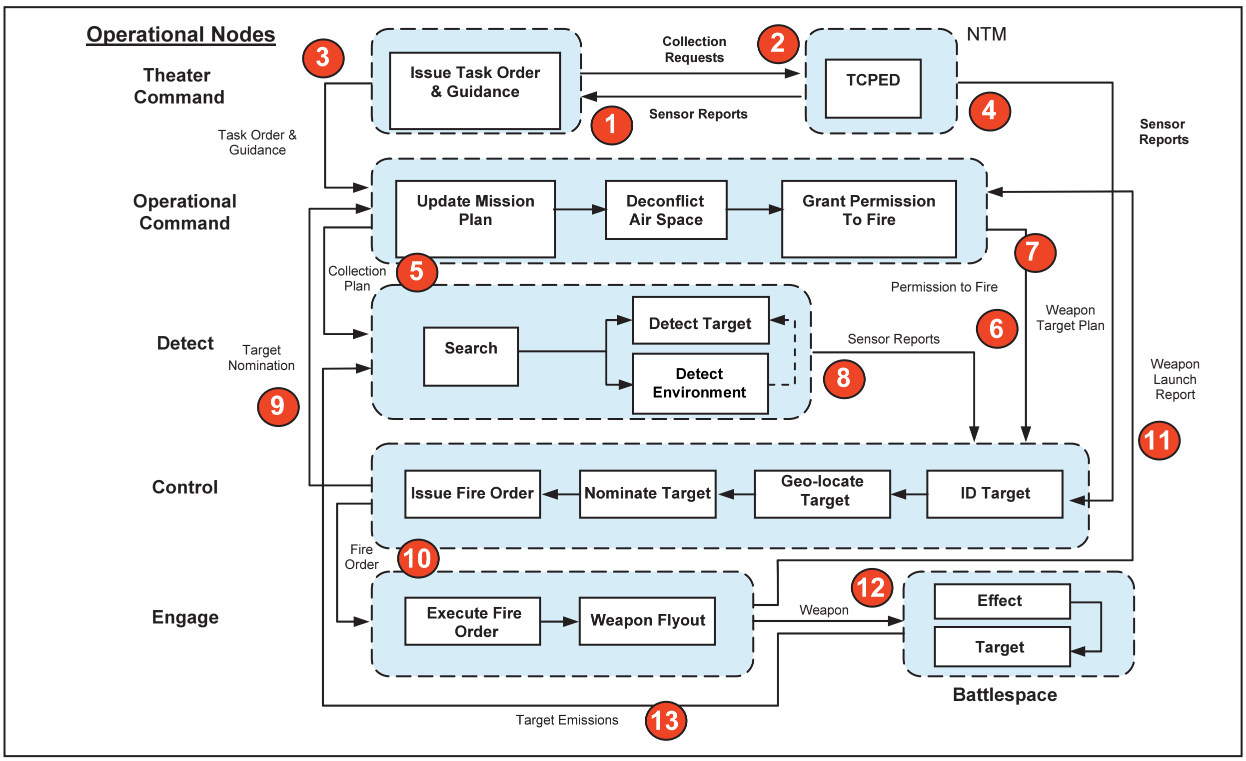

Figure 4-7. Operational Event/Trace Nodal Description (OV-6c Nodal)

To further clarify the information in the Operational Event/Trace Nodal Description, basic elements from this diagram can be extracted to show the producing and consuming nodes along with their required information elements. Table 4-1 shows the Operational Event/Trace Nodal Description interfaces (identified by their assigned numbers in Figure 4-7) along with their sources nodes, IEs, and destination nodes. Amplifying information is provided in Table 4-2, which adds the associated activities to the interfaces, source and destination nodes, and IEs.

Table 4-1
Interfaces, IEs, Source Nodes, and Destination Nodes

OV-6c Interface Identifier	IE	Source Node	Destination Node
1	Sensor Reports	NTM	Theater Command
4	Sensor Reports	NTM	Control
2	Collection Requirements	Theater Command	NTM
3	Task Order & Guidance	Theater Command	Operational Command
7	Weapon Target Plan	Operational Command	Control
5	Mission Plan	Operational Command	Control
5	Collection Plan	Operational Command	Control
6	Permission to Fire	Operational Command	Control
8	Sensor Reports	Detect (Guardrail)	Control
8	Sensor Reports	Detect (UAV)	Control
5	Collection Plan	Control	Detect (Guardrail)
5	Collection Plan	Control	Detect (UAV)
9	Target Nomination	Control	Operational Command
10	Fire Order	Control	Engage
11	Weapons Launch Report	Engage	Operational Command

Table 4-2
Interfaces, IEs, Source Nodes, and Destination Nodes (With Activities)

OV-6c Inter-face ID	IE	Source		Destination	
		Source Node	Activity	Dest. Node	Activity
1	Sensor Reports	NTM	TCPED	Theater Com.	Issue Task Order/Guidance
4	Sensor Reports	NTM	TCPED	Control	ID Target
2	Collection Requirements	Theater Com.	Issue Task Order/Guidance	NTM	TPCED
3	Task Order & Guidance	Theater Com.	Issue Task Order/Guidance	Op. Com.	Update Miss. Plan
7	Wpn. Tgt. Plan	Op. Command	Update Miss. Plan	Control	Issue Fire Order
5	Mission Plan	Op. Command	Deconflict Airspace	Control	Control
5	Collection Plan	Op. Command	Update Miss. Plan	Control	Mission Execution.
6	Perm. to Fire	Op. Command	Grant Perm. to Fire	Control	Issue Fire Order
8	Sensor Reports	Detect (Guardrail)	Detect Tgt./Environ.	Control	ID/Geolocate Targ.
8	Sensor Reports	Detect (UAV)	Detect Tgt./Environ.	Control	ID/Geolocate Targ.
5	Collection Plan	Control	Control	Detect (GR)	Detect Tgt./Environ.
5	Collection Plan	Control	Control	Detect (UAV)	Detect Tgt./Environ.
9	Target Nom.	Control	Nominate Target	Op. Com.	Grant Perm. to Fire
10	Fire Order	Control	Issue Fire Order	Engage	Weapon Fly-Out
11	Wpn. Launch Rpt.	Engage	Weapon Fly-Out	Op Com.	Update Miss. Plan

System Functional Mapping

The five principal types of systems can be used to organize lists of actual physical systems that enable the systems functions. This type of organization is shown in Table 4-3. The physical systems lists can come from any number of sources, including POM acquisition plans, Battleforce Orders of Battle, Operational Use Cases, or proposals by system developers or the science and technology community. The list used to illustrate the assemblage of the FoS in this case study has been taken from the Precision Engagement high-level concept graphic (OV-1) presented previously in Figure 4-1.

Table 4-3
Case Systems List for Precision Engagement Example

Networks	Sensors	Processors	Weapons	Platforms
• CDL • GSM Network/Links • SATCOM/TRIXS	• Senior Glass • Guardrail Common Sensor (GRCS)	• ASAS • TBMCS • AFATDS	• ATACMS	• Future High-Altitude UAV • Guardrail • GSM

Systems Matrices (SV-3)

Using the systems listed in Table 4-1, it is then possible to develop the System-to-Systems Functions Matrix (SV-3a) shown in Figure 4-8. Links will be considered as a special type of network, namely a point-to-point network (vice a many-to-one or many-to-many connection). Figure 4-9, the Operational Activity to System Traceability Matrix (SV-3b), is the companion matrix that relates systems to operational activities.

Enabling System	System Function			
	Sense	Command	Act	Interoperate
Networks		SATCOM	Multiple Subscriber Equipment (MSE)	TRIX, GSM Network Links, MSE
Sensors	Senior Glass, GRCS			
Processors		ASAS, TBMCS	AFATDS	DCGS-A
Weapons			ATACMS	
Platforms			Multiple Launch Rocket System (MLRS)	

Figure 4-8. Systems-to-Systems Functions Matrix (SV-3a) for Precision Engagement Example

Enabling System	Operational Activity		
	Detect	Control	Engage
Sensor	Senior Glass, GRCS		
Processor		ASAS	
Weapon			ATACMS

Figure 4-9. Operational Activity to System Traceability Matrix (SV-3b) for Precision Engagement Example

The operational concept described in the previous section of this chapter expresses the concept for system interoperation as well as command and control from the theater level. The Systems[2] Matrix (SV-3c Nodal), shown in Figure 4-10, provides a view of the operational concept (shown previously in Figure 4-1) through nodal relations and more specifically reveals the nodal connectivity illustrated earlier in this chapter in Figure 4-6.

	GRCS	Senior Glass	TBMCS	ASAS	ATACM
Guardrail		-	-	CDL-SATCOM	-
Senior Glass			-	CDL-SATCOM	-
TBMCS				SATCOM	-
ASAS					Fiber Optic
ATACM					

Note: Platform control is provided by UHF/VHF Comms.

Figure 4-10. Nodal System[2] Matrix (SV-3c Nodal) for Precision Engagement Example

System Interface Mapping

System Interface Mapping for the Precision Engagement example can be supported through the use of three Architecture Framework products:

- Operational Node Connectivity Description (OV-2) instantiated with actual systems
- Technical Architecture Profile (TV-1)
- Systems Information Exchange Matrix (SV-6c)

Each of these products is described in the following paragraphs.

Instantiated Operational Node Connectivity Description (OV-2)

Figure 4-11 provides an instantiated Operational Node Connectivity Description (OV-2) for the Precision Engagement example. As shown, FoS level detection in the Battlespace is carried out by four sensors complemented by TCPED. The fundamental activities of Detect, Control, and Engage for the FoS and for Command and Control are organized into the same nodes used previously in Chapter 3. Similarly, FoS level execution is organized into a separate node. Figure 4-11 also shows how the need lines are instantiated.

Technical Architecture Profile (TV-1)

The technical component of the architecture provides the set of rules and standards that govern system implementation and operation. In the case of FoS systems engineering, the standards and protocols associated with the transport layer of interfacing and communications between systems will be especially important. Table 4-4 provides a Technical Architecture Profile that applies to the FoS systems for the Precision Engagement example. This profile can be considered a comprehensive list from which applicable standards and protocols can be selected based on the specific systems used to support the mission. Table 4-1, shown previously in this chapter, provided the lists of systems.

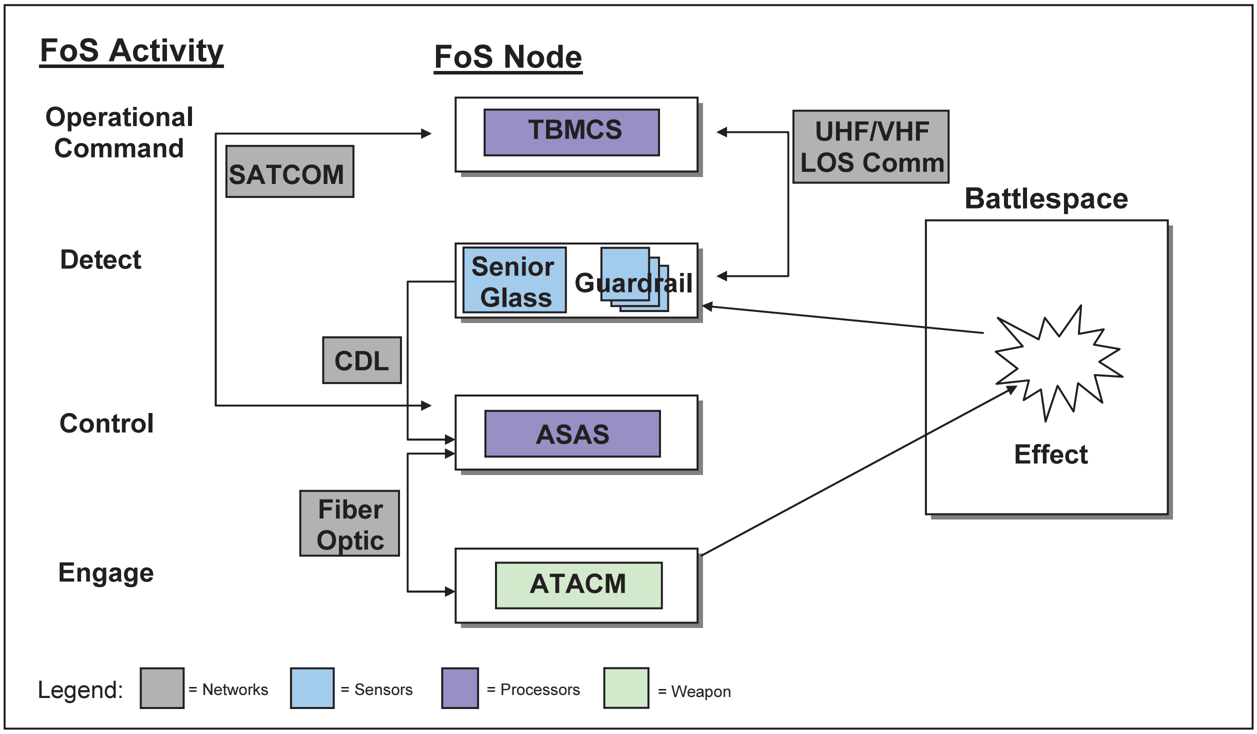

Figure 4-11. Instantiated Operational Node Connectivity Description (OV-2) for Precision Engagement Example

Table 4-4
Technical Architecture Profile for Precision Engagement Example

Interface Category	Protocol	Common Name	Reference Standard	Description
Communications Equipment				
CDL			NATO STANAG 7085	Interoperable Data Links for Multi-INT Systems
TRIXS		UHF (LOS)		
TIBS		UHF (SATCOM)	MIL-STD-188-181B	Standard for Single Access 5-Khz and 25-Khz UHF Satellite Communications Channels, 20 March 1999
			MIL-STD-188-164	Interoperability and Performance Standards for C-Band, X-Band, and Change 1, 9 September 1998
TRAP		UHF (SATCOM)	MIL-STD-188-181B	Standard for Single Access 5-Khz and 25-Khz UHF Satellite Communications Channels, 20 March 1999
			MIL-STD-188-164	Interoperability and Performance Standards for C-Band, X-Band, and Change 1, 9 September 1998

IBS		UHF (SATCOM)	MIL-STD-188-181B	Standard for Single Access 5-Khz and 25-Khz UHF Satellite Communications Channels, 20 March 1999
			MIL-STD-188-164	Interoperability and Performance Standards for C-Band, X-Band, and Change 1, 9 September 1998
MSE				
SINGARS		VHF-FM (LOS)		
TADIL-J		UHF (LOS)	MIL-STD-6016	
TADIL-B				
Two-Wire		HDSL		
Processing Equipment				
CTT/JTT	TCP/IP		IETF 1122	Network Interface
			IETF 1123	Application Protocol
	SMTP		IETF Standard 10/RFC 821/RFC 1869/RFC 1870	Simple Mail Transfer Protocol
AFATDS	TCP/IP		IETF 1122	Network Interface
			IETF 1123	Application Protocol
	SMTP		IETF Standard 10/RFC 821/RFC 1869/RFC 1870	Simple Mail Transfer Protocol
ASAS	TCP/IP		IETF 1122	Network Interface
			IETF 1123	Application Protocol
Information Elements				
Character-Oriented Messages		USMTF		
Imagery			NATO STANAG 7023	Primary Imagery Format
Imagery			MIL-STD-2500B	National Imagery Transmission Format V2.1
Imagery			NATO STANAG 4545	Secondary Imagery Format
Imagery Library			NATO STANAG 4559	Standard Imagery Library Interface
JTIDS Message			MIL-STD 6016	J Series Message Formats

From the comprehensive list of standards and protocols provided in Table 4-4, a list of standards and protocols that apply to the system connections in the Precision Engagement example can be identified. Table 4-5 provides the Operational Event/Trace Nodal Description interfaces (identified by their assigned numbers in Figure 4-7) along with their IEs, source and destination systems and functions, and the source and destination system protocols.

Table 4-5
Interfaces, IEs, and Source and Destination Systems, System Functions, and Protocols

OV-6c Inter-face ID	IE	Source System	Source System Function	Source System Protocol	Destination System	Destination System Function	Dest. System Protocol
1	Sensor Reports	NTM	TCPED	NTF, USMTF	JDISS	Decision Planning	NTF, USMTF
4	Sensor Reports	NTM	TCPED	NTF, USMTF	TOC CTT, ASAS, TROJAN	Target ID	NTF, USMTF
2	Collection Reqs.	JDISS	Task Sensors	USMTF	NTM	Multi-Sensor Sense	USMTF
3	Task Order/ Guidance	JTF TBMCS, GCCS	Update Mission Plan	USMTF	JFACC TBMCS, GCCS	Update Mission Plan	USMTF
7	Wpn. Tgt. Plan	JFACC GCCS	Weapon Tgt. Assoc.	USMTF	TOC AFATDS	Issue Fire Order	USMTF
5	Mission Plan	JFACC TBMCS	Air Pic. Int., Dyn. Deconflict.	USMTF	TOC GCCS	Mission Execution	USMTF
5	Collection Plan	JFACC GCCS	Collection Planning	USMTF	TOC GCCS	Mission Execution	USMTF
5	Collection Plan	JFACC UHF SATCOM Radio	Collection Execution	USMTF	UAV UHF SATCOM Radio	Single Sensor Sense	Voice
6	Permission to Fire	JFLCC GCCS	Decision, Target Prioritiz.	USMTF	TOC AFATDS	Issue Fire Order	USMTF
8	Sensor Reports	Guardrail CTT	Single Sensor Sense	USMTF	GSM ASAS	Multi-Sensor Sense, Feat. Extraction	USMTF
8	Sensor Reports	UAV SYERS/ ASARS/IRIS	Single Sensor Sense	Binary	GSM ASAS, TROJAN	Multi-Sensor Sense, Feat. Extraction	Binary
5	Collection Plan	GSM UHF Radio	Collection Execution	Voice	Guardrail UHF Radio	Single Sensor Sense	Voice
5	Collection Plan	CARS/ DCGS	Collection Execution	Binary	UAV SYERS/ ASARS/IRIS	Single Sensor Sense	Binary
9	Target Nom.	TOC GCCS	Decision, Target Prioritiz.	USMTF	JFACC GCCS	Decision, Target Prioritiz.	USMTF
10	Fire Order	TOC AFATDS	Issue Fire Order	USMTF	MLRS-FDC, AFATDS, ATACMS	Weapon Initialization and Launch	USMTF
11	Wpn. Launch Rpt.	MLRS FDC AFATDS	Weapon Initialization & Launch	USMTF	JFACC AGCCS	Collection Planning	USMTF

Systems Information Exchange Matrix (SV-6)

Throughout this chapter, the discussion has focused on the instantiation of the NCW abstraction presented in Chapter 3 using an actual NCW mission, Precision Engagement. The development of the Architecture Framework's Systems Information Exchange Matrix (SV-6) is the culmination of the logical, progressive building of Architecture Framework products to describe the static interoperability of an FoS to deliver mission capabilities. Table 4-6, which is shown on the following page, presents an expanded view of the System Information Exchange Matrix. It retains the attributes of the existing Framework product, which is defined as the information exchanges within a node and from those systems to systems at other nodes, but the expanded version contains information on source and destination node activity, function, and protocol as well. The top portion of Table 4-6 shows the source node, systems, and functions that produce the required information element, while the bottom portion of the table shows the consumer node, systems, and functions as well as the inter-nodal transport necessary to convey the information. This view provides enough information to assess the current state of FoS interoperability as well as future requirements.

The expanded Systems Information Exchange Matrix is derived from the Operational Information Exchange Matrix (OV-3), the Technical Architecture Profile (TV-1), the Operational Activity to System Traceability Matrix (SV-3b), and the Systems[2] Matrix (SV-3c). This makes the Systems Information Exchange Matrix the system analog to the Operational Information Exchange Matrix (OV-3). The expanded Systems Information Exchange Matrix can be derived because the matrices of the preceding architecture products can be used to create end-to-end views of system information and service exchanges. These end-to-end views were built using the information presented previously in Tables 4-1 through 4-5. Each communication and exchange of service between two systems can trace the capabilities, activities, functionality, and logical and technical interfaces of the architecture.

Architecture Assessments

To conduct the architecture assessment, it is helpful to assess the system sequencing, or the order in which the events in a particular scenario may occur. Table 4-7 provides a possible system sequence for the Precision Engagement example. The Systems Information Exchange Matrix lines are ordered from 1 to 16, representing the possible order in which each would occur. Each of these lines is also mapped to the Operational Activity/Trace Diagram (OV-6c) interface identifier in the second column of the table. By showing the system sequence along with the IEs, the system function that produced the IEs, and the candidate systems that may perform the system functions, it is possible to determine additional interaction that may be necessary between nodes in order to accomplish the mission. For example, Sequence Lines 6 through 11 all map to the same operational interface (Number 5) in the Operational Activity/Trace Diagram. Close examination reveals that the collection plan for the Guardrail must first go to the Control Node because it is a tactical asset, but the same information can travel directly from the JFACC to the future high-altitude UAV, because the UAV is a theater asset. By reviewing the systems sequencing in this manner, the systems architect can begin to assess the interoperability of the FoS architecture.

Table 4-6
Expanded Systems Information Exchange Matrix (SV-6c)

OV-6c Int. ID	Source Node					
	Source Node	IE	Activity	Source System	Source System Function	Source System Protocol
1	NTM	Sensor Reports	TCPED	NTM	TCPED	NITF, USMTF
4	NTM	Sensor Reports	TCPED	NTM	TCPED	NITF, USMTF
2	Theater Command	Collection Reqs.	Issue Task Ord./Guid.	JDISS	Task Sensors	USMTF
3	Theater Command	Task Order/Guid.	Issue Task Ord./Guid.	JTF TBMCS, GCCS	Update Mission Plan	USMTF
7	Op. Command	Wpn. Tgt. Plan	Update Mission Plan	JFACC GCCS	Weapon Target Assoc.	USMTF
5	Op. Command	Mission Plan	Deconflict Airspace	JFACC TBMCS	Air Pic. Int./Dyn. Deconflict.	USMTF
5	Op. Command	Collection Plan	Update Mission Plan	JFACC GCCS	Collection Planning	USMTF
6	Op. Command	Permission to Fire	Grant Perm. to Fire	JFLCC GCCS	Decision, Tgt. Priority	USMTF
8	Detect (Guardrail)	Sensor Reports	Detect Tgt./Environ.	Guardrail CTT	Single Sensor Sense	USMTF
8	Detect (UAV)	Sensor Reports	Detect Tgt./Environ.	UAV SYERS/ASAS/IRIS	Single Sensor Sense	Binary
5	Control	Collection Plan	Control	GSM UHF Radio	Collection Execution	Voice
5	Control	Collection Plan	Control	CARS/DCGS	Collection Execution	Binary
9	Control	Target Nomination	Nominate Target	TOC GCCS	Decision, Tgt Priority	USMTF
10	Control	Fire Order	Issue Fire Order	TOC AFATDS	Issue Fire Order	USMTF
11	Engage	Wpn. Launch Rpt.	Weapon Fly-Out	MLRS FDC AFATDS	Wpn. Init. and Launch	USMTF

OV-6c Int. ID	Destination Node					
	Inter-nodal Transport	Destination Node	Activity	Destination System	Dest. System Function	Dest. System Protocol
1	IBS	Theater Com.	Issue Task Order/Guid.	JDISS	Decision Planning	NITF, USMTF
4	IBS	Control	ID Target	TOC CTT, ASAS, TROJAN	ID Target	NITF, USMTF
2	JWICS	NTM	TCPED	NTM	Multi-Sensor Sense	USMTF
3	SIPRNet, JWICS	Op. Command	Update Mission Plan	JFACC TBMCS, GCCS	Update Mission Plan	USMTF
7	SIPRNet	Control	Issue Fire Order	TOC AFATDS	Issue Fire Order	USMTF
5	SIPRNet	Control	Control	TOC GCCS	Mission Execution	USMTF
5	SIPRNet, JWICS	Control	Control	TOC GCCS	Mission Execution	USMTF
6	SIPRNet, JWICS	Control	Issue Fire Order	TOC AFATDS	Issue Fire Order	USMTF
8	CDL	Control	ID Tgt./Geolocate Tgt.	GSM ASAS	Multi-Sens. Sense, Feat. Ext.	USMTF
8	CDL	Control	ID Tgt./Geolocate Tgt.	GSM ASAS, TROJAN	Multi-Sens. Sense, Feat. Ext.	Binary
5	UHF LOS Radio	Detect (Guardrail)	Detect Tgt./Environ.	Guardrail, UHF Radio	Single Sensor Sense	Voice
5	CDL	Detect (UAV)	Detect Tgt./Environ.	UAV SYERS/ASARS/IRIS	Single Sensor Sense	Binary
9	SIPRNet	Op. Command	Grant Perm. to Fire	JFACC GCCS	Dec., Tgt. Prioritization	USMTF
10	MSE	Engage	Weapon Fly-Out	MLRS-FDC, AFATDS, ATACMS	Wpn. Init. and Launch	USMTF
11	MSE	Op. Command	Update Mission Plan	JFACC AGCCS	Collection Planning	USMTF

Table 4-7
System Sequencing

Seq. ID	OV-6c Int. ID	IE	Source System	Source System Function	Destination System	Destination System Function
1	2	Collection Requirements	JDISS	Task Sensors	NTM	Multi-Sensor Sense
2	1	Sensor Reports	NTM	TCPED	JDISS	Decision Planning
3	3	Task Order & Guidance	JTF TBMCS, GCCS	Update Mission Plan	JFACC TBMCS, GCCS	Update Mission Plan
4	4	Sensor Reports	NTM	TCPED	TOC CTT, ASAS, TROJAN	ID Target
5	7	Weapon Target Plan	JFACC GCCS	Weapon Target Assoc.	TOC AFATDS	Issue Fire Order
6	5	Mission Plan	JFACC TBMCS	Air Picture Integration/ Dynamic Deconfliction	TOC GCCS	Mission Execution
7	5	Collection Plan	GSM UHF Radio	Collection Execution	Guardrail UHF Radio	Single Sensor Sense
8	5	Collection Plan	CARS/DCGS	Collection Execution	UAV/SYERS/ASARS/IRIS	Single Sensor Sense
9	5	Collection Plan	JFACC GCCS	Collection Planning	TOC GCCS	Mission Execution
10	5	Collection Plan	JFACC UHF SATCOM	Collection Execution	UAV UHF SATCOM Radio	Single Sensor Sense
11	8	Sensor Reports	Guardrail CTT	Single Sensor Sense	GSM ASAS	Multi-Sensor Sense, Feature Extraction
12	8	Sensor Reports	UAV SYERS/ASAS/IRIS	Single Sensor Sense	GSM ASAS, TROJAN	Multi-Sensor Sense, Feature Extraction
13	9	Target Nomination	TOC GCCS	Decision, Target Prioritization	JFACC GCCS	Decision, Target Prioritization
14	6	Permission to Fire	JFLCC GCCS	Decision, Target Prioritization	TOC AFATDS	Issue Fire Order
15	10	Fire Order	TOC AFATDS	Issue Fire Order	MLRS-FDC, AFATDS, ATACMS	Weapon Initialization and Launch
16	11	Weapons Launch Report	MLRS FDC AFATDS	Weapon Initialization and Launch	JFACC AGCCS	Collection Planning

The systems architecture team begins the interoperability assessments by reviewing each line in the Extended Systems Information Exchange Matrix (SV-6), taking into consideration each of the following questions:

- Does the line describe an as-is or to-be status?
- Do the specified systems provide the required functionality?
- Do the systems on each line process the required information, and/or are they integrated?
- If the line reflects an as-is status, are there any known interoperability issues?
- If the line reflects an as-is status, have the systems interfaces been certified?

Each line in the SV-6 is the integration requirement for the given operational concept. As such, it is important to recognize the "as-is" or "to-be" status of each line. For clarification purposes, an "as-is" line describes program of record systems beyond Milestone B, or possibly some systems that have been demonstrated in Advanced Concept Technology Demonstrations (ACTDs). "To-be" systems, on the other hand, are defined as concept systems. This distinction is important because the "as-is" systems provide the baseline interoperability, performance, and capability data. From this baseline, concept or "to-be" systems' interoperability, performance, and capability can be extrapolated.

It is also important to note that that the SV-6 line assessments involve consideration of a desired requirement for interoperability, performance, and capability, not verification of performance or contribution to capability. The examples shown previously in Table 4-6 are all considered "as-is" lines from an integrated perspective and can be used to provide a baseline architecture concept. The "as-is" and "to-be" integration status prefaces all remaining questions regarding how to access data and how confidence is derived in the assessments. Operationally, however, the direct flow of information from the Engage node to the Operational Command node is a "to-be" concept. Normally, this flow of information goes up through the Command node and then to the Operational Command node. For the sake of illustration, the sensing functions in the SV-6 table are based on "as-is" systems and systems functions.

System-to-system functional mapping assessments start with review of existing documentation from Mission Need Statements (MNSs), Operational Requirements Documents (ORDs), Functional Descriptions, Interface Descriptions, and data collected from previous tests and architecture assessments. At the level of detail in Table 4-6, all systems are assessed to be capable of performing the required system functions. It is again important to note that no effort was made to validate that systems are optimized in an engineering sense; rather, the table provides evidence of baseline functionality as a starting point toward achieving the full benefits of the NCW concept.

When the lines in the expanded Systems Information Exchange Matrix in Table 4-6 are assessed for their ability to process the desired information and level of integration, some interesting areas requiring further investigation are revealed. For example, for the System Information Exchange Matrix lines showing system integration requirements between GCCS and Army Field Artillery Tactical Data System (AFATDS), no documentation could be found showing that these systems have been interfaced; rather, operator intervention may be required at an operator console. This is not a problem, but it should be recognized with regard to the level of FoS integration.

Tracking the interoperability issues requires checking the Troubled Systems Lists, Casualty Reports, and a variety of data from test commands. While several systems in the Systems

Information Exchange Matrix in Table 4-6 were found to have minor system issues, none was associated with the context of this operational concept or information exchange.

Each service has a technical test command and interoperability agencies that certify systems and interfaces to be interoperable to some level. The Joint Interoperability Test Command (JITC) is responsible for overall Joint certification. Databases from individual test and interoperability agencies as well as JITC are typically reviewed to determine the existence of certifications for each system, system interface, and inter-nodal transport. For the systems in Table 4-6, this assessment found that all mature systems were certified.

To illustrate how results are derived using this type of assessment, consider that the expanded Systems Information Exchange Matrix (SV-6) presented in Table 4-6 was found to present moderate interoperability risk in the context of the NCW operational concept. While the systems within each Battle Functional Area (BFA) were revealed to be integrated and interoperable, areas in which BFAs were traversed (e.g., Intelligence (ASAS) to Fires (AFATDS)) could be assessed as presenting greater interoperability risk due to undefined interfaces. Similarly, where tactical control of an asset was separated from operational control of that same asset, the required interaction and the systems integration also presented higher levels of interoperability risk.

The value in this type of architecture assessment is threefold:

- It provides the ability to baseline the operational concept within the context of given architecture framework products.
- It enables architects to extrapolate interoperability, performance, and capability data for "to-be" operational concepts.
- It provides assistance in developing systems requirements.

These benefits give the warfighter, architect, and engineer a common framework for exchanging and communicating end-to-end requirements. Further, the warfighter, architect, and engineer can all optimize their perspectives (e.g., operational, system, performance improvements, interoperability, etc.) through recomposition of activities, systems, functions, sensors, platforms, and C2 to assess the impact to warfighter capability and outcomes.

FoS/SoS Concepts versus Classical Systems Engineering

This chapter has used military doctrine and the specification of actual systems to impart a more detailed understanding of the architecture abstracted in Chapter 3 through the instantiation of those abstractions. The architecture views presented in this chapter for a hypothetical case study that incorporates a mix of legacy and possible future Army/Air Force systems closely parallel the Navy work in targeting that will be discussed in the next chapter. The Precision Engagement example in this chapter and its architectural description were chosen for their simplicity. Even with the addition of NTM, there are only 11 nodal connections to be made in the Operational Event/Trace Description (OV-6c). By contrast, the targeting architecture used by the Navy for the POM 04 and PR05 analyses included 39 end-to-end mission threads and 2,857 identified nodal connections.

Summary

The abstract nodal architecture developed in Chapter 3 can be instantiated with the FoS used in the Precision Engagement example. The FoS is seen to have adequate functionality and connectivity to support the Precision Engagement capability.

CHAPTER 5
FLEET BATTLE EXPERIMENT INDIA TIME SENSITIVE TARGETING

Purpose

The Precision Engagement Case Study in the previous chapter focused on how the first three architecture product groups can be used in analyzing the ability of an FoS to deliver a specific capability. This chapter presents another case study, Fleet Battle Experiment – India (FBE-I) Time Sensitive Targeting (TST), which focuses on how alternative systems that could instantiate the architecture can be assessed in order to build an acquisition plan. It focuses on the fourth architecture product group, Acquisition Planning. This chapter will provide the reader with a better understanding of the need for alignment of systems in their procurement schedules to ensure the inclusion of resources for the FoS systems engineering and integration that will enable the interoperation of the systems in the family.

Background

FBEs are a Chief of Naval Operations (CNO) initiated series of experiments designed to investigate Network Centric Operation as a framework for development of new doctrine, organizations, technologies, processes, and systems for future warfighting. Experiments are designed to address near- and long-term service warfighting issues in a Joint context using likely future threat scenarios. The Navy Warfare Development Command (NWDC) is the CNO's agent for planning and implementing these experiments in partnership with the numbered fleets. FBE-I was the ninth in the FBE series.

The vision of FBE-I was to "operationalize" NCW by building and maintaining a C4ISR architecture that provided Joint forces with wide area connectivity, enhanced bandwidth, and reach-back capability. The experiment focused on three primary areas:

- Providing Joint Fires in support of maneuvers, including TST, operational maneuver from the sea, and ship-to-objective-maneuver
- Delivering assured access and optimization of the littoral Anti-Submarine Warfare (ASW) force warfighting capability by establishing real-time connectivity between the C4I architecture and a submarine
- Assessing Information and Knowledge Advantage (IKA) provided by the ability to build and maintain the network-centric C4ISR architecture

The experiment was conducted as part of the overarching Pacific Command (PACOM)-sponsored exercise Kernel Blitz and was coordinated by Commander Third Fleet.

For the Joint Fires portion of the experiment, the ASN RDA Chief Engineer (CHENG) conducted architecture analysis. The FBE-I Joint Fires TST architecture analysis effort had three specific objectives:

- Provide NWDC with engineering experience and discipline in documenting, recording, and analyzing FBE-I TST technical and system functional architecture views
- Evaluate the architecture analysis process used by CHENG in this experiment as proof of concept to institutionalize the CHENG approach for continued use

- Identify key performance system integration solutions for TST that impact mission capability and evaluate the possible acquisition of those solutions for the Fleet

The results of the experiment were used to support the development of an investment strategy in POM 04 to improve strike capabilities.

FBE-I Operational Concept

To describe the FBE-I Operational Concept, an Operational View and an Activity Model were developed. Details on the architecture products developed to support the FBE-I Operational Concept are presented in the following paragraphs.

High-Level Operational Concept (OV-1)

Figure 5-1 is the Operational View 1 (OV-1) depicting the general concept of the experiment. The OV-1 used in FBE-I also included a detailed narrative that described the concept of operations used in the Joint Fires portion of the FBE-I experiment, but due to its length, that narrative has not been included in this example. In general, the objective of the Joint Fires portion of FBE-I was evaluation of the concept of using Joint Fires in support of Land Maneuver. As shown in Figure 5-1, this portion of the experiment involved the Marines launch of a Littoral Penetration Task Force (LPTF) that was attempting to maneuver to the objective (indicated by the red triangle). In order to defeat an opposing enemy threat, surface weapons (e.g., Extended Range Guided Munitions (ERGMs), Land Attack Standard Missiles (LASMs), Tactical Tomahawk Land Attack Missiles (TTLAMs), and Advanced Land Attack Missiles (ALAMs)) would be likely to require rapid retargeting data, and Tactical Air (TACAIR) assets could require in-flight redirection. The network provided in the experiment would, in theory, provide the timely information required to influence the maneuver ashore.

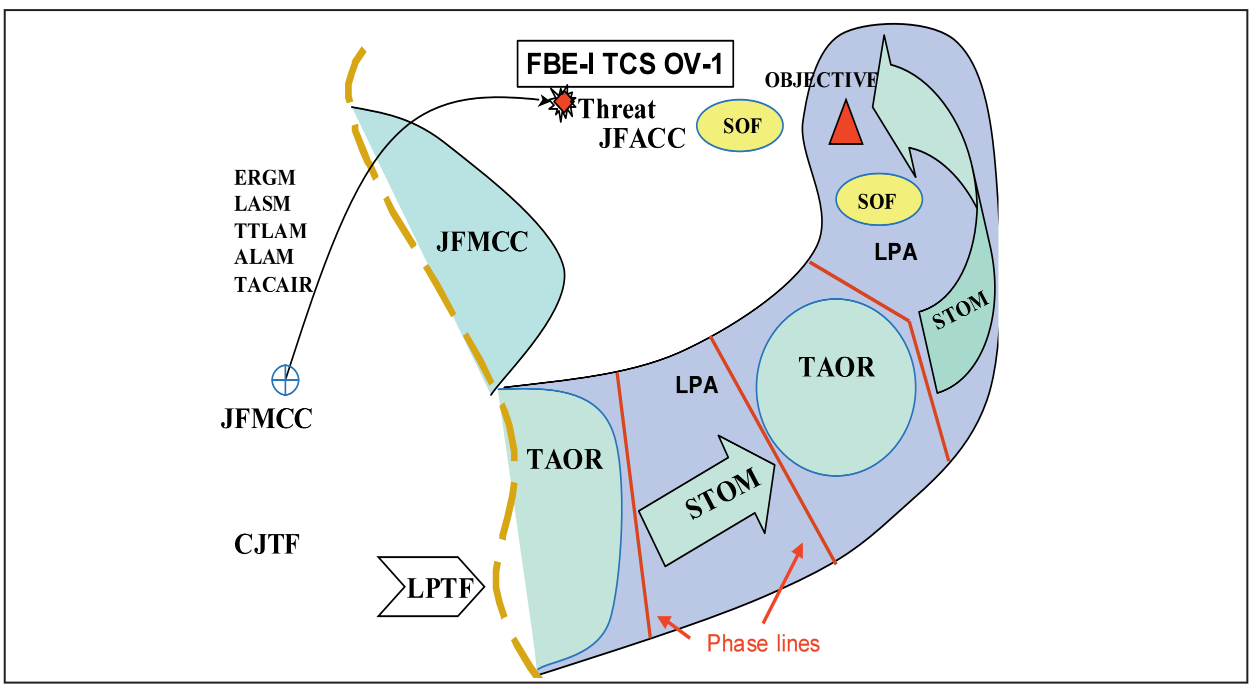

Figure 5-1. FBE-I TST Joint Fires Operational View (OV-1)

Activity Model

Figure 5-2 provides the Joint Targeting Doctrine augmented for TST. This doctrine was used as the basis for the FBE-I TST Joint Fires Operational Concept. In the graphic, the various aspects of targeting are integrated into a unified model. This activity model is traceable to the Joint Targeting Doctrine for the Precision Engagement example presented in Chapter 4 (Figure 4-3). The main difference is an inner loop for TST that is triggered by observations made either locally or through TCPED during the execution of the planned mission.[⌖]

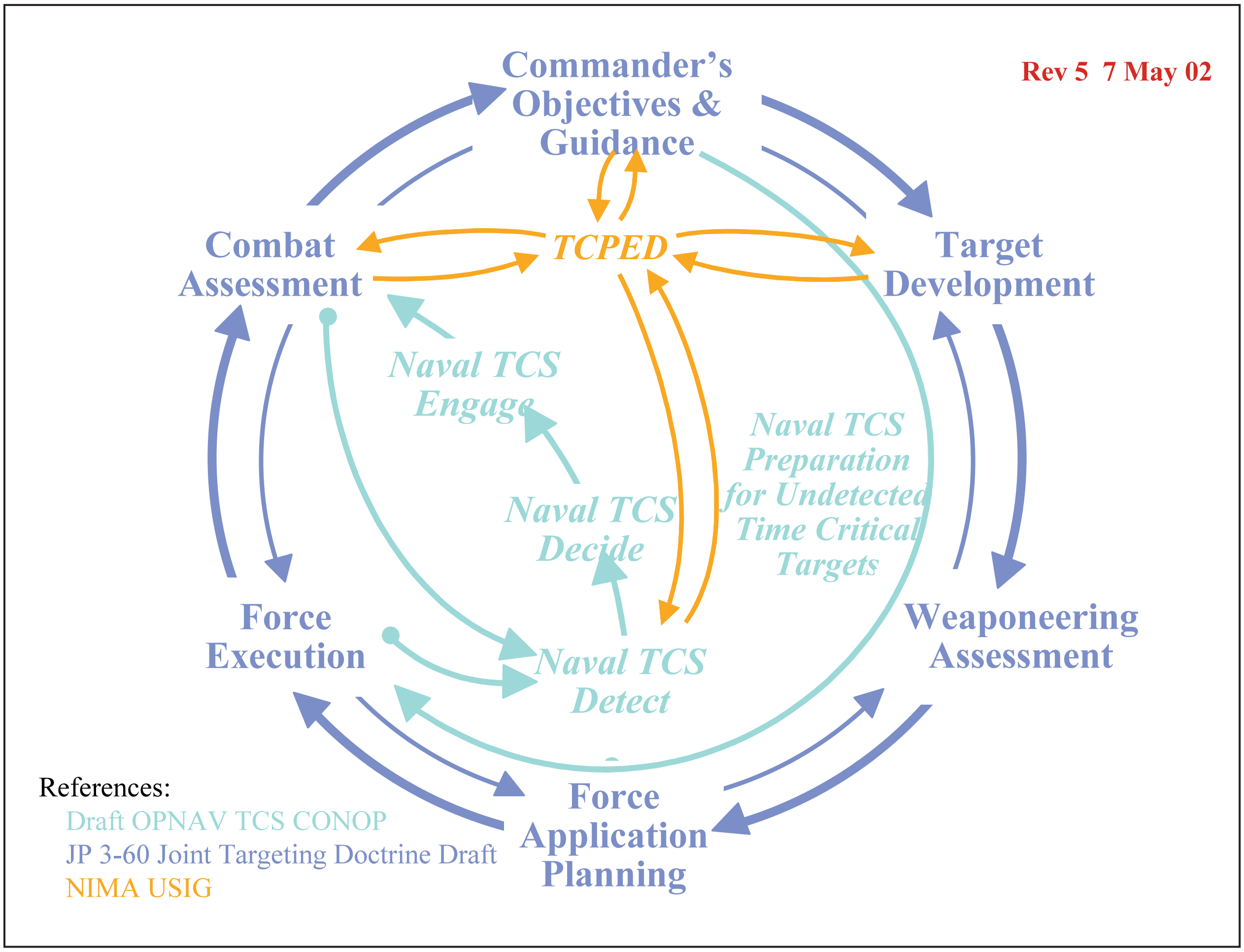

Figure 5-2. Joint Targeting Doctrine Augmented for TST

Figure 5-3 is the modified Activity Diagram (OV-6c) that captures the notional decomposition of activities associated with the TST experiment in FBE-I. It is a hierarchical depiction of the CONOPs-developed list of activities. The first tier activities (Detect, Decide, Engage, Assess) provide the most basic description of how TST was accomplished in FBE-I. (Note that an additional Prepare phase was provided in the background, but that phase was not in the scope of

[⌖]This model was developed by the Naval Targeting Operational Architecture team. The development conducted by this team was a collaborative effort with participation from across the Fleet and OPNAV. The team was led by Dr. Cheryl Walton (who was the RDA CHENG Deputy Director of Architectures at that time) and BGen (ret) Bruce Byrum.

the FBE-I CONOPS.) The second tier activities (e.g., Receive TST Cue, Assess, etc.) are more detailed descriptions of how the first tier activities will be accomplished. Finally, the third tier activities, which were drawn from the Universal Naval Task List/Naval Tactical Task List [11] vice the CONOPs, were used to cross-reference the first- and second-tier activities in FBE-I to approved Naval Tasks.[♦♦]

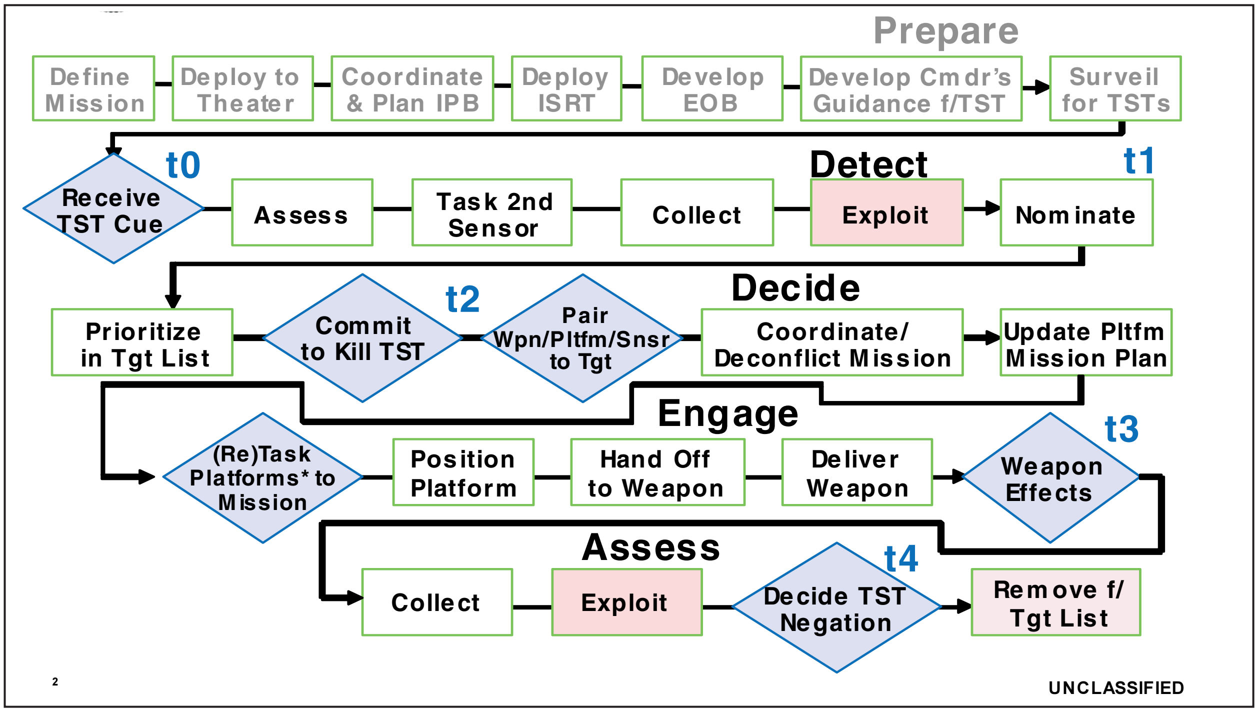

Figure 5-3. Modified Activity Diagram (OV-6c) for the TST Experiment in FBE-I

The Activity Flow Diagram served as a basis for comparing alternative systems. By transferring the concept of operations into a detailed Activity Flow Diagram, it was then possible to map the activities to specific systems functions. Once the system functions are identified, they can be mapped to the desired activities with specified time limits (represented by t0 through t4). It is then possible to map the systems that support those activities and functions in order to identify where alternatives may exist for particular activities and/or functions.

FBE-I System Functional Mapping

To provide a stable model to facilitate management of the complex information describing the systems, their relationships, and their evolution, a System Functionality Description and Operational Activity to System Function to System Mapping were developed. Details on the architecture products developed to support the FBE-I System Functional Mapping are presented in the following paragraphs.

[♦♦] This model was developed under the leadership of Scott Millet at the Naval Air Weapons Center, China Lake, CA.

System Functionality Description

Table 5-1 provides the Second-Level Systems Functions List for the architecture. System functions are defined as the steps taken by hardware or software to complete a process. These functions act in concert with the activities described in the Activities Diagram in Figure 5-2 and together represent the steps taken by people and organizations to complete a process. The functions listed below served as a starting point for the mapping. Higher levels of fidelity in the systems functions were used to complete the mapping to the actual systems that supported the activities. Table 5-1 lists the second level functions used before the move to the next level of fidelity.

Table 5-1
Second-Level Systems Functions List (SV-4a)

First-Level Functions	Second-Level Functions	Definitions
Sense	Single Sensor (SS) Sense	Functions that perform detection, identification, and development of imagery, track, and parametric data by a single sensor on objects in area of interest
	Multi-Sensor (MS) Sense	Functions that create and maintain a correlated and fused common sensor picture from multi-sensor data
Command	Situational Assessment (SA)	Functions that generate a common tactical picture and provide awareness of the tactical situation, including engagement status reporting, battle damage reporting, and warning reports to support planning and decision-making
	Plan (P)	Functions that allocate assets, determine coverage requirements, assign areas of responsibility, develop platform movement orders, and determine sensor and weapon system configurations required to execute a mission
	Decision (D)	Functions that support the development of engagement orders including threat prioritization, development of fire control solutions, target-weapon pairing, and dynamic deconfliction
Act	Engagement Execution (EE)	Functions necessary to execute an engagement (electronic attack, platform/weapon fly-out) and to collect information to support combat assessment
	Force Positioning (FP)	Functions necessary to deploy, maneuver, sustain, and/or configure, platforms, troops, cargo, sensors, and weapons
Interoperate	Communicate Sense Data (CSD)	Functions that support the dissemination, including formatting, access and routing, of sensor data which is to include detection or track data, signal feature or ID data, or imagery data
	Communicate Force Orders (CFO)	Functions that support the dissemination, including formatting, access, and routing, of rules of engagement, target lists, intelligence, and restricted areas
	Communicate Status (CS)	Functions that support the dissemination, including formatting, access, and routing, of engagement results and status, including imagery and mission and operations status
	Communicate Order (CO)	Functions that support the dissemination, including formatting, access, and routing, of calls for fire, weapon tasking, aim-point data, disarming orders, warning orders
	Precision Navigation and Timing (PNT)	Functions that supply current time, navigation data, and METOC data to all other functions

Operational Activity to System Function to System Mapping

Figure 5-4 provides the Activity Flow Diagram, with mapping of functions and systems to each operational activity. The activity flow diagram established for this notional task is framed by the activities written in each box. In the corner of the box is a number that represents the system function that maps to the activity in the box. There is also a system with a number that is mapped to each box. Each system number represents an actual system that can and has been used to perform the activity and function in each box. As shown in the figure, the same system may perform several of the activities and functions. In some cases, several systems are identified that are capable of performing the same function; in other cases, there are no systems available to perform the function.

The Activity Flow Diagram in Figure 5-4 provides a critical mapping of operator activities, systems functions, and systems that can allow users to see where possible overlaps and gaps may exist in the end-to-end process. It should be noted that this is only an initial indication of the existence and location of possible overlaps and gaps; further analysis must be conducted in order to identify where necessary and unnecessary duplication may exist and where there may be desired gaps in system coverage. For example, in combat operations, there is often the need for designed-in redundancy to increase the probability of success. Additionally, combat has certain aspects that demand that intervention and processing be performed by human beings rather than systems; accordingly, certain activities may be intentionally unaligned with systems to perform support for that activity.

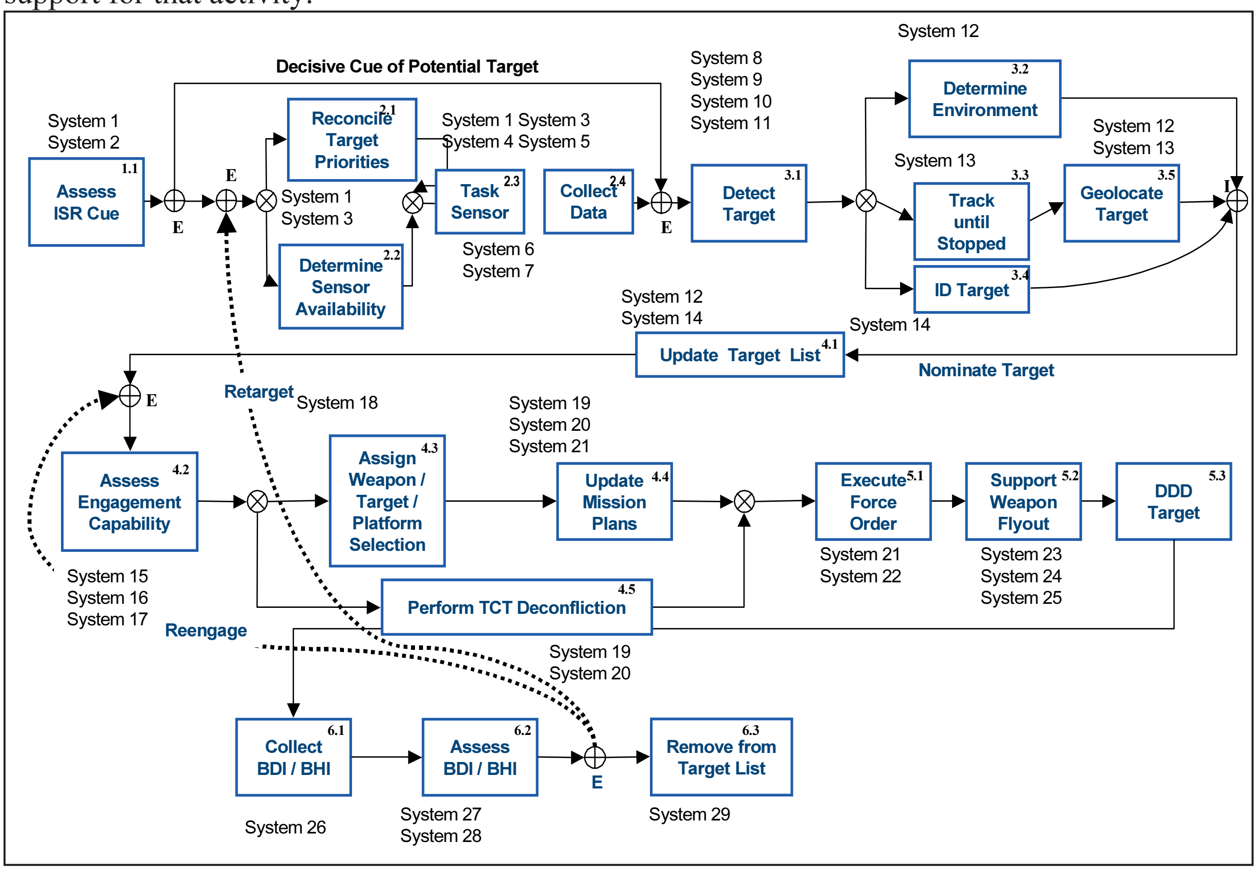

Figure 5-4. Activity Flow Diagram with Function and Systems Mapping

While this mapping only provides an initial look at possible gaps and overlaps, it is a helpful tool for determining areas for further investigation. The notional results of the functional analysis can be presented in the manner shown in Figure 5-5.

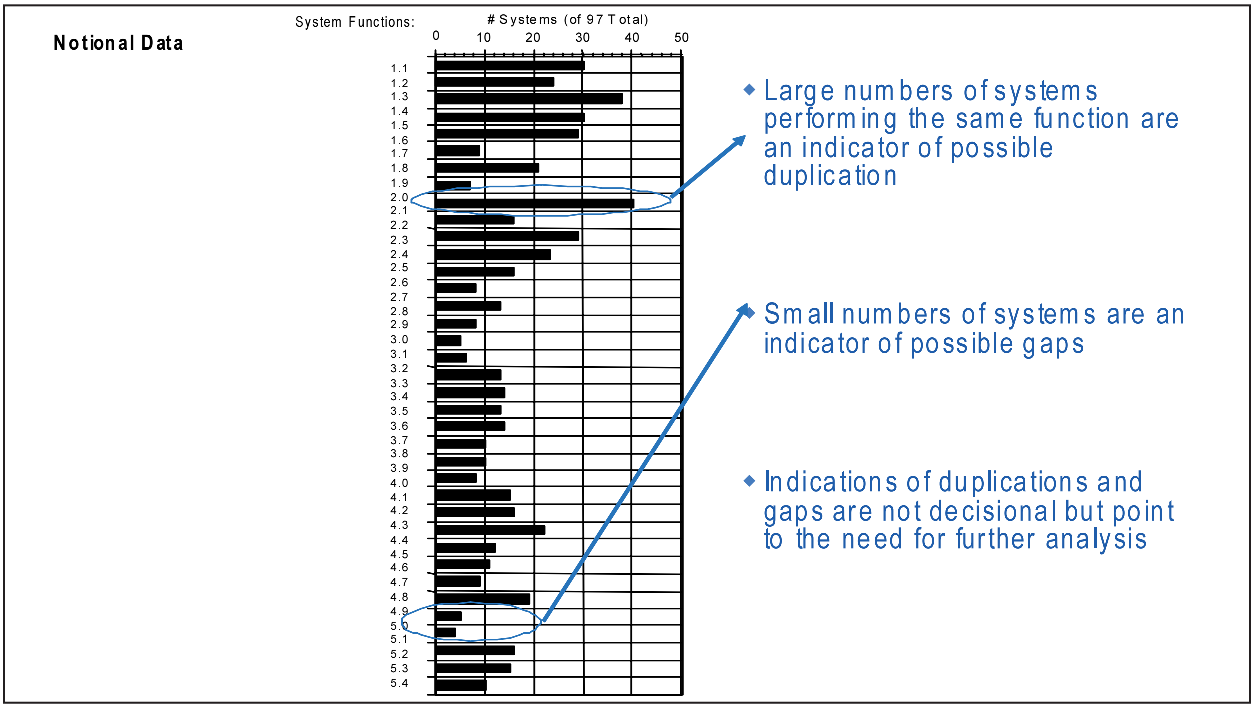

Figure 5-5. Gaps/Overlaps Analysis Results

At first glance, it is clear that there are initial indications of possible gaps and overlaps that merit further analysis. If the analysis indicates that there is unnecessary overlap based on an accepted level of risk to the stakeholder, then further analysis should be conducted to determine if the system is required. This analysis should begin with an assessment of the system in the performance of the specific activity and function, but beyond this assessment, there are several sensitivities that must be considered before a final decision can be made to determine if the duplicate system is required.

It is important to note that because systems are often procured based on individual assessments of a single system in the areas of cost, schedule, and performance, the procurement of systems that can perform overlapping functions is not unusual. Until a system of systems is evaluated against the objective operational architecture, the impact of the overlaps cannot be fully realized. Further, the failure to evaluate systems of systems against an objective operational architecture has resulted in a trend of investing in the improvement of systems that have proven to be capable of conducting certain functions, and this trend has resulted in the acquisition of multiple systems that can conduct these certain functions. Meanwhile, little investment has been made in new systems that are required to fill gaps. Additionally, new systems that are procured are frequently not fully interoperable with their respective system of systems, into which significant investment has already been made. This fact makes achieving end-to-end interoperability nearly impossible.

The architecture analysis conducted as part of FBE-I was designed to show how the architecture products could be used to evaluate systems of systems against an objective operational architecture. The results of FBE-I were used to assess the performance of systems in an end-to-end process to achieve the concept of operations described previously in Figure 5-1. For the set of systems used in FBE-I, actual experiment data was recorded to indicate the end-to-end performance as well as the individual system performance in the specified task and scenario. This process yielded an objective activity flow diagram mapped to a desired set of system functions and mapped to a set of systems that were going to be used for the experiment. It was then possible to map multiple programs of record to the same desired operational activities and functions, providing an indication of the existence of other systems capable of performing those same functions. The addition of these systems from programs of record enabled identification of potential overlaps and gaps. In cases where overlaps were identified, additional analysis was conducted to see if the overlap was a necessary or unnecessary duplication.

During POM 04 decision-making, Navy personnel used architectures to develop a gaps and overlaps analysis like the one shown previously in Figure 5-5. The results of this analysis provided pointers for more detailed systems engineering trades that enabled determination of whether or not overlaps were indeed duplications and allowed assessment of the operational impact of system functional gaps. The process is summarized in Figure 5-6.

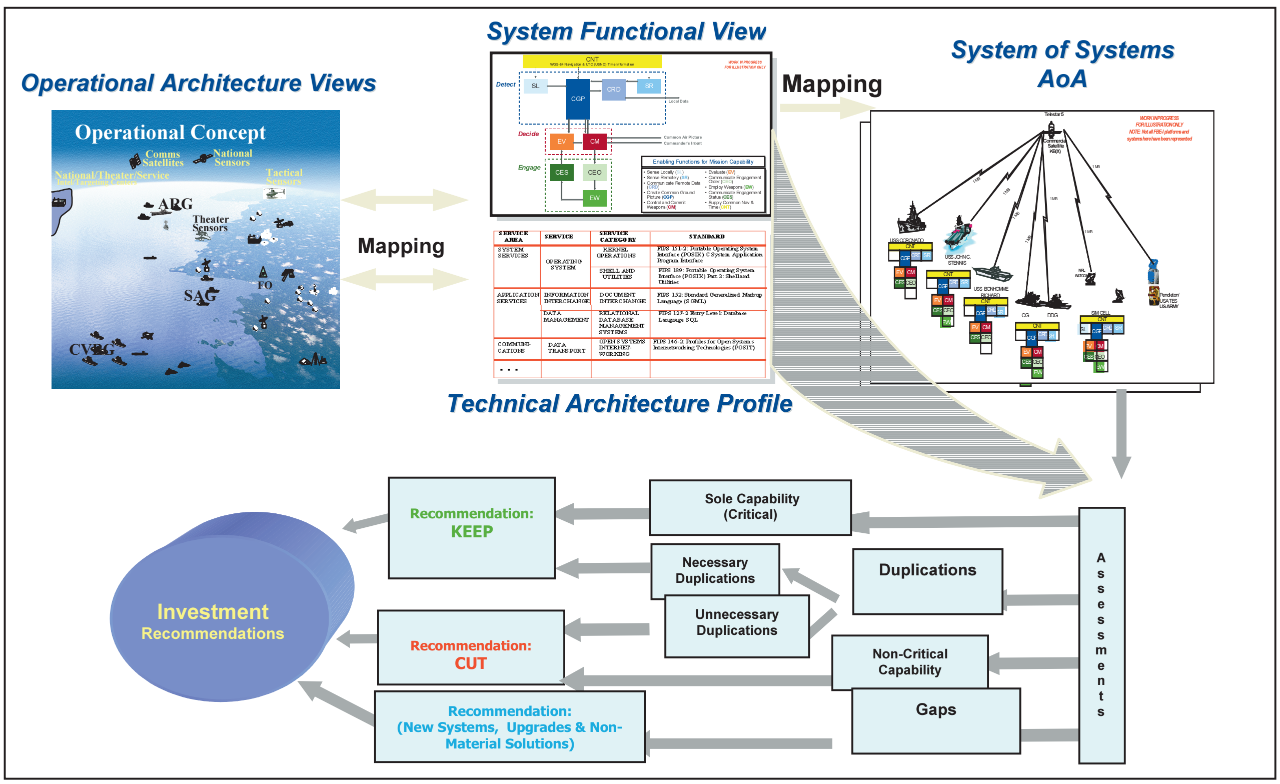

Figure 5-6. Analysis Process used for POM 04

FBE-I System Interface Mapping

To gain a better understanding of the connectivity between FBE-I systems, a system interface mapping was developed. Details on the architecture products created to support this area of the analysis are described in the following paragraphs.

Systems Interfaces and Connectivity

A system interface mapping was developed in order to conduct the experiment. The physical interfaces set up for the experiment were leveraged by identifying the IERs that were used as well as the standards and protocols applied. Figure 5-7 provides a notional description of the physical interfaces that were used. This system interface mapping represents the physical platforms and systems that were used to support the activity and function flow diagram presented previously in Figure 5-3. The actual database stored in the Joint Mission Area Analysis Tool (JMAAT) enabled drill-down to the individual systems on each of the platforms described. The system interface mapping was used as a baseline to enable identification and evaluation of each system for its ability to integrate with other systems and to support the required functions in order to meet the specifications of the architecture. This mapping also led to identification of systems that performed duplicate functions. When systems were identified as providing unnecessary duplication in function, further analysis was conducted to determine if the systems were required in support of the activity and function.

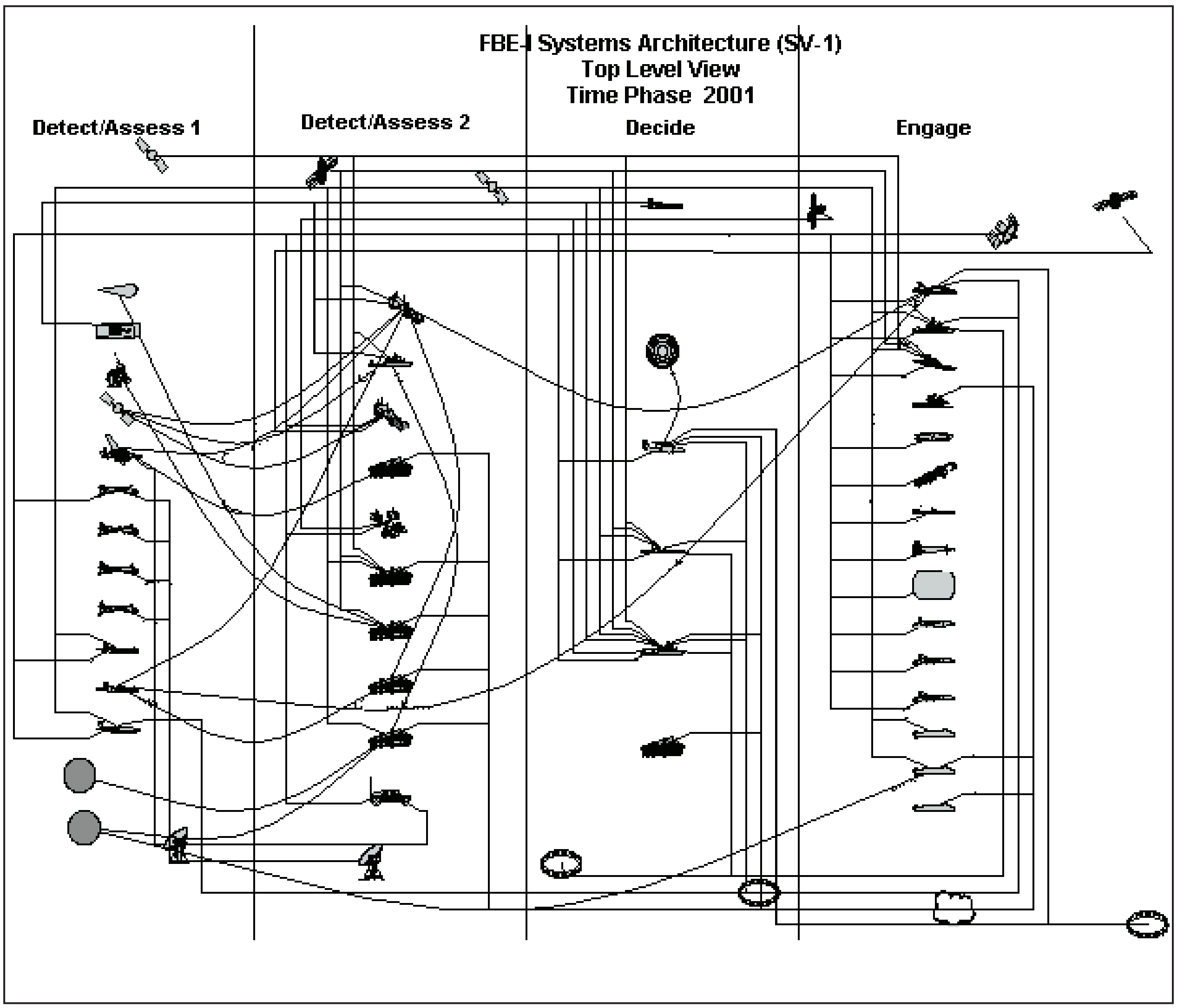

Figure 5-7. Notional FBE-I TST Platform and Links Relationship (SV-1)

System Information Exchange Matrix (SV-6)

The System Information Exchange Matrix (SV-6) describes, in tabular format, information exchanges between systems within a node and from those systems to systems at other nodes. The focus of the System Information Exchange Matrix, however, is on how the data exchanges actually are (or will be) implemented. Including system-specific details covering such technical characteristics as specific protocols and data or media formats is critical to understanding the potential for overhead and constraints introduced by the physical aspects of the implementation.

The System Information Exchange Matrix can be adapted for use in the FoS system engineering process by broadening this view to create end-to-end views of system information and service exchanges. This expanded System Information Exchange Matrix will retain the attributes of the existing framework product, which includes the information exchanges within a node and from those systems to systems at other nodes. The expanded matrix can be easily derived from information in the Operational Information Exchange Matrix, Technical Architecture Profile, Operational Activity to System Traceability Matrix, and Systems Matrix. By combining the information from these four products, the expanded System Information Exchange Matrix becomes the system analog to the Operational Information Exchange Matrix. The expanded matrix product can be created because the matrices of the preceding architecture products can be used to develop end-to-end views of system information and service exchanges. Each communication between two systems can be traced to illustrate the source and destination nodes, activities, systems, system functions, information elements, technical standards, and attributes of logical and technical interfaces of the FoS architecture. As shown in Figure 5-8, this matrix can then be used to identify gaps in interoperability.

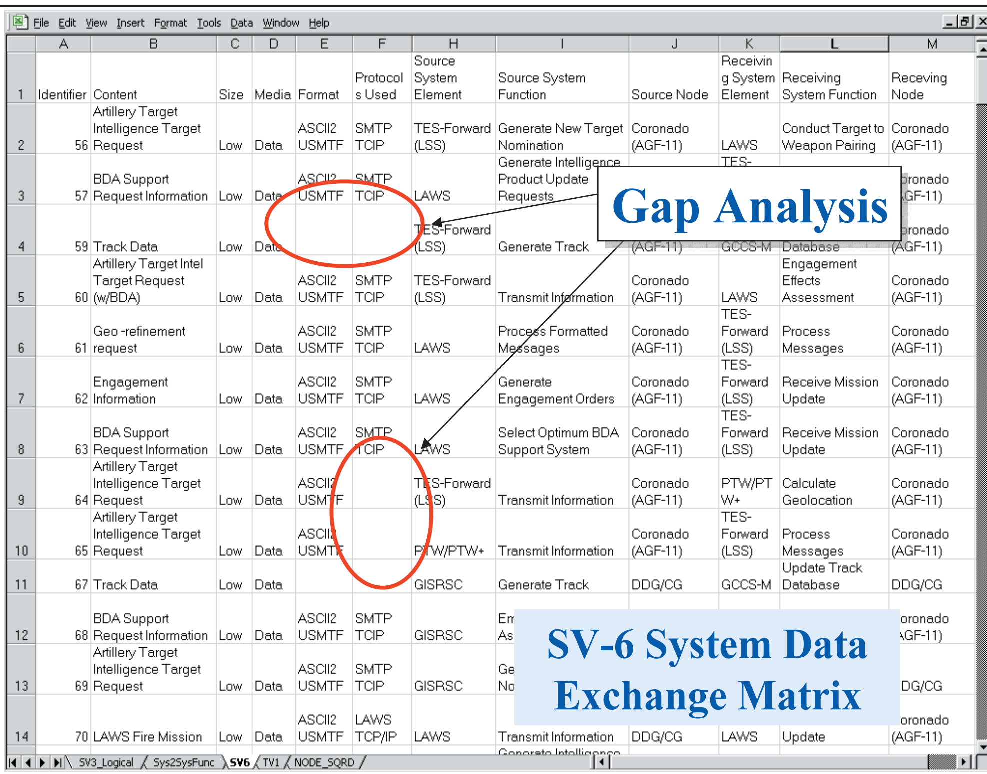

Figure 5-8. Use of System Information Exchange Matrix for Gap Analysis

As noted previously, in a complex system, it is the interfaces and connections that provide unique, value-added FoS functions. The added value (e.g., a more coherent, integrated picture of the Battlespace) is derived from the interaction among components rather than from contributions of the individual components. The expanded System Information Exchange Matrix defined in the previous paragraph describes the complex FoS entirely in terms of its "application-to-application" interfaces. These logical interfaces (not the physical interfaces) are associated with both the information elements being exchanged (data) and the system function (application) processing the data on either end of the interface. Information elements exchanged between systems have traceability back to the IERs defined in the operational views (particularly in the Operational Node Connectivity Description and the Operational Information Exchange Matrix) because these information elements are the contents of the IERs. The interaction of information elements and system functions together provide key FoS "services" that are fundamental for achieving interoperability. Interoperability is commonly defined as the ability of systems, units, or forces to provide services to and accept the same from other systems, units, or forces and to use the data, information, material, and services so exchanged to enable them to operate effectively together.[23]

The enhanced System Information Exchange Matrix is only concerned with primary system functions. Primary system functions have at least one input and at most one output. The inputs are information elements that are acted upon or changed in some way by the primary system function to create the output. Primary system functions are distinguished from supporting system functions in that the latter are typically attributes of infrastructure (or supporting) systems that move (e.g., route, switch, transmit) information but do not change the content or context of the data. Supporting system functions do not act upon or change the content or context of the information element as it is moved from source to destination (primary system functions). Multiple supporting systems are usually required to support a single logical interface (primary-to-primary system function interface).

It is critical to remember that a primary system function can have no more than one output. If it appears that a primary system function has more than one output information element, then the levels of abstraction between the system functions and the products of the system functions are inconsistent and require reconciliation by the FoS architect. The requirement to have only one output per primary system function is important for the integrity of the architecture, and this importance will become even more evident later in the discussion of executable architectures.

In developing the System Information Exchange Matrix, the System Functions can be decomposed, which also enables the decomposition of the associated information elements. Ultimately, a standard FoS functional view along with standard information elements can be defined for each mission area and can be used in the expanded System Information Exchange views, a line item of which is shown in Figure 5-9.

SV-6 Line Item

ID	Source System	Source Function	Source Node	Dest System	Dest Function	Dest Node	Info Element	Content
336	APY-6 RADAR	Detect Imagery Signals	Hairy Buffalo	TES-Forward (L	Receive Imagery Signals	Coronado (AGF-11)	Imagery	Imagery

Figure 5-9. Expanded SV-6 Line Item with Standard System Functions and Standard Information Elements

System Interface Description (SV-1)

In the Architecture Framework, the System Interface Description (SV-1) is a view that illustrates the relationships and interdependencies between systems by linking the operational and system interface views of the architecture. This view depicts the assignments of systems and their interfaces to the nodes and need lines described in the Operational Node Connectivity Description. The Operational Node Connectivity Description for a given architecture shows operational nodes (not always defined in physical terms), while the System Interface Description depicts the corresponding systems nodes. Systems nodes include the allocations of specific resources (e.g., people, platforms, facilities, and systems) that will be used for implementing specific operations.

While a System Interface Description will typically provide a graphical representation of many systems and their interfaces, there is also a relationship between the System Interface Description and the Expanded System Information Exchange (SV-6). Figure 5-10 has been used to illustrate the descriptor for one interface in the FBE-I FoS. This single row describes two systems, the APY-6 radar and the TES-Forward, and their interface in the context of accomplishing a specific mission task associated with TST. The system functions and the information exchange required are a direct result of an operational requirement defined by the operational views. The figure also shows that there are two physical nodes, the Hairy Buffalo P-3 and the Coronado Command Ship, specified in the interface. At the highest level, a physical node may also be considered a system in the System Interface Description. It can be assumed that these two platforms were selected for their ability to support specific tasks in the mission. The decision to assign these tasks to these two platforms also influenced what system functions had to be available at each node and limited the available solutions for the communication between functions (as illustrated by the Systems Communications Description (SV-2)). Once the nodes for supporting a mission activity have been identified, the required system functions can be identified using the System Functionality Description (SV-4). The solution for moving required information elements between two communicating system functions differs greatly based on the geographic location of the node(s).

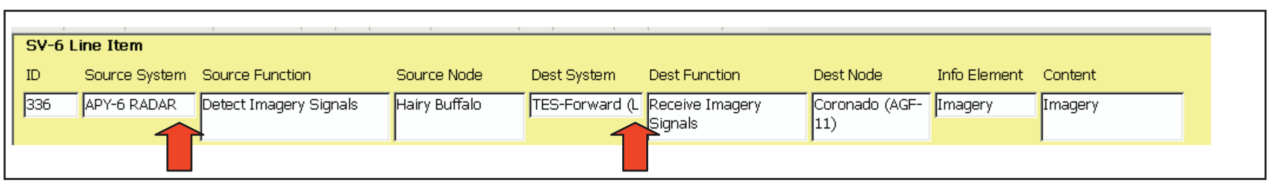

Figure 5-10. Illustration of a Descriptor for One Interface in the FBE-I FoS

FBE-I Performance Assessment Results

To quantify the impact of the FBE-I results on capabilities-based acquisition planning, individual system assessments were conducted using a Multi-Attribute Analysis process. This process enabled systems to be ranked and then mapped into an acquisition investment plan that showed funding and schedule data plotted against time and allowed visualization of program dependencies and phasing issues in a Capabilities Evolution Description (CED) or CV-6. The incorporation of capability analysis and the Multi-Attribute Analysis are described in this section, and the CED is described in the following section on capability-based acquisition planning.

Incorporating Capability Analysis

Capability analysis involves the measurement of an individual system's ability to perform required functions and the FoS's ability to satisfy required mission capability objectives. As discussed in previous chapters, performance and effectiveness can be measured through modeling and simulation, experiments, or properly documented operational lessons learned. Measuring an individual system's performance differs greatly from measuring FoS performance. Individual system performance can be measured by evaluating actual performance against well-defined requirements and specifications. FoS performance effectiveness, however, must be measured by evaluating the FoS's ability to meet mission objectives. This method of measurement introduces the challenge of dealing with several sensitivities. For FBE-I, the capability analyses were performed at the classified level by Naval Weapons Development Center and Naval Air Warfare Center, China Lake, CA.

The effectiveness of an FoS capability analysis is dependent upon identifying the proper components within the architecture for analysis and selecting the most appropriate architecture for the mission area environment. In other words, it is important to make investment decisions to select the proper systems to comprise the mission capability package architecture, but it is also critical to select an appropriate architecture that can achieve the mission capability based on a balance among operator requirements, fiscal constraints, and capability tradeoffs. These tradeoffs can be affected by the impact of both non-material and material solutions. Changing any component of Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities (DOTMLPF) can have a major impact on the analysis and its results.

The decisions that must be made when seeking mission capability are not solely dependent on maximum system architecture performance in achieving the mission, but also on the tradeoffs among other non-material solutions. Simply put, it may become a decision between a 100 percent solution versus an 80 percent solution when it comes to balancing operational requirements, capabilities, and cost.

System Assessment through Multi-Attribute Analysis

The first few chapters of this book discussed the development of architectural views for selected cases or operational situations that can be used to establish a framework that clearly describes the required activities, functions, and systems that, when fully integrated, can provide the desired mission capability. The development of these views will provide the basis for conducting architecture assessments to support Multi-Attribute Analysis. These assessments of the Architecture Framework views provide analysts with another tool for balancing operator requirements against capability achievement and fiscal constraints in order to better define choices. They also provide a starting point for the systems engineering trade-off analysis. The architecture assessments for Multi-Attribute Analysis are critical to the development of Mission Capability Packages that support operationally sound, technically feasible, and cost-effective acquisition decisions.

During FBE-I, the impact of an individual system on the end-to-end process was determined using a Multi-Attribute Analysis conducted by assessing the following attributes:

- Functional Utility
- Fleet and Other Issues
- Interoperability
- Alignment with Future Vision
- OpSit Utility
- Fiscal Rank

Where necessary, further Engineering Analysis was conducted to analyze detailed performance issues. Figure 5-11 illustrates the Multi-Attribute Analysis approach used for FBE-I, and Figure 5-12 illustrates the ranking process used to perform the attribute analysis for TST Command and Control Systems for POM 04. These analyses provided a system-by-system ranking for each attribute as well as an overall ranking. The Multi-Attribute Analysis builds on the gap and duplication analysis to balance operator requirements against FoS capability achievement and cost. The six attributes listed previously have been found to be fundamental to the Multi-Attribute Analysis process. Each of these attributes is illustrated in Figure 5-11 and is described in the paragraphs that follow Figures 5-11 and 5-12.

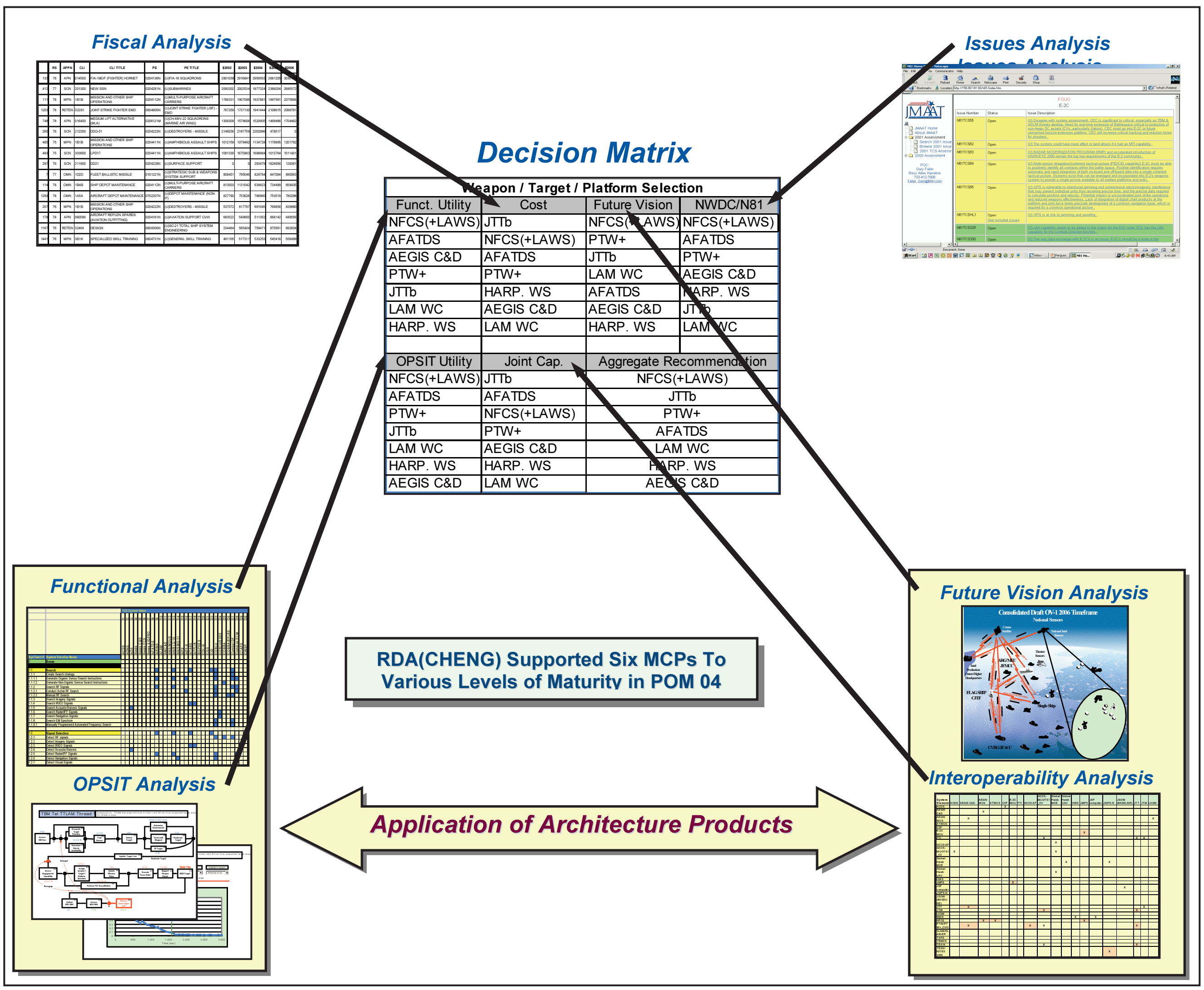

Figure 5-11. Multi-Attribute Analysis Approach Used for FBE-I

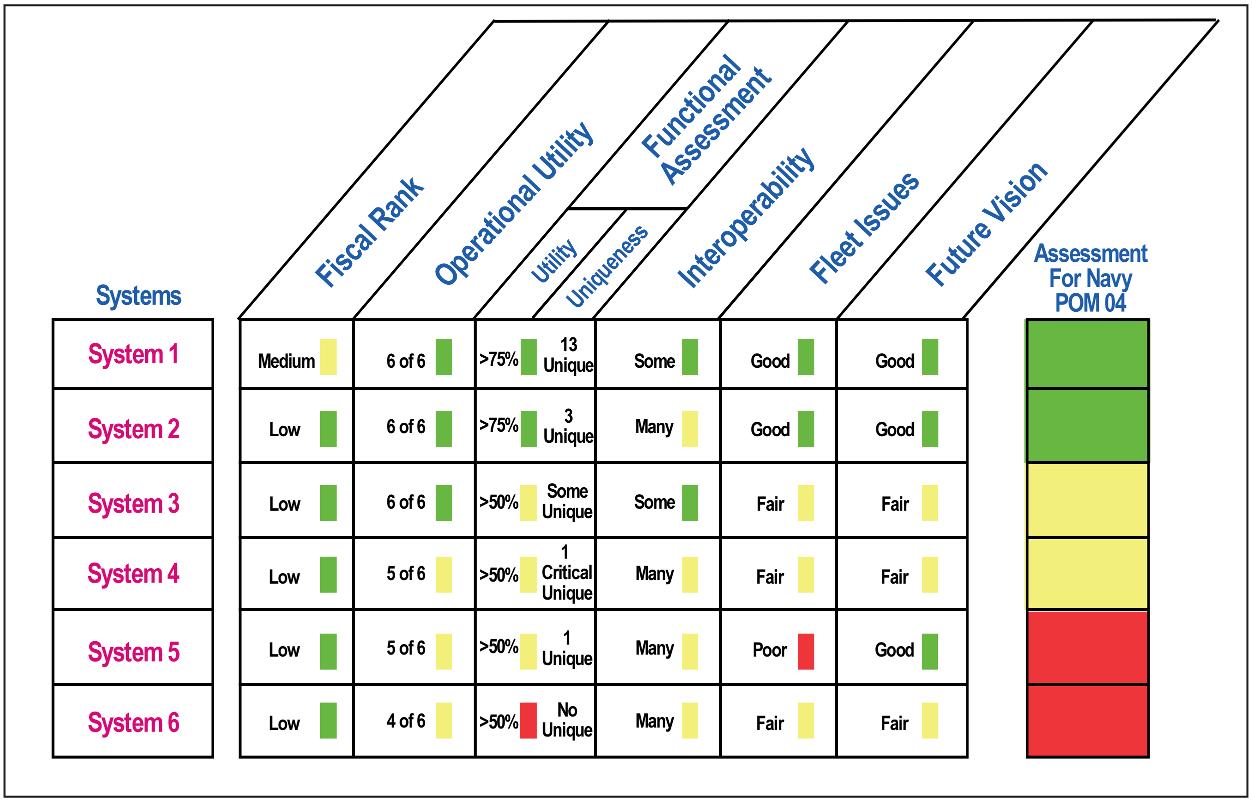

Figure 5-12. Multi-Attribute Ranking Process used for Time Sensitive Targeting Command and Control Systems during POM 04

The first attribute used in the Multi-Attribute Analysis process is an assessment of functional utility. Evaluation of this attribute involves determining whether or not the system can perform the required functions defined by the architecture framework System Views and derived from the required operator activity Operational Views. If the system is capable of performing these functions, it remains in consideration.

Once the system has been determined to be capable of performing its required functions, its ability to perform other functions is assessed in the second attribute of the analysis. It is critical that the system be capable of providing the functional utility to meet desired functional requirements of the architecture. Even so, if a system can perform other functions required in the architecture in addition to the selected functions from the list of required performance specifications, it will receive a higher ranking in the Multi-Attribute Analysis.

The third attribute in the Mulit-Attribute Analysis involves determining how well a system can be integrated or can interoperate with another system or systems to support the desired process or capability. While acceptable performance in the first two attribute areas (the ability to perform specific functional requirements and to be capable of supporting multiple functions) is important, integrated performance is also critical to supporting specific mission capabilities. This part of the assessment is also referred to as the static interoperability assessment.

How a given system supports a future vision is evaluated as the fourth attribute of this process. If two systems can perform the desired functions but only one of the two can meet additional future requirements, the one that can meet the criteria in both attributes will be ranked higher. For example, if a desired system can support Joint and combined operations in addition to specific service objectives, it would score higher in its ranking.

The number and variety of operational situations the system can support will be evaluated as the fifth attribute in determining the value of the system or program. For FBE-I, the architecture framework for the analysis and the systems that supported the architecture were evaluated in six separate operational situations that allowed for varying sensitivities in pursuing different target sets and performing in diverse operational environments. These varying scenarios enable analysts to determine the system's capability to support multiple operational environments and conditions. In evaluating this attribute, systems or programs that can support the architecture in multiple operational situations will be valued and will be ranked higher than those that cannot.

The sixth attribute used in the analysis process is cost. Lifecycle costs should be used when comparing systems or programs that support the various functions required by operators. The lifecycle costs include full system implementation, maintenance, and personnel training. Within this attribute, the higher-ranking programs or systems are those that can satisfy desired functions within required specifications at lower costs for implementation and continued support.

In addition to the six attributes discussed previously, the process also involves consideration of other available assessments of programs. These assessments include analyses conducted by the Assistant Secretary of Defense (ASD) for Network Integration and Interoperability (NII) staff in reviewing C4I Support Plans (C4ISPs) at the program's major acquisition milestone review. Technical and programmatic issues cited by ASD(NII) should also be used in the assessment.

The Multi-Attribute Analysis results presented previously in Figure 5-12 summarized the preliminary assessment of the six attributes for the primary C2 systems for the POM 04 TST Mission Capability Package. An analysis of some of the information in that graphic can provide a better understanding of how Multi-Attribute Analysis can be used to support acquisition decision-making. In the graphic, System Numbers 5 and 6 were targeting systems. One was an experimental system, and the other was a legacy Joint system. There was interest in the legacy Joint system primary because it was used by the Marines, and the Navy was considering purchasing it. Using the Multi-Attribute Analysis results, it appears that purchasing the legacy system would not be a good idea for the Navy. The analysis shows that the functionality can be obtained from other systems, and it may present serious problems in terms of integration. The Navy will need to interoperate with the Joint system, but this interoperability could be accomplished using System Number 3 (a Navy system more suitable for shipboard use). The Multi-Attribute Analysis also addressed the experimental system, which was interesting to the Navy because it provided the ability to support dynamic targeting and four-dimensional deconfliction. Again, the Multi-Attribute Analysis indicated that the system was not a good acquisition choice for the Navy because it required the Navy to purchase duplicative functionality in other areas in order to get the one unique function. Integrating the unique functionality of the experimental system into another system, like System 2, should be cheaper and less problematic.

Capabilities-Based Acquisition Planning Using Architecture Framework Products

A capabilities-based acquisition plan aligns the evolution of systems, technologies, and standards to allow development of a roadmap to support the evolving capabilities needed from the FoS. Three existing Architecture Framework products and a proposed new product can be used together to provide a description of the evolution and acquisition of the system improvements to the FoS that is traceable to mission capabilities. Describing the acquisition plan requires three existing Architecture Framework products and a proposed new product:

- SV-9: System Technology Forecast
- TV-2: Standards Technology Forecast
- SV-8: System Evolution Description
- CV-6: Capability Evolution Description

Each of these products is described in the following paragraphs.

System Technology Forecast (SV-9)

A System Technology Forecast (SV-9) is a detailed description of emerging technologies and specific hardware and software products. It contains predictions about the availability of emerging capabilities and about industry trends in specific timeframes (e.g., 6-month, 12-month, 18-month intervals) and confidence factors for the predictions. The forecast includes potential technology impacts on current architectures and thus influences the development of transition and objective architectures. The forecast should be tailored to focus on technology areas that are related to the purpose for which a given architecture is being built and should identify issues that will affect the architecture.

Standards Technology Forecast (TV-2)

A Standards Technology Forecast (TV-2) is a detailed description of emerging technology standards relevant to the systems and business processes covered by the architecture. It contains predictions about the availability of emerging standards and the likely obsolescence of existing standards in specific timeframes (e.g., 6-month, 12-month, 18-month intervals) and confidence factors for the predictions. It also contains matching predictions for market acceptance of each standard and an overall risk assessment associated with using the standard. The forecast includes potential standards impacts on current architectures and thus influences the development of transition and objective architectures. The forecast should be tailored to focus on technology areas that are related to the purpose for which a given architecture description is being built and should identify issues that will affect the architecture.

System Evolution Description (SV-8)

The System Evolution Description (SV-8) describes plans for "modernizing" a system or suite of systems over time. Such efforts typically involve the characteristics of *evolution* (spreading in scope while increasing functionality and flexibility) or *migration* (incrementally creating a more streamlined, efficient, smaller, and cheaper suite), and will often combine the two thrusts. This product builds on the previous diagrams and analyses in that information requirements, performance parameters, and technology forecasts must be accommodated. In FoS systems engineering, the Systems Evolution Description will draw heavily not only from the System Technology Forecast (SV-9) but also the Standards Technology Forecast (TV-2). This is because the FoS derives its capabilities through the interoperation of systems, not just through the operation of individual systems. Thus, the evolution of system connectivity must be given equal attention with individual system evolution.

Capability Evolution Description (CV-6)

The Capability Evolution Description (CV-6) is a proposed new view under consideration by various elements of the DoD. This view would provide a high-level graphic for managers and executives to use for oversight of FoS alignment during acquisition. Portfolios of programs would be bundled by the capability increments referred to in the Operational Concept (OV-1). Increments of capability introduced over time would then establish the evolution of the FoS in acquisition. The delivery of systems and the associated integration and interoperability strategy would be aligned and displayed in the CV-6 graphic, so that connectivity, alignment, and traceability to capabilities are all displayed in one graphic.

FBE-I Capability Evolution Description (CV-6)

For FBE-I, once final rankings were made for the systems, the systems ranking the highest were mapped into an acquisition investment strategy over time to evaluate program phasing. When the funding and schedule data were plotted over time, it was easy to visualize program dependencies and phasing issues. The exhibit used to support this visualization was the CED (CV-6). The CED enabled visualization of program funding and schedule data in a manner that provided facilitated identification of program dependencies and phasing for specific capability objectives desired by a designated year. Figure 5-13 provides an illustration of the CED. As shown in Figure 5-13, programs of record can be aligned to specific desired capability objectives over time using a CED view. The red, yellow, and green colors in the capability objective lines indicate when the specific criteria for the capability objective has been entirely met (green), partially met (yellow), or not met (red). A new program coming on line can cause improvement in the achievement of a capability objective, but it is not necessarily the only cause, nor is technical achievement of a new capability enough by itself to ensure achievement of a capability objective. The new program must also be funded adequately to meet IOC by the objective year, and it must be able to be properly integrated with the other systems required to meet the capability objective. In other words, the investment strategy will result in meeting the capability objective only if the systems are developed and fielded on schedule, have the proper funding, and can meet the performance criteria in an integrated fashion as an FoS. If all the pieces come together at the right time and level of performance, then the FoS satisfies the capability objective and achieves “green” status.

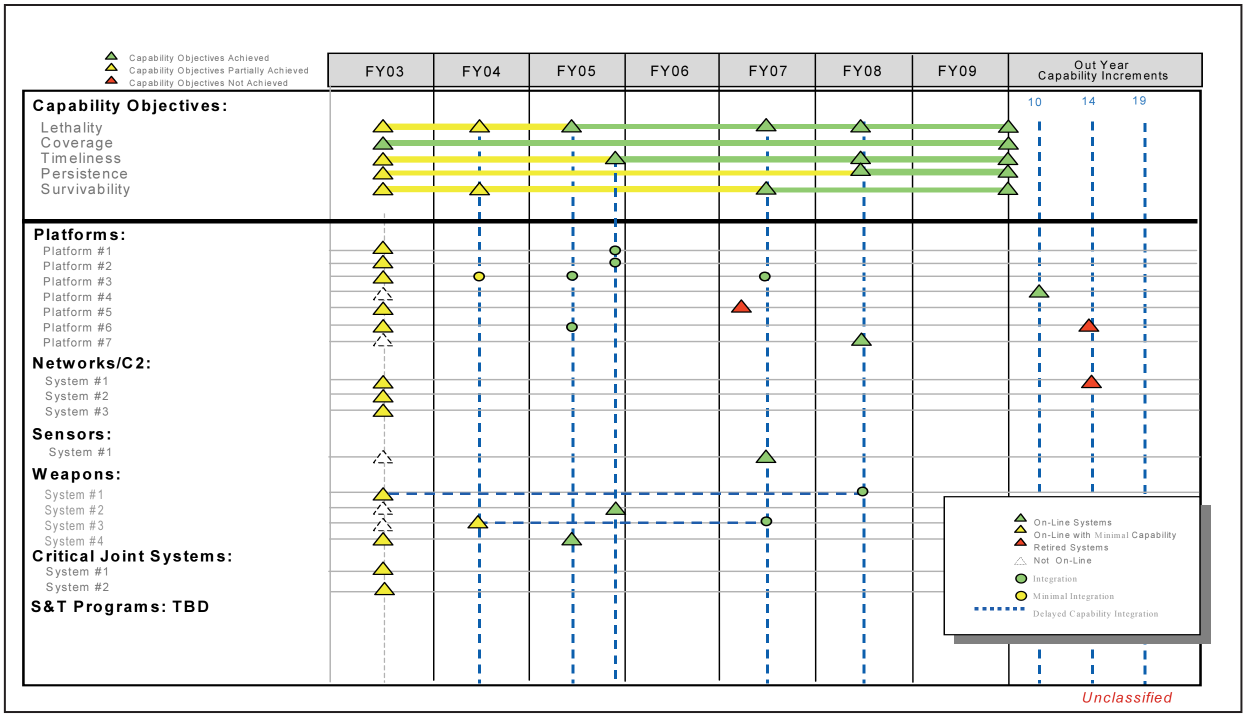

Figure 5-13. CED for FBE-I

The actual CED is a database that stores the data to drive the visualization depicted in Figure 5-13. The database stores the systems of systems data in groups labeled as use cases. Each use case includes stored has performance results associated with the set of systems depicted in a systems interface mapping (SV-1) linked to a capability objective. Also linked to the capability objective is a description of the activity flow diagram mapped to systems functions and systems (an OV-6c modified). Additionally, programmatic data, including cost and schedule, is linked to each program listed in the FoS.

FBE-I Results Impact on Capabilities-Based Acquisition Planning

The architecture analysis methodology, multi-attribute analysis, and CED used during FBE-I proved to be effective tools for supporting investigation of major POM-04 investments in the area of TST. Specifically, the architecture analysis performed during FBE-I yielded the following results:

- A demonstrated ability to document FBE-I TST operational, system, and technical architecture views that could then be used to define the TST Mission Capability Package Architecture in a standardized DoD format that could be compared to Joint and Combatant Commander architectures
- The capability to use FBE-I architecture products to identify and evaluate key performance system integration and interoperability solutions for TST, resulting in seven investment recommendations to improve TST
- The demonstrated ability to combine FBE-I architecture products with Naval Afloat Targeting Integrated Program Team (IPT), Naval Targeting Operational Architecture (NTOA), and National Reconnaissance Office Targeting, Processing, Exploitation, and Dissemination (NRO TPED) architecture products to support POM-04 investment decisions made in TST

Further, the FBE-I products and process provided the foundation to institutionalize the ASN RDA (CHENG) architectural analysis approach for future assessments of the Navy POM. Following FBE-I, the ASN RDA CHENG and the Commander of NWDC signed a Memorandum of Agreement under which ASN RDA CHENG agreed to provide future experiment support through architecture analysis and to use the results of these analyses to support investment decisions in a number of warfare areas. The architecture analysis process used during FBE-I and described in this chapter will be employed during future FBEs to support architecture documentation and comparison as well as evaluation of system integration and interoperability. This process is summarized in the following steps:

- Step 1: Use the Operational Architecture Views derived from the FBE concept of operations and validated by the Naval Forces and Combatant Commanders participating in the experiment to identify the key activities and capability objectives.
- Step 2: Gather existing systems functions from the appropriate Systems Commands. Map the system functions to the activities, and then map appropriate systems to the functions. These mappings will provide a first order assessment that will enable identification of potential gaps and overlaps in systems supporting the required functions based on the desired operational activities. Use Naval Forces and Combatant Commander representatives to identify the existence of necessary and unnecessary overlaps and gaps.
- Step 3: Identify any and all interoperability and integration problems that are affecting or will affect the achievement of desired Joint capability objectives. Use existing databases that assess standards and protocols between the nominated systems. Use documented interoperability issues recorded in the C4ISP program database to identify interoperability problems that may exist between the identified systems.
- Step 4: Use ongoing experimentation, modeling and simulation results, operational lessons learned, and executable architecture models to evaluate the performance and operational impact associated with key interoperability problems.
- Step 5: Document an acquisition plan to correct key interoperability and program synchronization problems identified in the assessment process. Use a CED view to map key system schedule, funding, and dependency factors to desired capability objectives. Use an existing database approach that enables storage of performance data with operational, systems, and acquisition views to facilitate visualization and comprehension of desired capability objectives in relation to specific systems, their functions, their interfaces, and their programmatic data, including cost and schedule.

Figure 5-14 illustrates the process used in FBE-I that will be applied to identify and solve key interoperability and integration problems in future experiments.

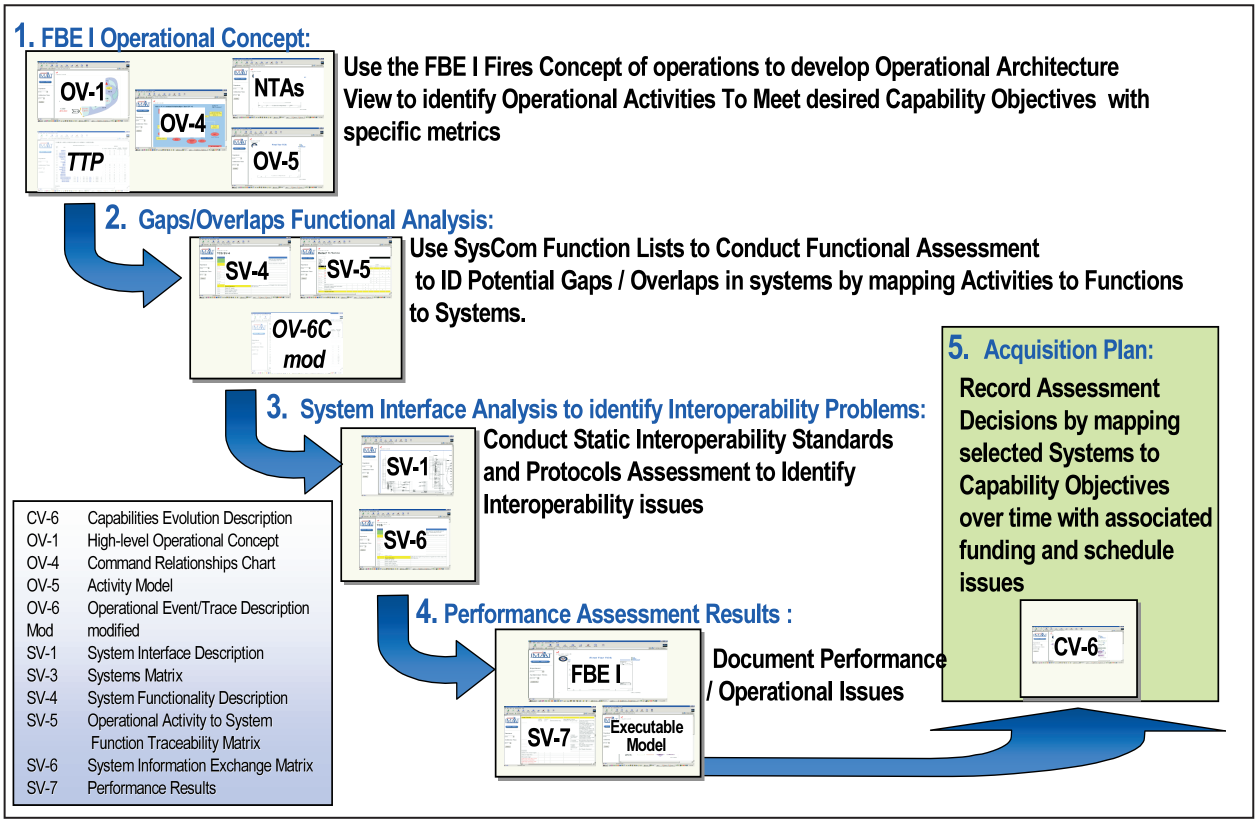

Figure 5-14. Summary of the FBE-I Architecture Analysis Process

Summary

Conducting architecture analysis for the Joint Fires TST portion of FBE-I provided valuable experience in documenting, recording, and analyzing technical and system functional architecture views and in using these architecture products to identify and evaluate key performance system integration solutions. Further, the architecture analysis process was institutionalized during the experiment to enable its future use in supporting architecture documentation and comparison as well as evaluation of system integration and interoperability. The architecture analysis process used in FBE-I begins with developing an operational concept to identify operational activities linked to achieving desired capability objectives. It continues with the listing of system functions and the mapping of these functions to activities and systems to identify potential gaps and overlaps. The next step is the conduct of a system interface analysis to identify interoperability problems, and this step is followed by a multi-attribute analysis to determine the impact of these interoperability problems on performance and operational issues. The final step is the mapping of key systems to mission capabilities using a CED to facilitate visualization and comprehension of desired capability objectives in relation to specific systems, their functions, their interfaces, and their programmatic data, including cost and schedule. The use of this process during FBE-I proved effective in supporting acquisition analysis in the area of TST during POM-04, and it will be used in future FBEs to support investment decision-making in a wide variety of warfare areas.

CHAPTER 6[ǂ]
JOINT MARITIME COMMAND AND CONTROL CAPABILITY

Purpose

This chapter discusses the Joint Maritime Command and Control Capability program, which was undertaken jointly by Naval Sea Systems Command (NAVSEA) and the Space and Naval Warfare Systems Command (SPAWAR) to define the future sea-based command and control capability and to develop the underlying architecture to support Joint Command and Control from a sea-based platform. The Joint Maritime Command and Control Capability (Experimental) (JCC(X)) architecture incorporates the three views (Operational, Systems, and Technical) that have been described in detail in the previous chapters of this book, but it provides specific focus on command and control capability and offers a detailed look at translating operational requirements into operational views. This chapter also provides an in-depth view of the Information Exchange Requirements (IERs) associated with the Operational View of the architecture. Despite the fact that JCC(X) as a program has been cancelled, the C4I mission package that this architecture describes lives on. A command and control variant that will use the JCC(X) architecture to support the requirements process is currently being explored, and the OSD Force Transformation Office has expanded the JCC(X) executable architecture to support training and experimentation.

Background

NAVSEA was tasked by CNO to define the future sea-based command and control capability associated with supporting military operations for a Commander, Joint Task Force (CJTF). The effort, which was called the Joint Maritime Command and Control Capability, also involved SPAWAR, which was tasked with developing the underlying architecture to support the Joint Command and Control Ship C4ISR requirements in operational environments and situations. SPAWAR was also tasked with identifying the architecture requirements associated with the joint operation of U.S. forces with Allied and Coalition partners, Other Government Organizations (OGOs), Non-Government Organizations (NGOs), and Private Volunteer Organizations (PVOs) when they were resident on board the Joint Command and Control Ship.

At the time of the writing of this book, the latest version of the JCC(X) Architecture had just been released. It was developed as a blueprint to support development of inputs to the JCC(X) ORD and the JCC(X) C4I Support Plan (C4ISP). It was also used to support the Analysis of Alternatives and will be used as a basis for the Preliminary Specification (P-Spec). Figure 6-1 shows the sources of information for the architecture development as well as the products the architecture was designed to ultimately support.

The Joint Task Force (JTF) Representative C4ISR Operational Architecture (JRCOA), developed by the Joint Battle Center for U.S. Joint Forces Command (USJFCOM), was used as the baseline for the development of the JCC(X) Architecture. The JRCOA database was then expanded to meet the requirements of the JCC(X) by including elements of the Joint Force Air Component Commander (JFACC), Joint Force Maritime Component Commander (JFMCC),

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[ǂ] This description of the JCC(X) program was prepared by Dennis Rilling and Kar Chan of the Space and Naval Warfare Systems Command (SPAWAR) Requirements Analysis and Assessments Department (SPAWAR 051) and Carl Carden et al with MITRE. The project was funded by the Chief of Naval Operations.

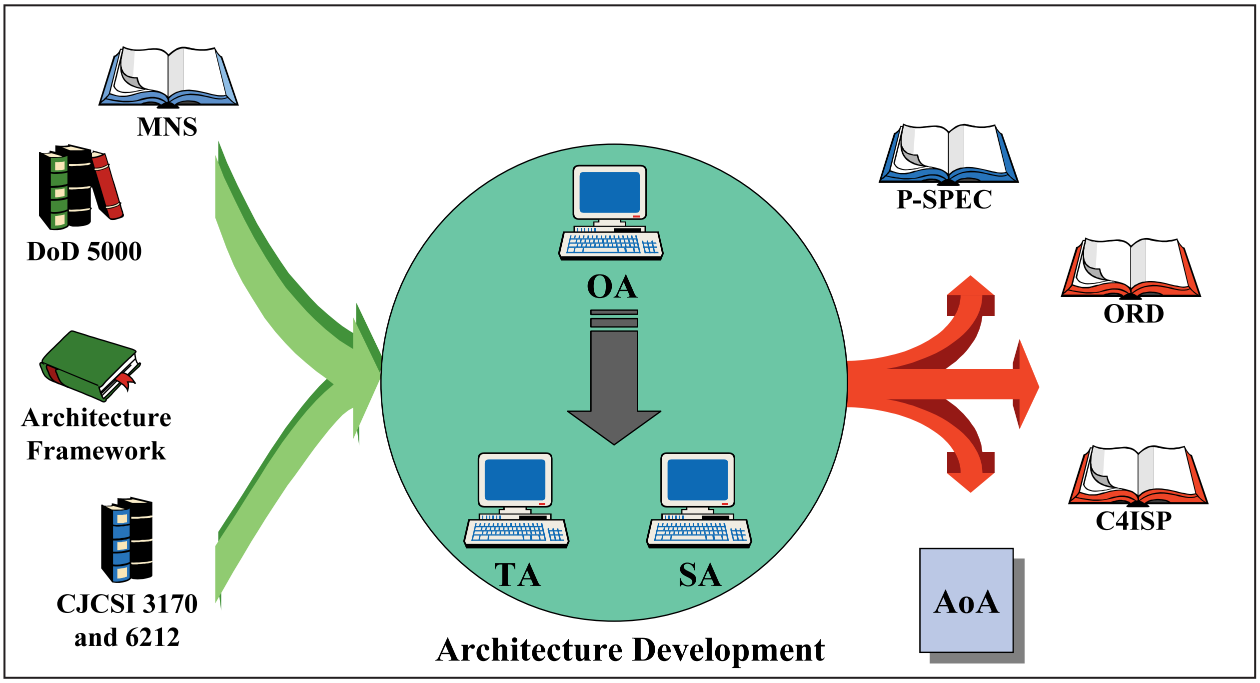


Figure 6-1. Sources of Information for and Products from Architecture Development

Joint Force Land Component Commander (JFLCC), Joint Psychological Operations Task Force Commander (JPOTFC), Joint Civil Military Operations Task Force Commander (JCMOTF), Joint Forces Special Operations Component Commander (JFSOCC), and Allied/Coalition forces.

JCC(X) Architecture Overview

The JCC(X) Architecture incorporates the three interrelated but separate views (Operational, Systems, and Technical) that have been described in detail in the previous chapters of this book. The Operational View describes the operational concept the architecture is being developed to support and identifies process and information requirements. For JCC(X), the Operational View focuses on the mission requirements, activities, and information exchange needs of the CJTF, JFACC, JFMCC, JFLCC, JPOTF, JFSOCC, JCMOTF, and Allied/Coalition commands and undefined organizations that may be part of the JCC(X) mission. As described in the JCC(X) MNS, the JCC(X) mission can range from Humanitarian Assistance/Disaster Relief (HA/DR) to Major Theatre War (MTW). The majority of this chapter focuses on the JCC(X) Operational Concept and the Operational Views developed to support that concept.

The Systems View describes how the process and information requirements identified in the Operational Views are to be implemented. For JCC(X), the Systems View focuses on functionality of system types rather than actual systems and depicts how multiple system types link and integrate based upon the capabilities and operation of particular system types within the architecture. The JCC(X) Systems View provides functional node descriptions to support the development of the C4ISR Mission Package Performance Specifications and Support Plan. These functional nodes are defined as nodes that support the operations of command nodes. Additionally, the Systems View identifies and depicts the DoD system type requirements for parameters including security, interoperability, and reach-back.

The Technical View identifies the standards that must be used to support interoperability interfaces. Developing the Technical Architecture (TA) involves identifying applicable portions of existing technical guidance documentation, tailoring those portions as needed and in accordance with the latitude allowed, and filling in any gaps. The JCC(X) architects recognized that the services and standards defined in the Joint Technical Architecture (JTA) were based on current technology and might no longer be applicable when JCC(X) was expected to be implemented (the 2011 time frame). Accordingly, the JCC(X) architects chose to use the Global Information Grid (GIG) and its associated interfaces, which are known as Key Interface Points (KIPs), in combination with the JTA to develop the Technical Views for JCC(X). The JTA services and standards and the GIG KIPs were identified at the interfaces between all of the JCC(X) node pairs depicted in the System Interface Description (SV-1) developed in the Systems View.

JCC(X) Operational Concept

To describe the JCC(X) Operational Concept, the architects developed the following products:

- High-Level Operational Concept Graphic (OV-1)
- Operational Node Connectivity Description (OV-2)
- Command Relationships Chart (OV-4)
- Operational Event/Trace Description (OV-6c)
- Executable Model

Details on the architecture products developed to support the JCC(X) Operational Concept are presented in the following paragraphs.

High-Level Operational Concept Graphic (OV-1)

The High-Level Operational Concept Graphic (OV-1) depicts the high-level command nodes that were envisioned for JCC(X). This product depicts the nodal connectivity displayed in the Operational Node Connectivity Description (OV-2) products presented later in this chapter. The OV-1 information presented in this section is displayed in the context of the five phases of JTF operations in a generic operational scenario. These phases (Pre-Deployment, JTF Afloat, JTF Afloat-to-Ashore Transition, JTF Ashore, and JTF Shore-to-Afloat Transition) reflect how connectivity between nodes may change based upon the operational phase. Figures 6-2 and 6-3 provide a sample High-Level Operational Concept Graphic for two of the five phases, JTF Afloat and JTF Afloat-to-Ashore Transition.

Operational Node Connectivity Description (OV-2)

Nodes and nodal connectivity (also referred to as need lines) of the Operational View are shown graphically in the Operational Node Connectivity Description (OV-2) product. Complete and accurate identification of the need lines in the Operational Node Connectivity Description provided a basis for ensuring that all required connectivity was achievable.

It should also be noted that the requirement to support Allied and Coalition operations created unique requirements that had to be addressed in the Operational Node Connectivity Description. In the Operational Node Connectivity Description products developed for JCC(X), Allied and Coalition Forces were integrated into the JTF/Component Command structure. Also shown in the Operational Node Connectivity Description products were the information exchanges between the component commanders and the command level of the tactical forces.

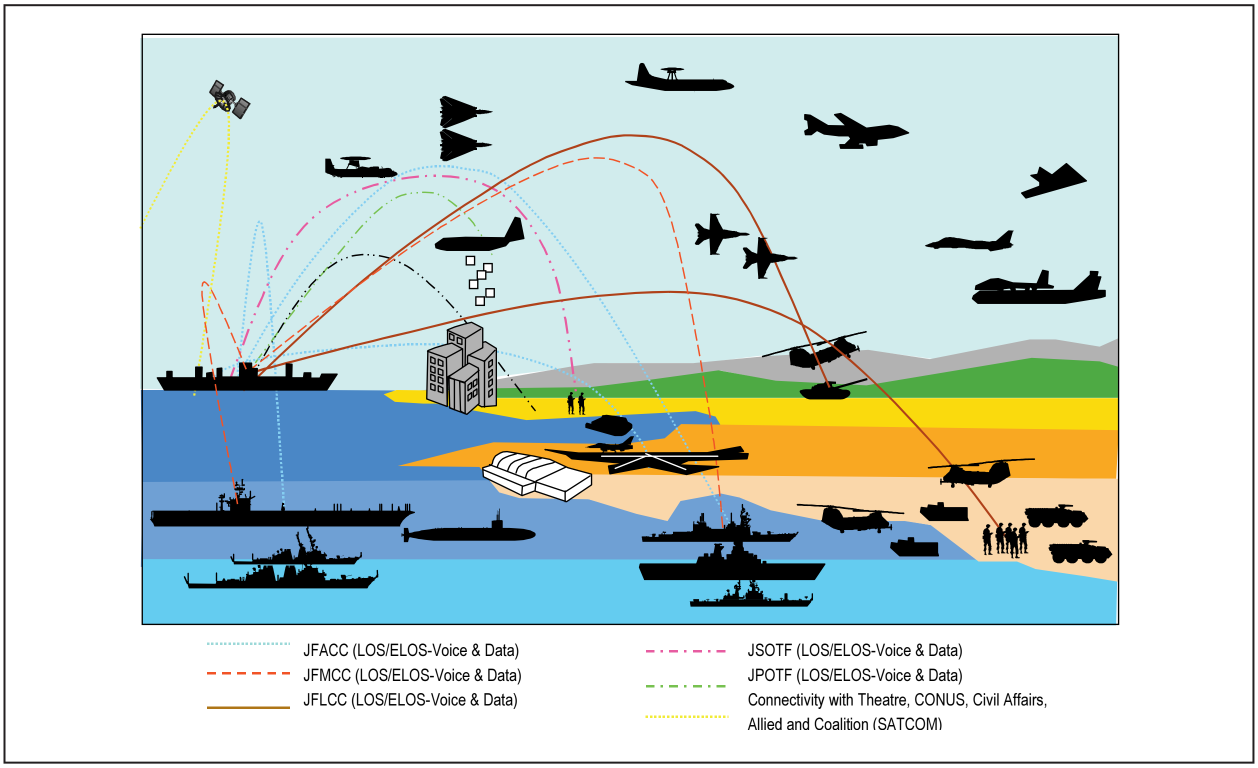


Figure 6-2. High-Level Operational Concept Graphic (OV-1) for JTF Afloat

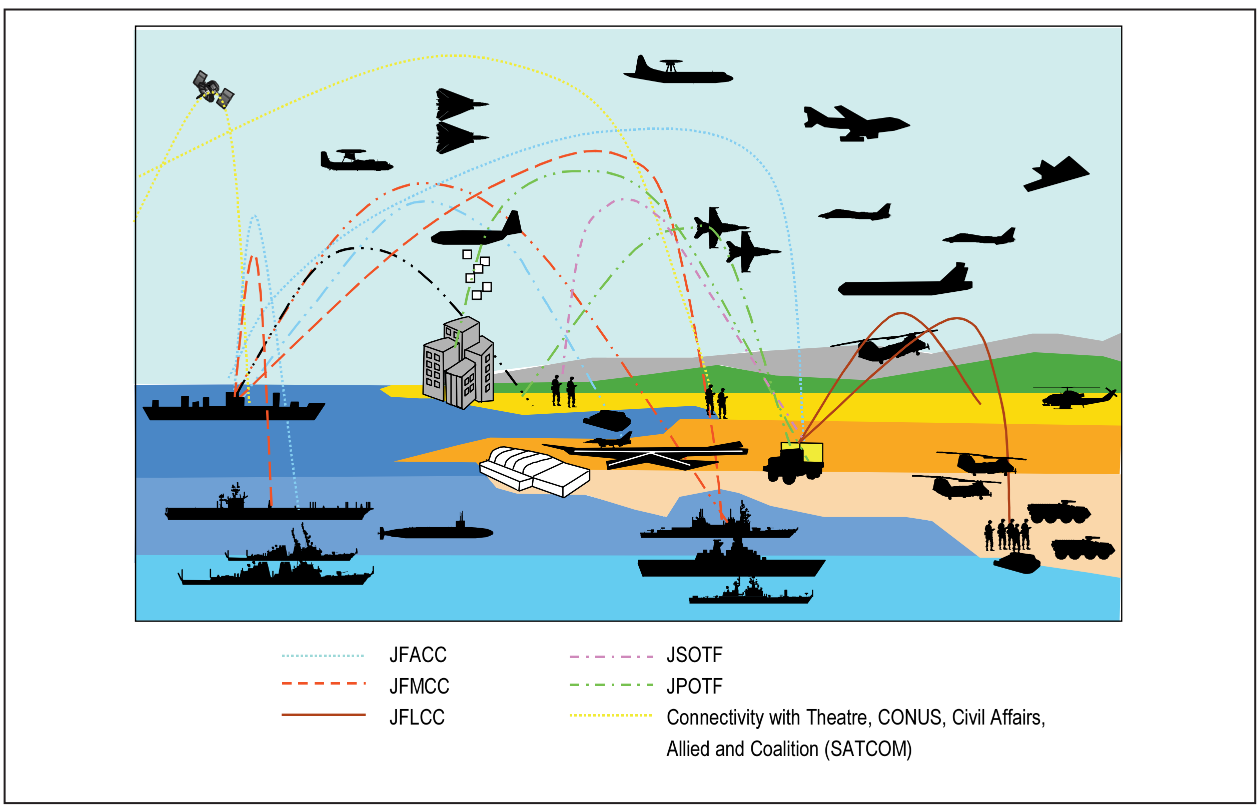


Figure 6-3. High-Level Operational Concept Graphic (OV-1) for JTF Afloat-to-Shore Transition

Figure 6-4 provides a JTF-centric Operational Node Connectivity Description depicting the operational nodes and elements and the need lines (information flows) between them. All nodes and organizations that could have been located onboard the Joint Command and Control Ship are shown inside the shaded box. The red triangle in the corner of a box indicates the presence of Allied/Coalition personnel within that nodal command structure. Since it was envisioned that the Service Organizations could have command elements located on the Joint Command and Control Ship and tactical elements located elsewhere, they are shown partially inside the shaded box and partially outside.

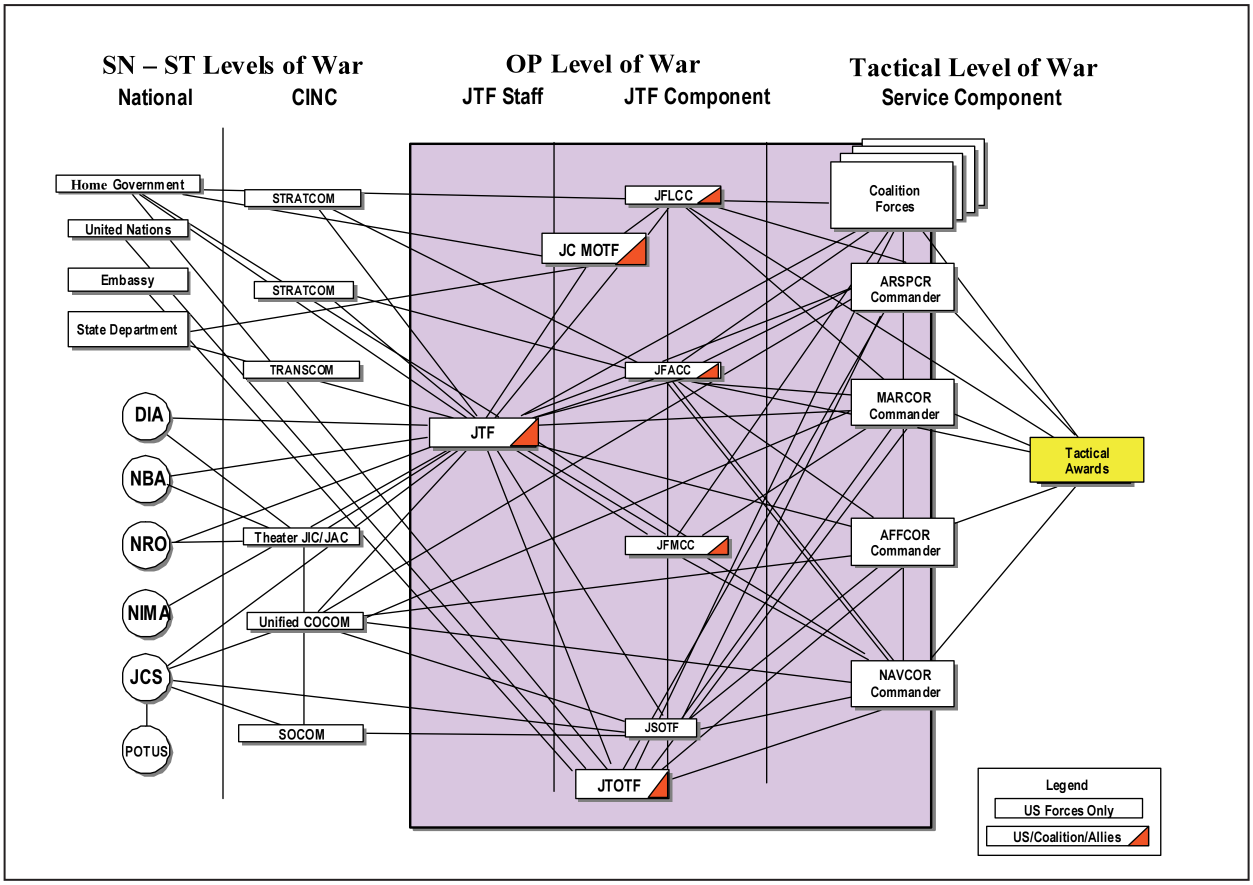


Figure 6-4. JTF-Centric Operational Node Connectivity Description (OV-2) for JCC(X)

Each of the boxes within the JCC(X) shaded area in Figure 6-4 can be decomposed to display a view from the perspective of that box. Figure 6-5 provides another JTF-centric Operational Node Connectivity Description view decomposed down to its sub-elements (e.g., J1, J2, J3, etc.).

Similar views for each of the major Component Commanders (JFACC, JFLCC, JFMCC, JSOTF) were developed as an expansion of the work done in the JFCOM JRCOA. Additional views were developed to reflect the perspective of the JPOTFC and the JCMOTF. Operational Node Connectivity Description products for JPOTF and JCMOTF centric views are provided in Figure 6-6 and 6-7.

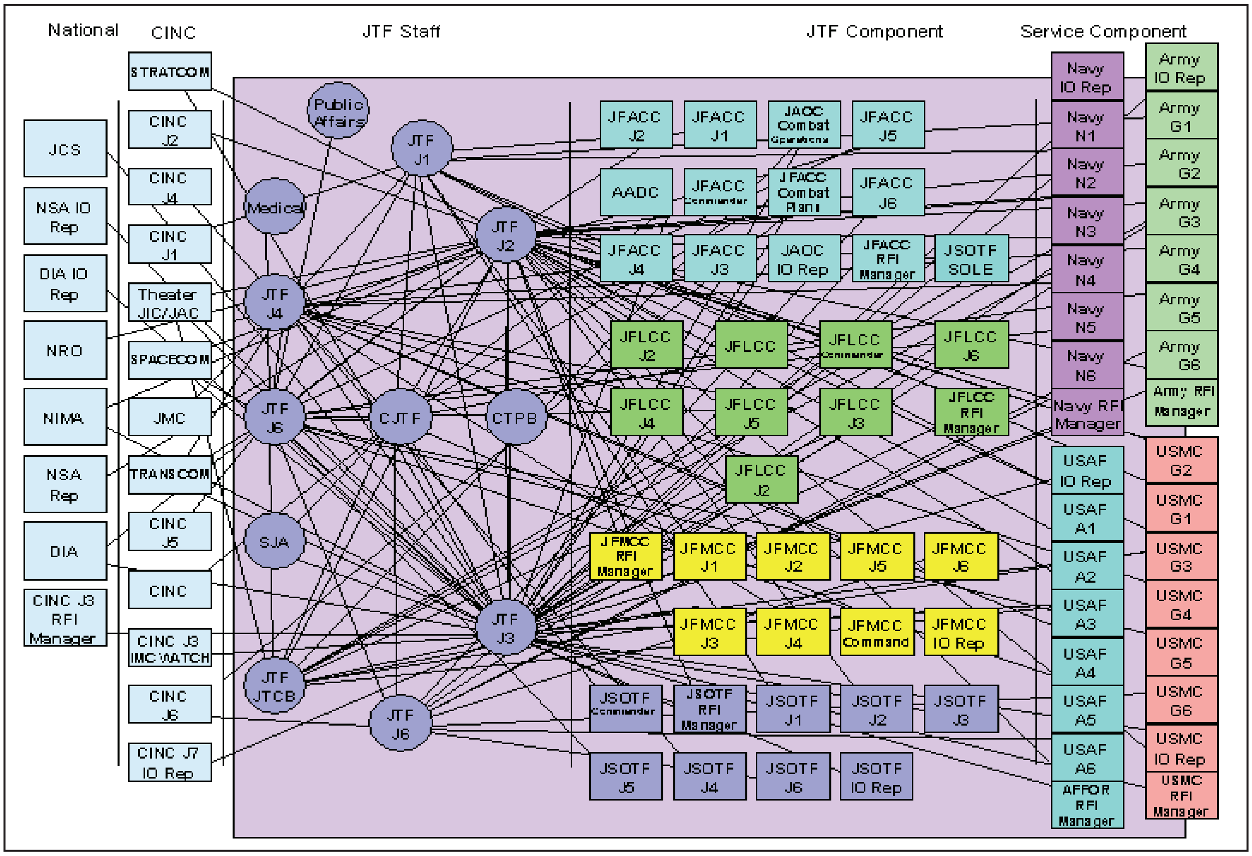


Figure 6-5. JTF-Centric Operational Node Connectivity Description (OV-2) Decomposed to Sub-Element Views

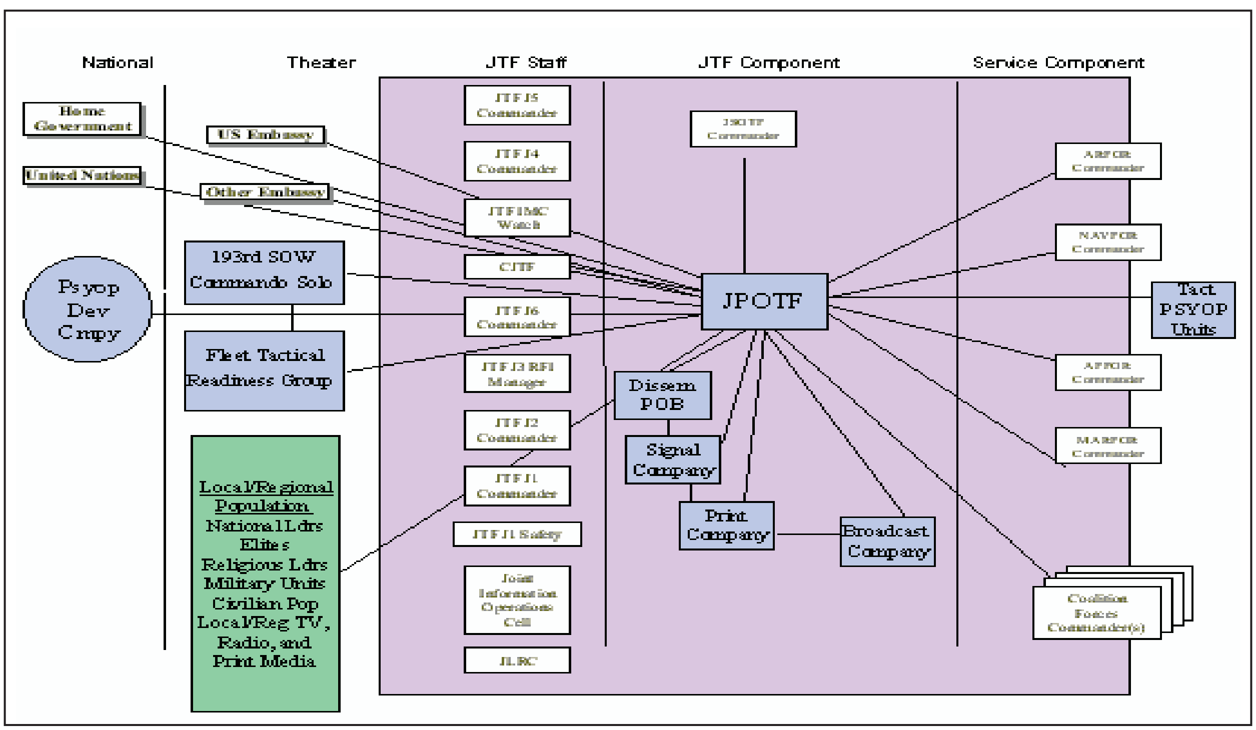


Figure 6-6. JPOTF-Centric Operational Node Connectivity Description (OV-2) for JCC(X)

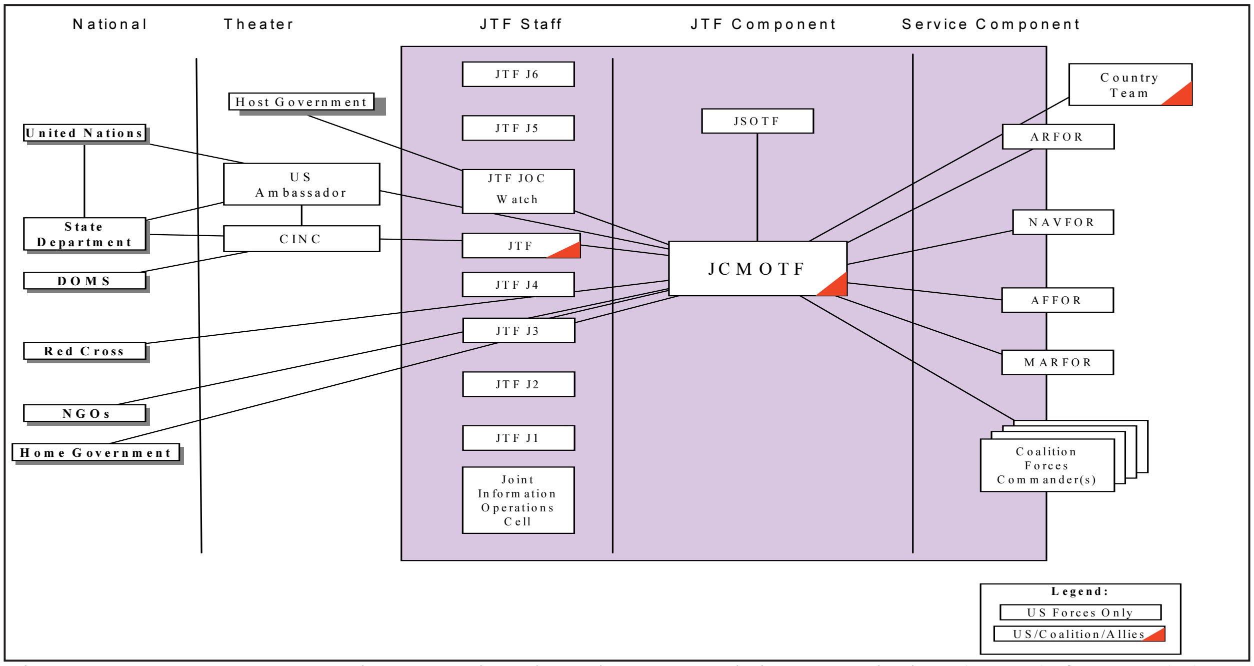


Figure 6-7. JCMOTF-Centric Operational Node Connectivity Description (OV-2) for JCC(X)

Command Relationships Chart (OV-4)

The anticipated High-Level Command Relationships that were anticipated to support the JCC(X) are presented in the Command Relationships Chart (OV-4) in Figure 6-8. As shown, the CJTF had overall responsibility for the Service Components (shown in the second tier of the chart) as well as the JFACC, JFLCC, JFMCC, JFSOCC, JCMOTF, and JPOTF.

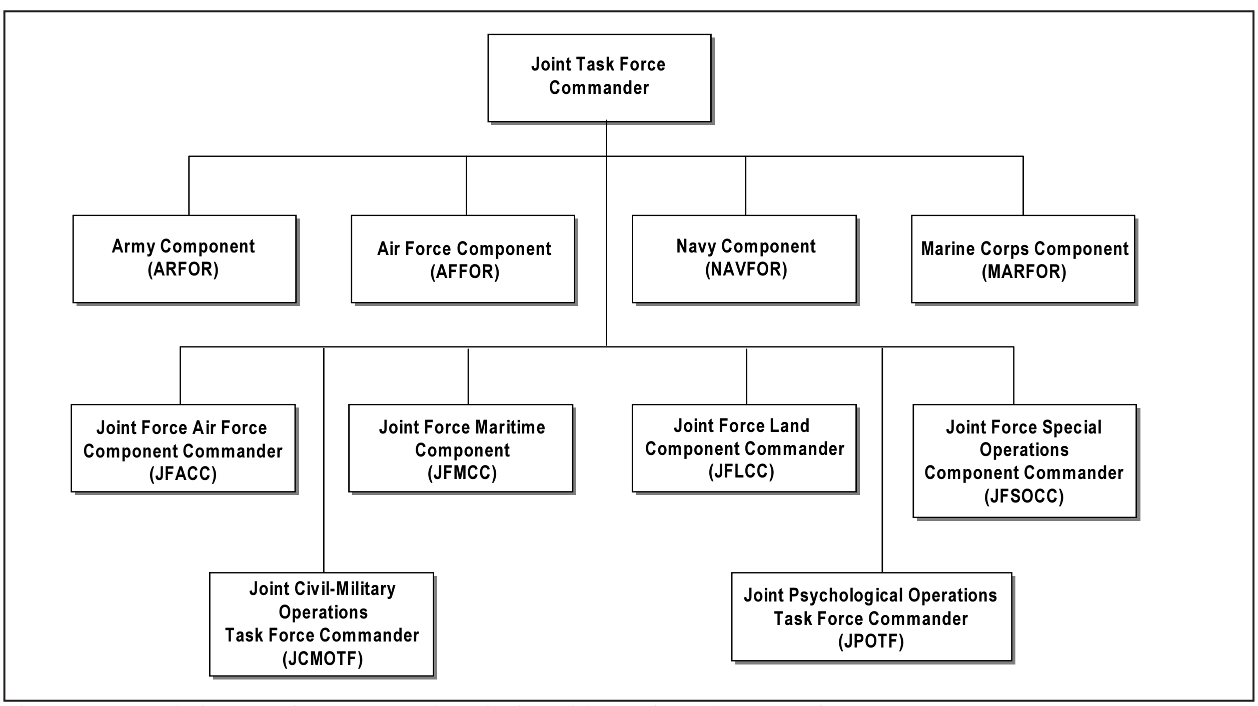


Figure 6-8. High-Level Command Relationships Chart (OV-4) for JCC(X)

A decomposition of each of the high-level commands and a discussion of the responsibilities of each of the sub-elements were also developed in the JCC(X) architecture. Figure 6-9 reflects the JTF decomposition and functional boards and groups within the JTF. Each of the major organizations was then further decomposed to the next level of detail. Figure 6-10 shows this level of decomposition for the JTF J3 organization.

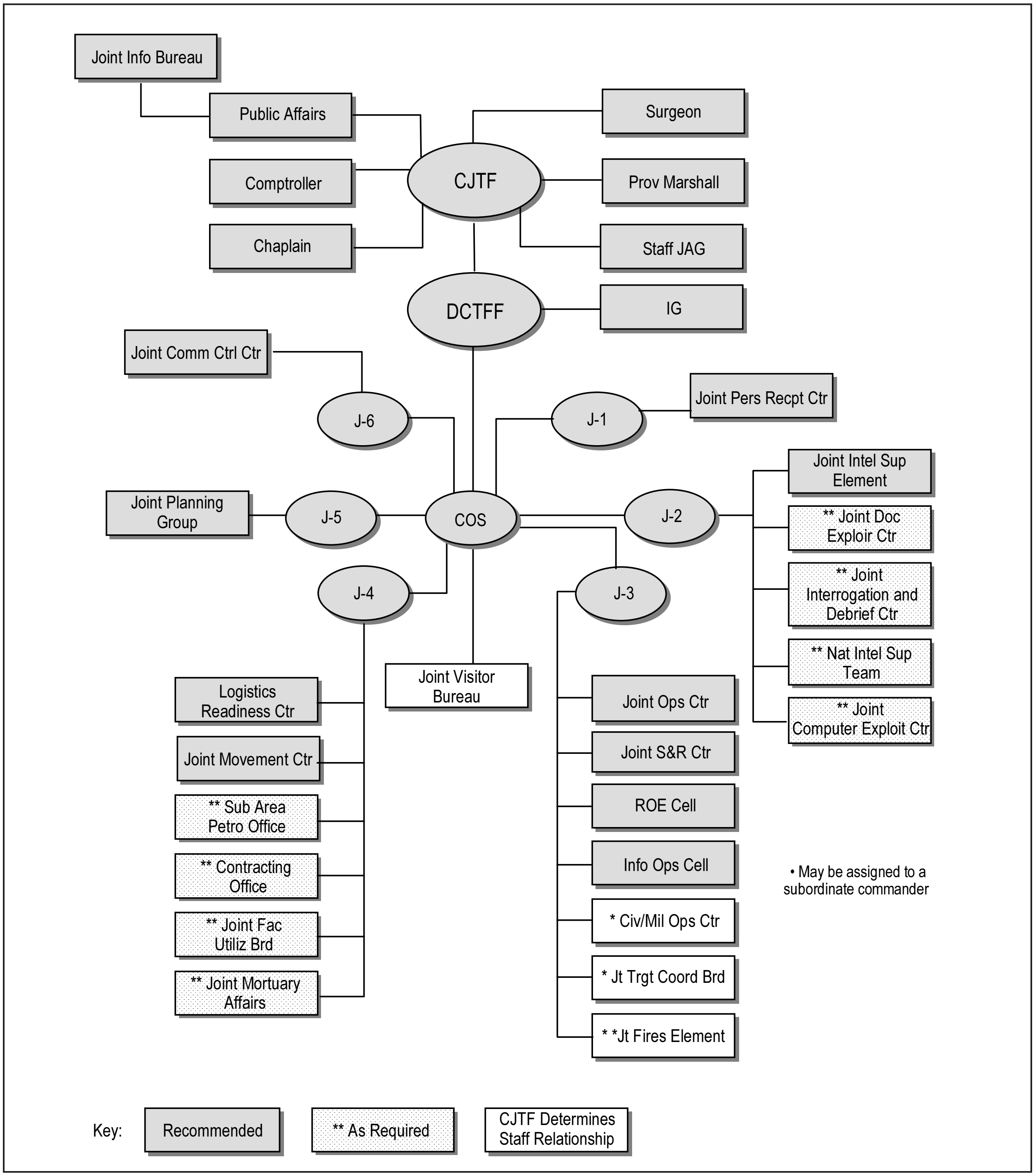


Figure 6-9. Notional JTF Headquarters Command Relationships Chart (OV-4)

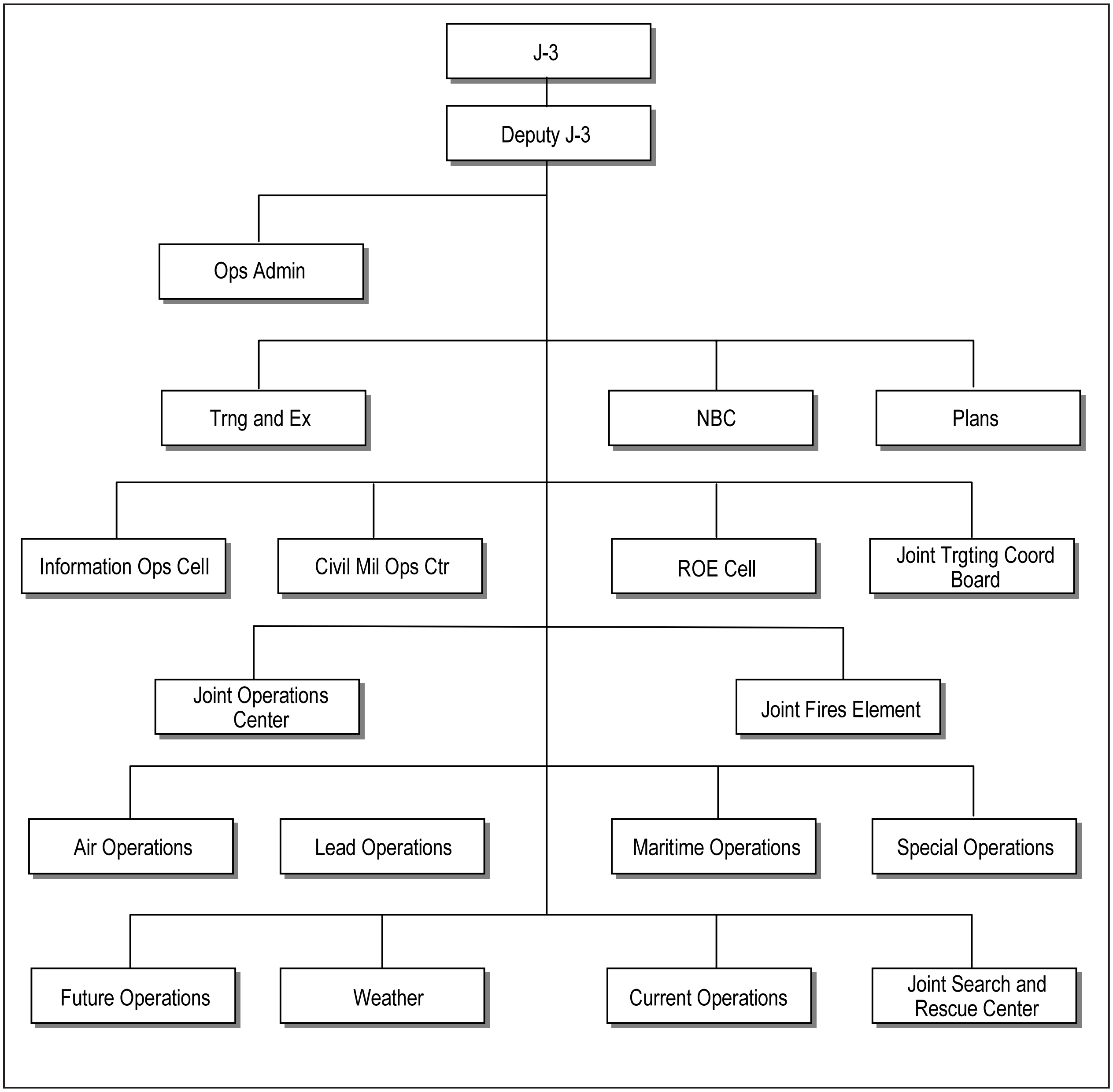


Figure 6-10. Notional JTF J-3 Command Relationships Chart (OV-4)

Operational Event/Trace Description (OV-6c)

Most of the Operational View products, including the High-Level Operational Concept Graphic (OV-1), the Operational Node Connectivity Description (OV-2), the Operational Information Exchange Matrix (OV-3), the Command Relationships Chart (OV-4), and the Activity Model (OV-5), provide *static* views of the architecture. While these products are helpful in building the Operational View, it is important to note that many of the critical characteristics of an architecture can only be discovered when an architecture's *dynamic* behavior is defined and described. This dynamic behavior includes the timing and sequencing of events that frame the operational behavior of a process. The Operational Event/Trace Description (OV-6c) describes critical timing and sequencing behavior in the Operational View, and it is the first of the

Operational View products that provides a dynamic view into the architecture. Both static and dynamic views provide benefits in developing the architecture. Figure 6-11 highlights some of these benefits.

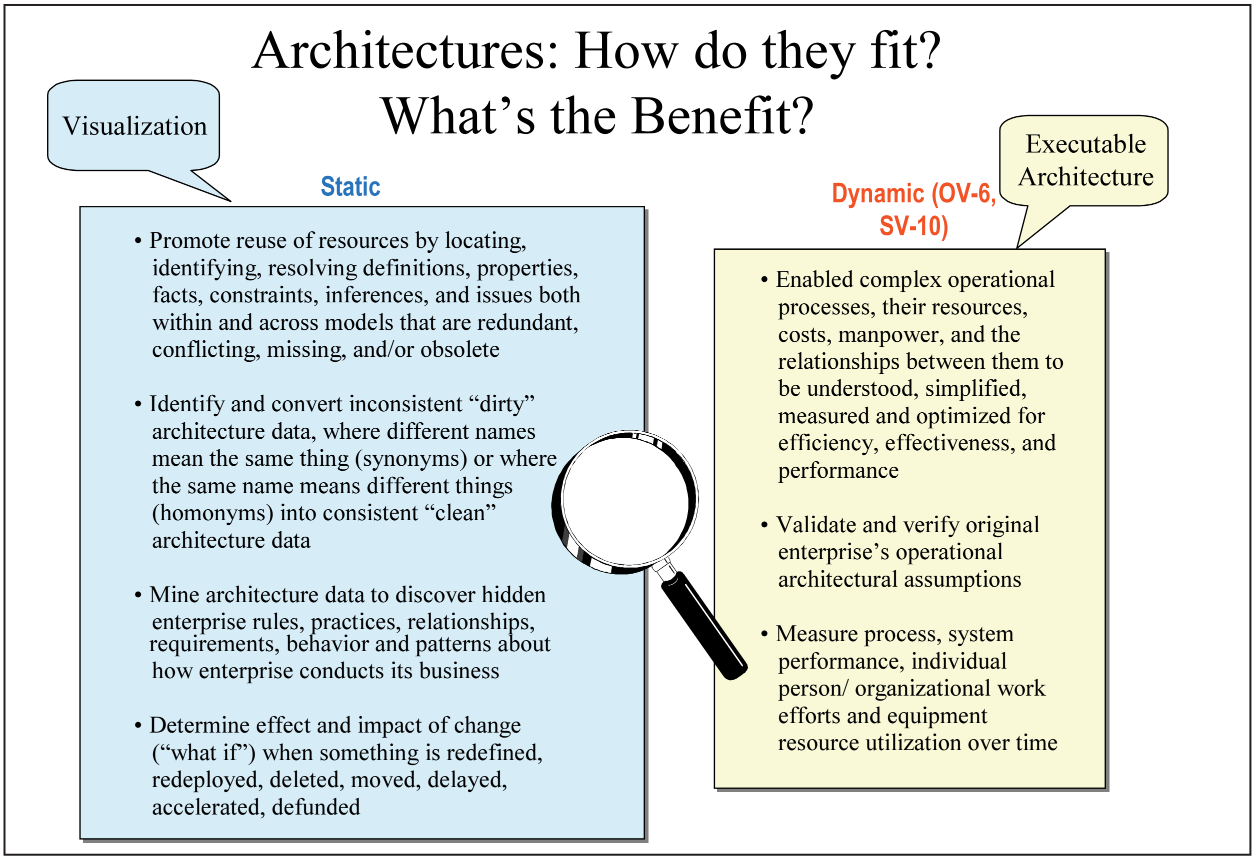


Figure 6-11. Benefits of Static and Dynamic Views in the Architecture

Dynamic views support the development of executable architectures that are designed to enable architects to perform the following tasks:

- Identify Key Performance Parameters (KPPs) associated with Mission Essential Tasks and Threads
- Facilitate analysis in split-base organization and staffing, organizational consolidation, and split-base communication requirements
- Develop and analyze of system design requirements

In developing and implementing an executable model for the JCC(X), system architects employed the following process:

- Identification of what to model using approved Joint Mission Essential Task Lists (JMETLs) as the source and correlating source data to Joint Chiefs of Staff (JCS) Mission Areas
- Development of the model through utilization and reuse of existing information and refinement of information by Subject Matter Experts
- Execution of the model and performance of mission-specific needs assessment involving trade-off analysis balancing doctrine and Tactics, Techniques, and Procedures (TTPs), manning and organization, and system requirements

Figure 6-12 provides a graphical depiction of this process.

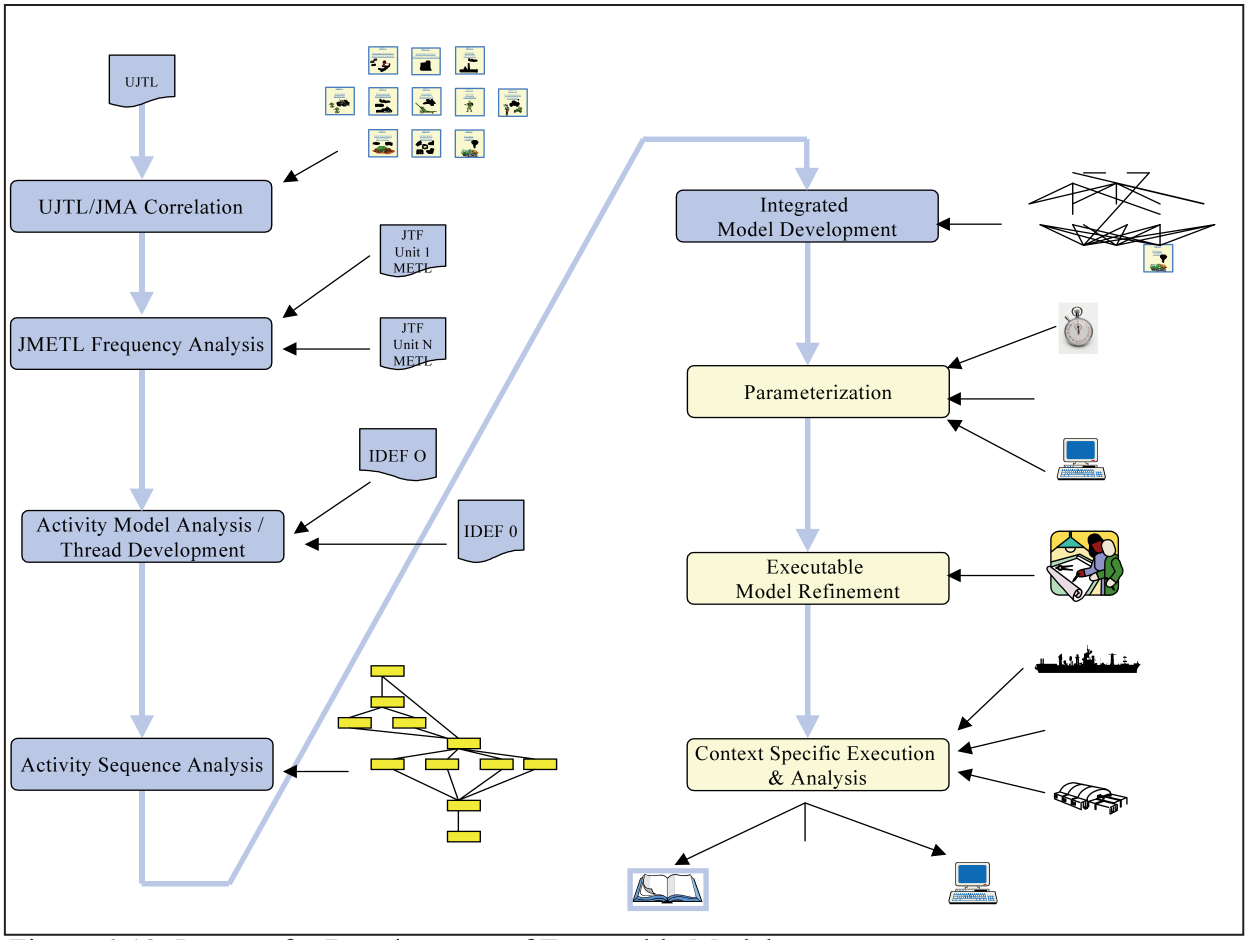


Figure 6-12. Process for Development of Executable Model

To develop the model, it was necessary to recognize a natural order among the 11 Joint Mission Areas (JMAs). Figure 6-13 shows this natural ordering.

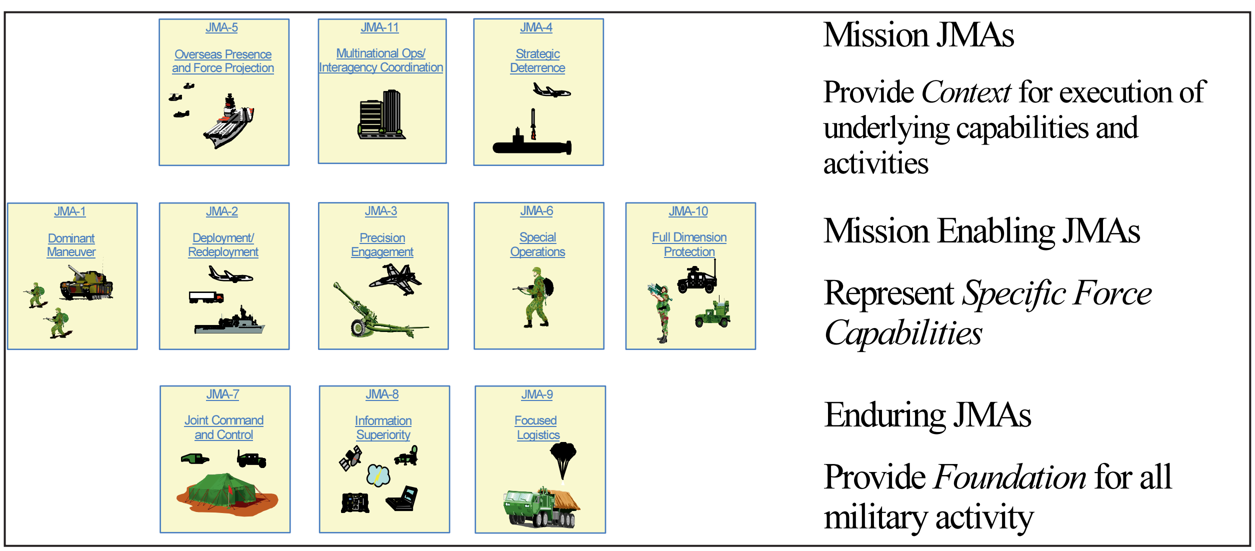


Figure 6-13. Three-Tier Natural Ordering of 11 JMAs

Figure 6-14 provides a high-level view of the completed model that illustrates the complexity of operations at the Joint Task Force Headquarters. Each of the yellow boxes in the graphic correlates with the 11 JMAs shown in Figure 6-13, and each has its own set of sequenced activities, information exchanges, organizations, and system resources used to support these activities.

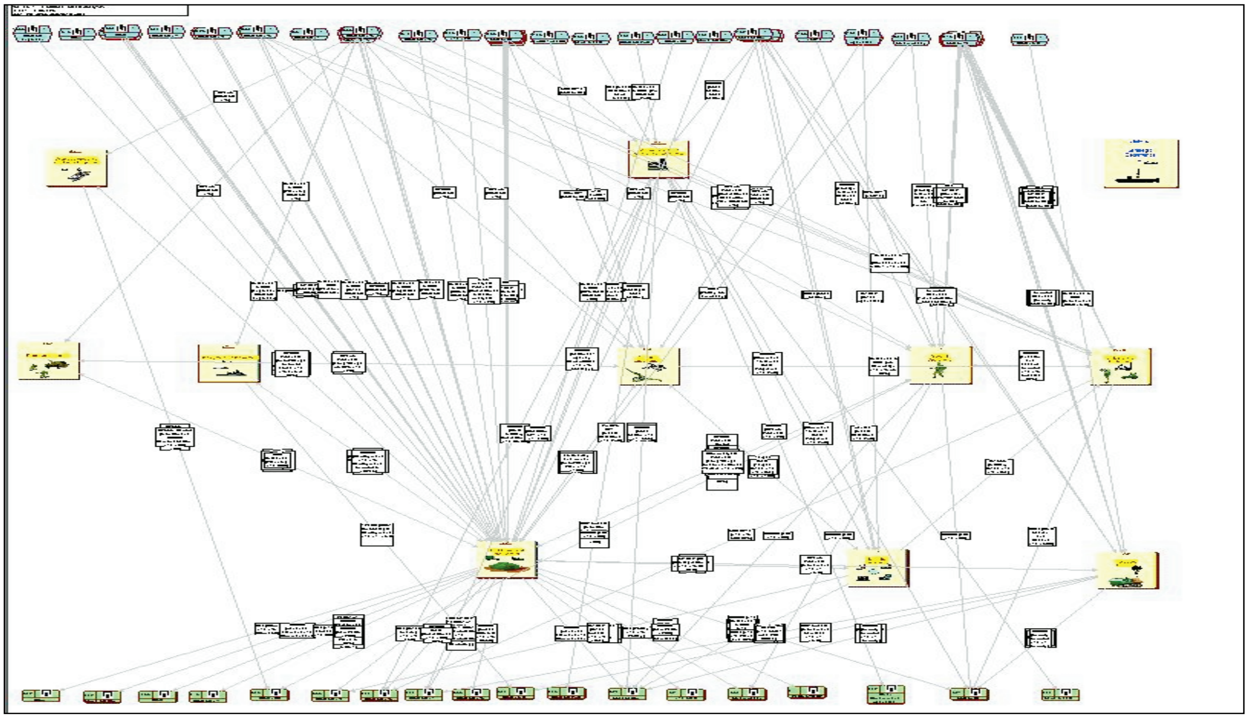


Figure 6-14. High-Level View of Completed JCC(X) Executable Model

A clearer view of the thread analysis and the Measures of Effectiveness (MOEs) and Measures of Performance (MOPs) associated with each thread is provided in Figure 6-15. By providing the architect with the ability to fully execute each of these threads, the executable model delivers significant power in supporting analysis of business processes, organizational structure, and system performance and helps determine the best methods for achieving improvements.

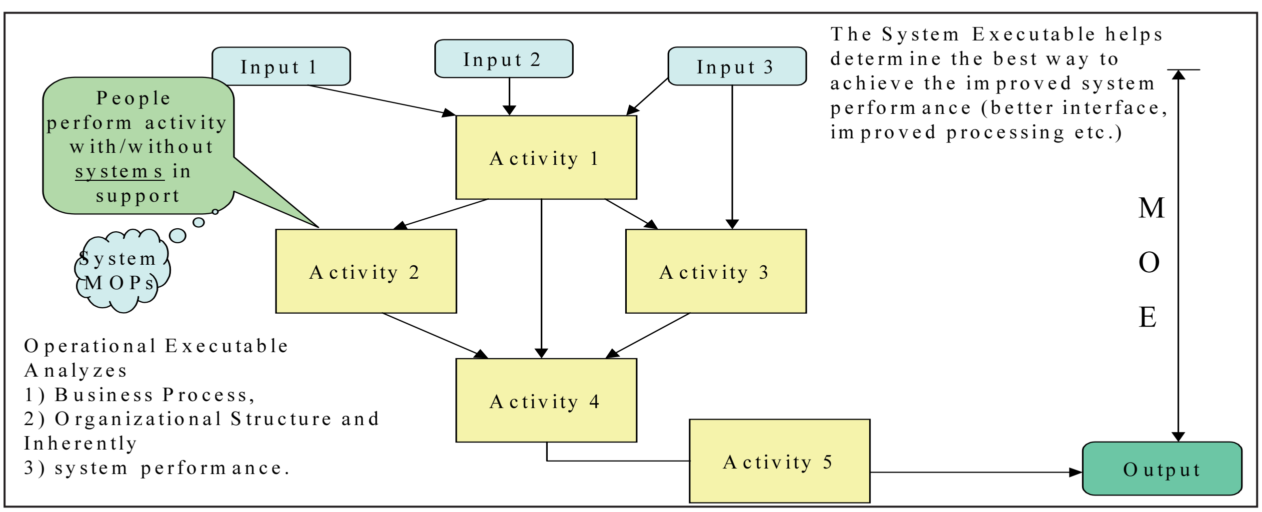


Figure 6-15. Critical Thread Analysis and Associated MOEs and MOPs

The Joint Air Tasking Order Process/Time Critical Evaluation was one thread in the JCC(X) process for which an Operational Event/Trace Description (OV-6c) and executable model were developed. Figures 6-16 though 6-22 show how each activity in this thread was identified and then decomposed into further levels of detail in order to support the development of the executable model. The graphics begin with the Operational Event/Trace Description for the high-level air campaign process and continue with a decomposition of the high-level "Generate ATO" process. The subsequent figures show the decomposition of activities including Perform Targeting, Weaponeering, ATO Mission Area Analysis Planning (MAAP) Generation, ATO Air Control Order Generation, and Final ATO Generation.

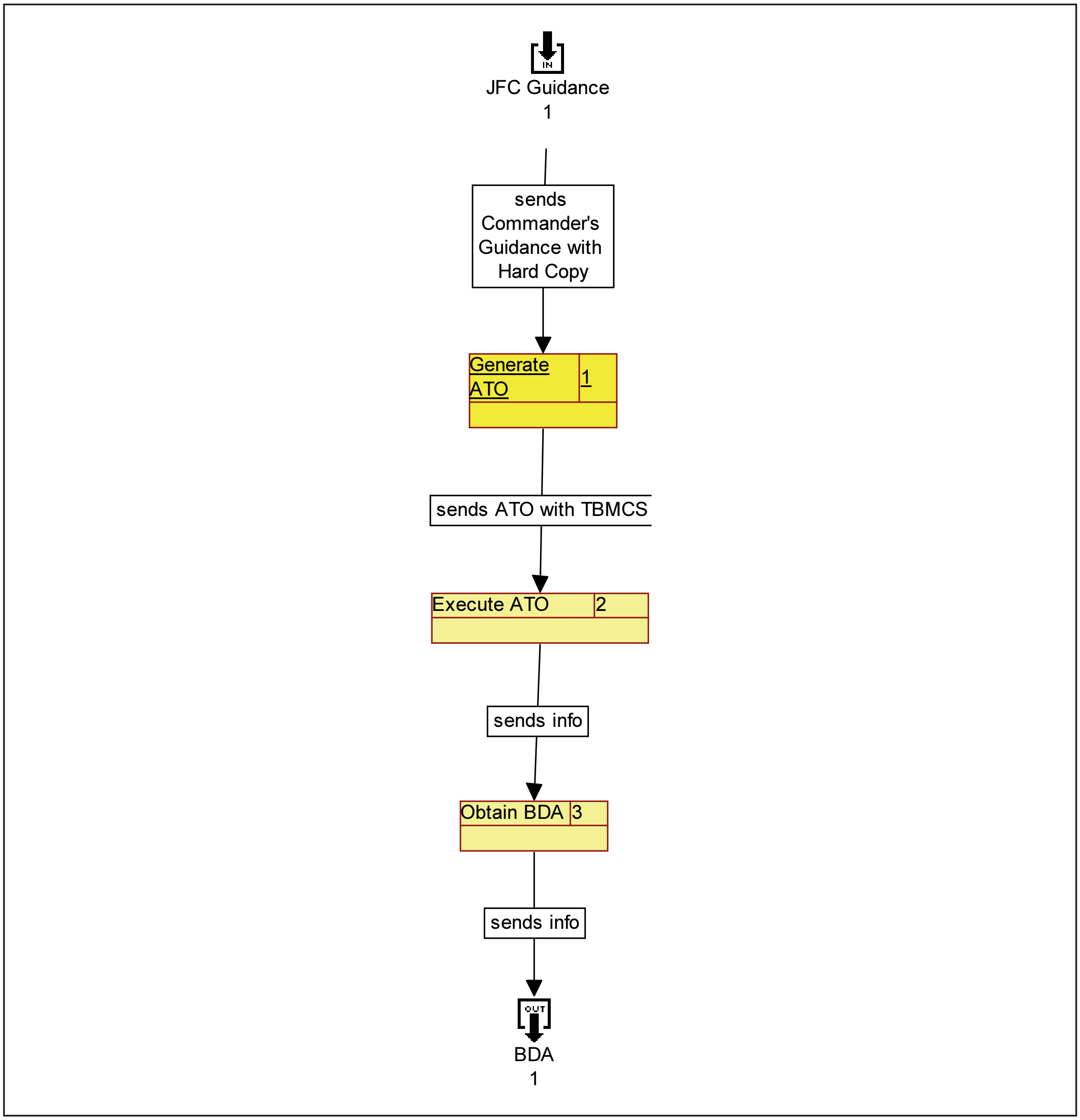


Figure 6-16. Operational Event/Trace Description (OV-6c) for High-Level Air Campaign Process

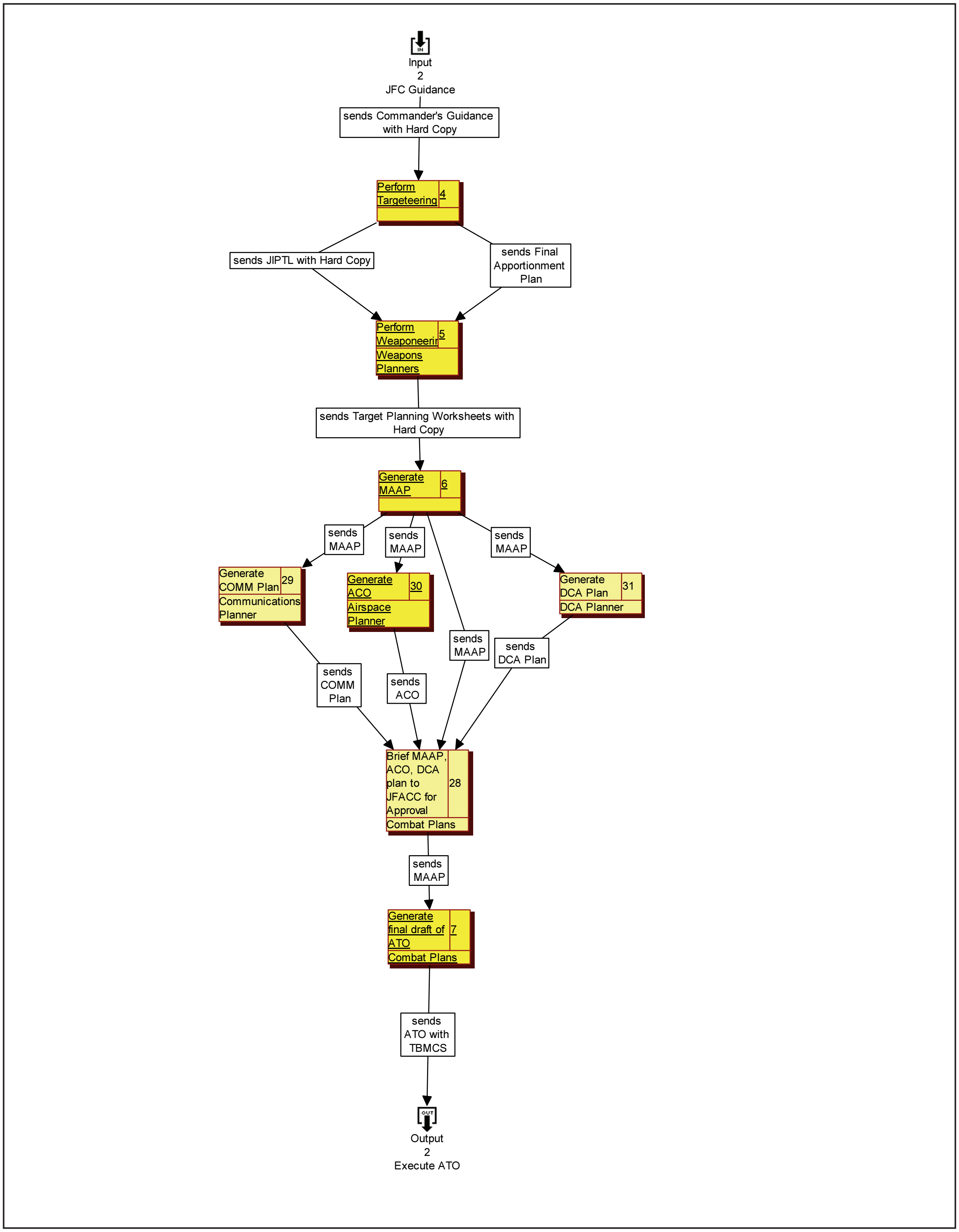


Figure 6-17. Operational Event/Trace Description (OV-6c) for High-Level Generate ATO Process

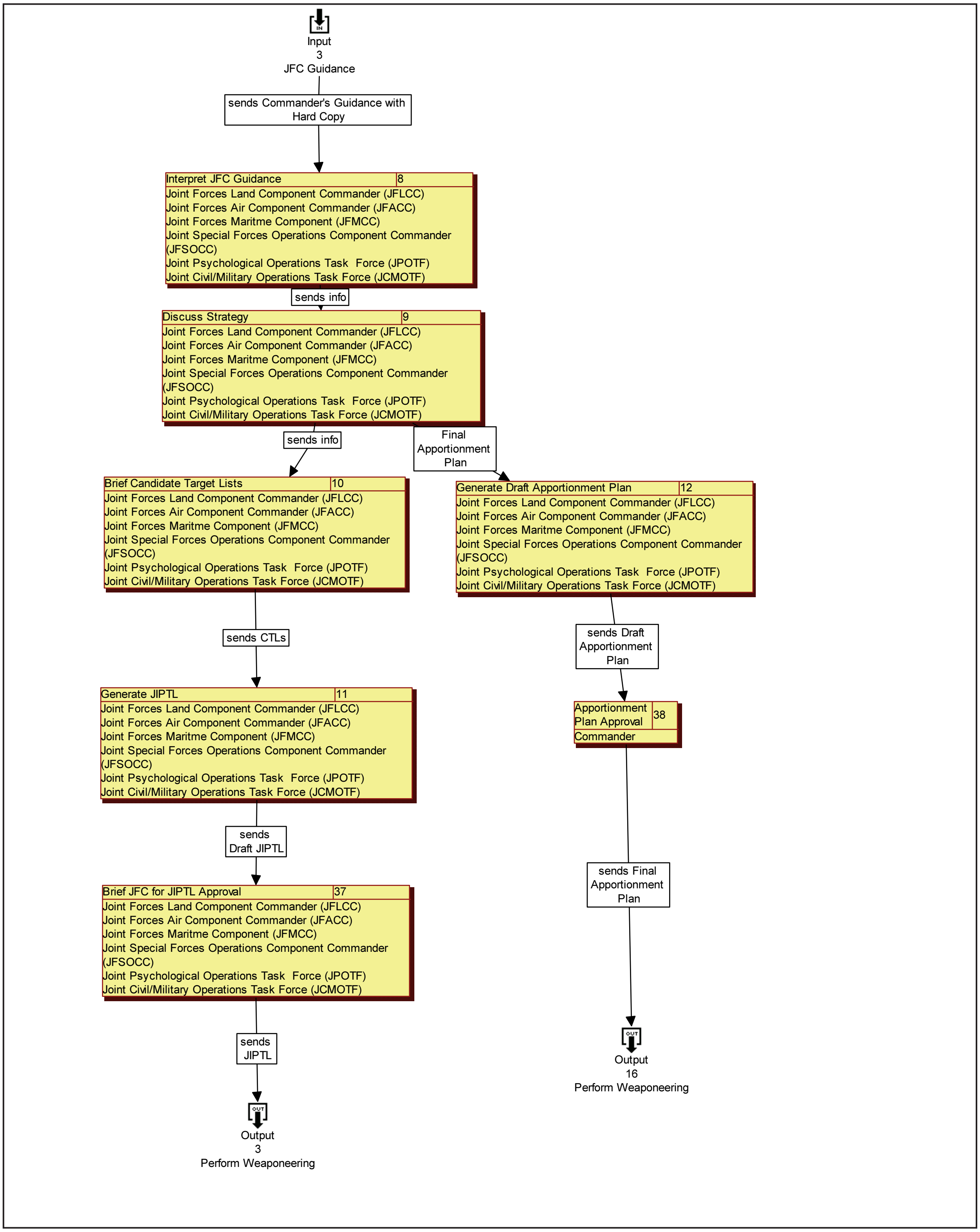


Figure 6-18. Operational Event/Trace Description (OV-6c) for ATO Development Phase

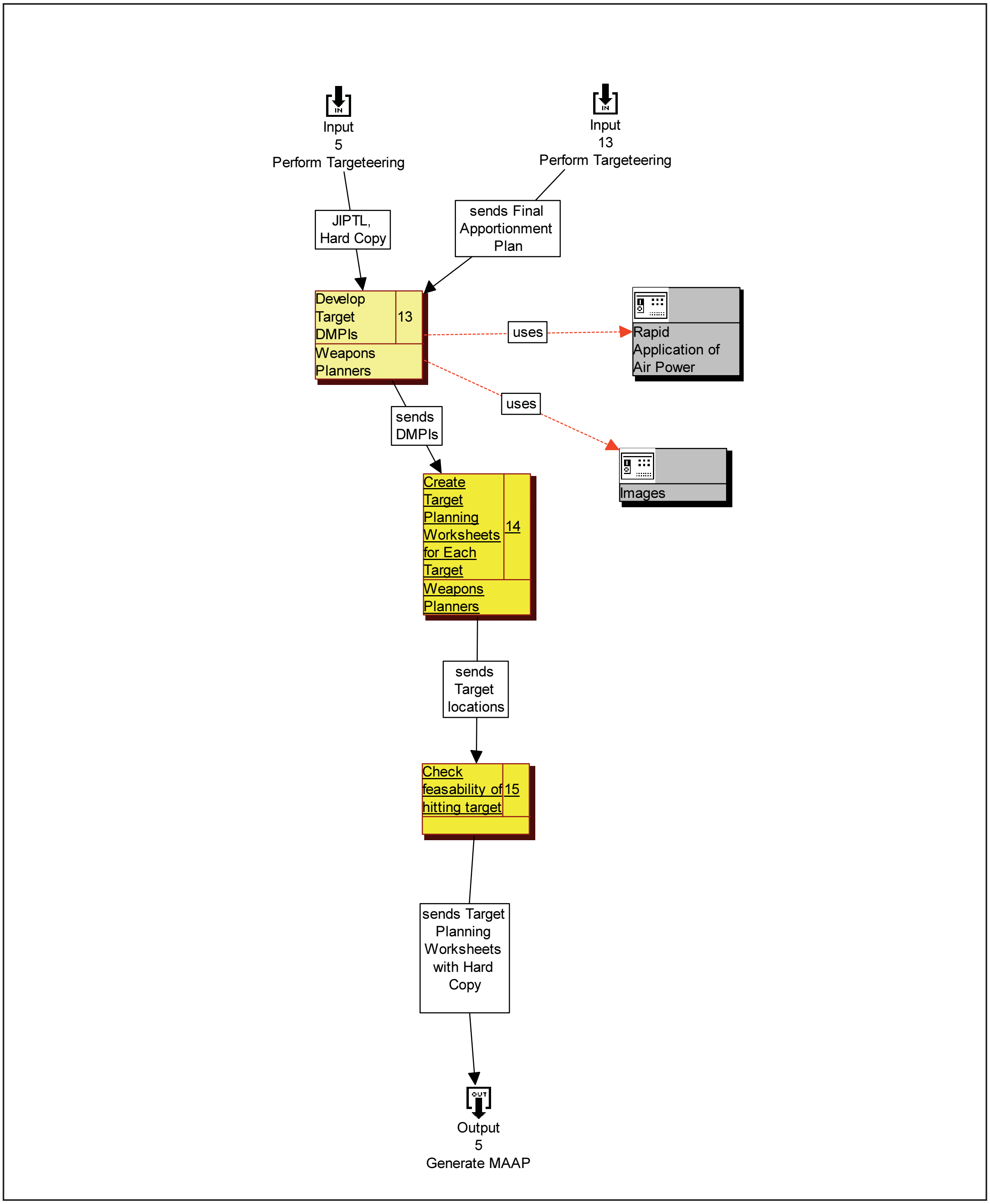
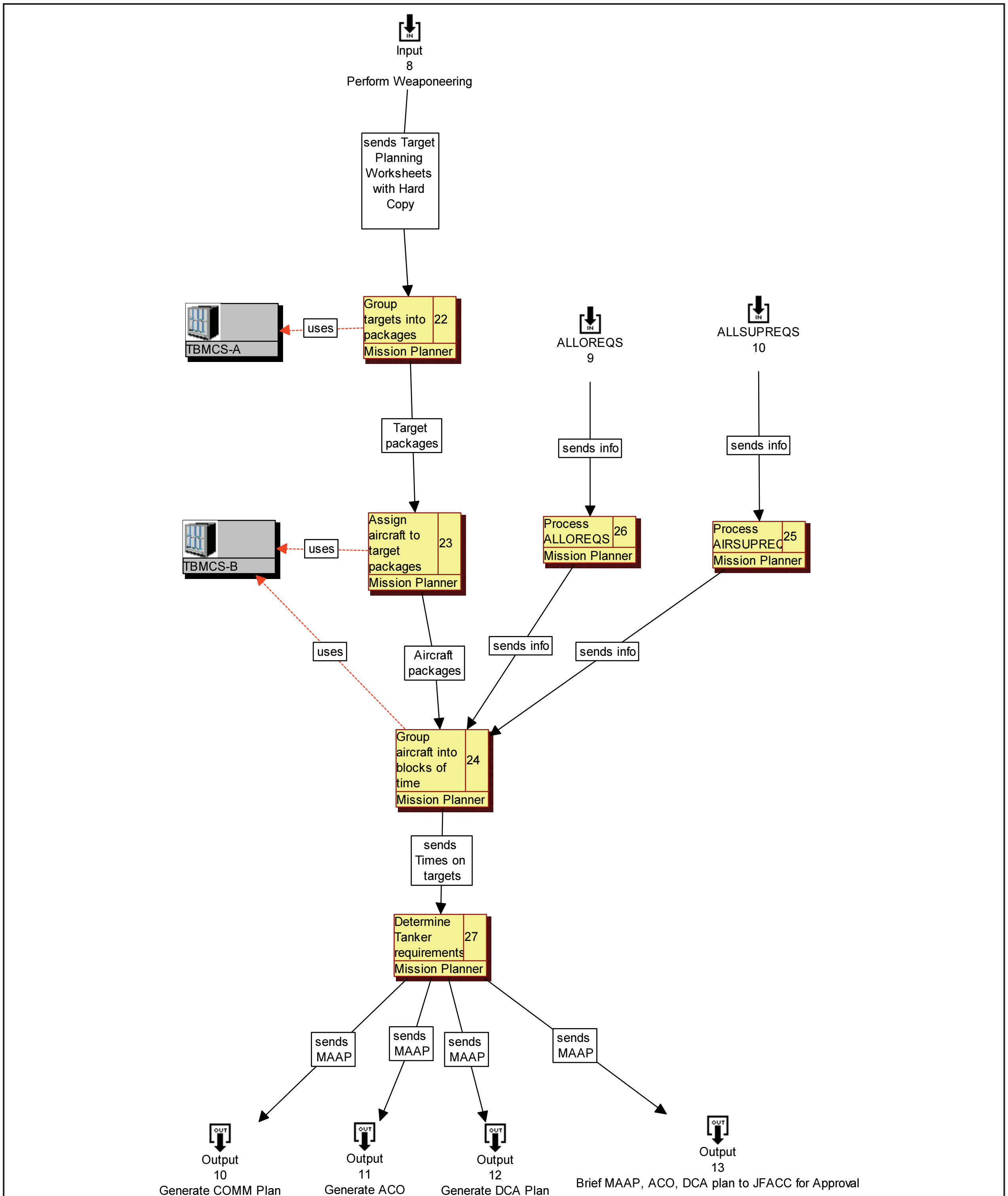


Figure 6-19. Operational Event/Trace Description (OV-6c) for ATO Weaponeering Phase



Note: System Resources are shown in gray. The yellow blocks show not only the activity being performed but also the organization performing that activity. The white boxes depict the information being transferred.

Figure 6-20. Operational Event/Trace Description (OV-6c) for ATO MAAP Generation

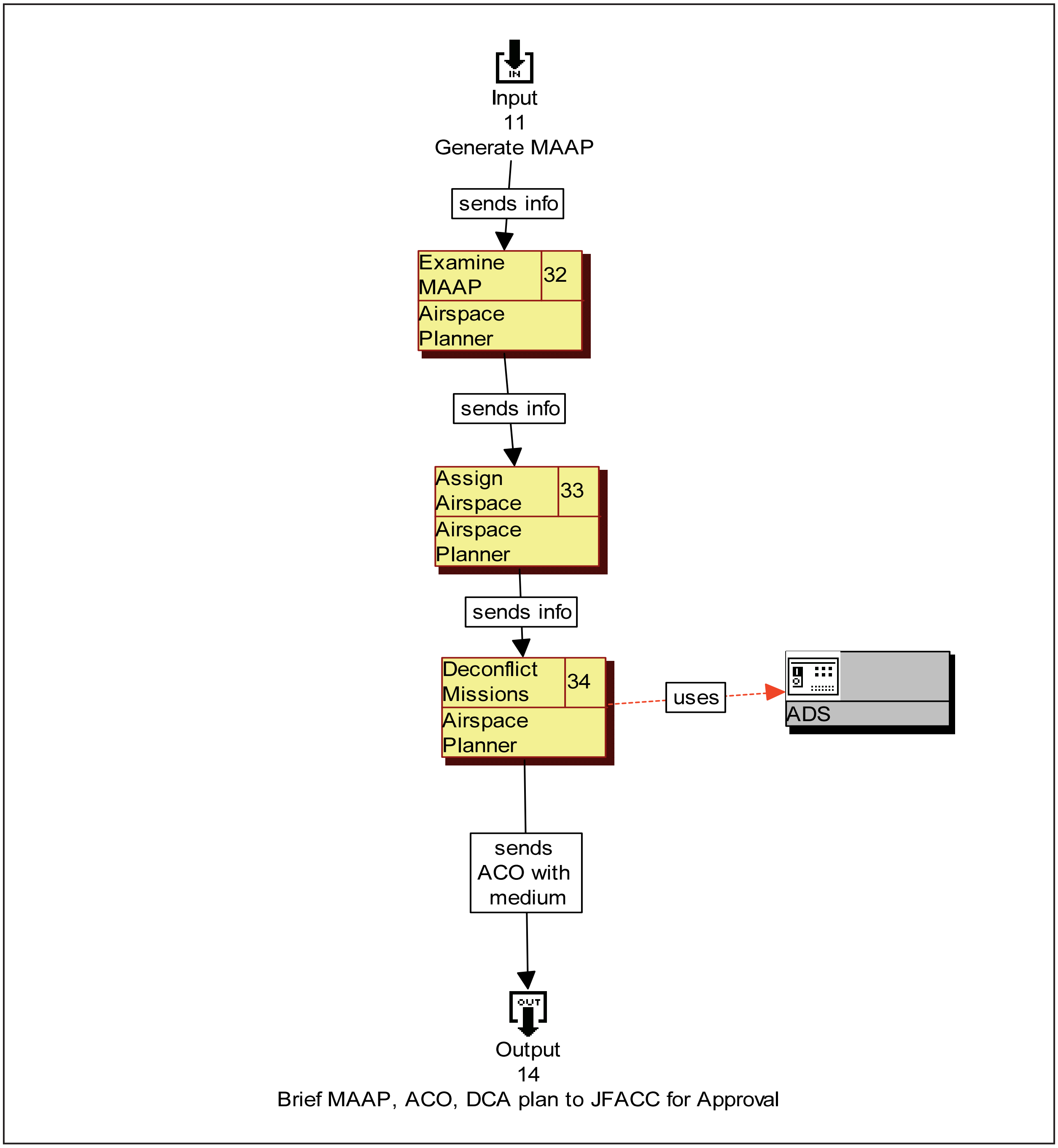


Figure 6-21. Operational Event/Trace Description (OV-6c) for ATO Air Control Order Generation

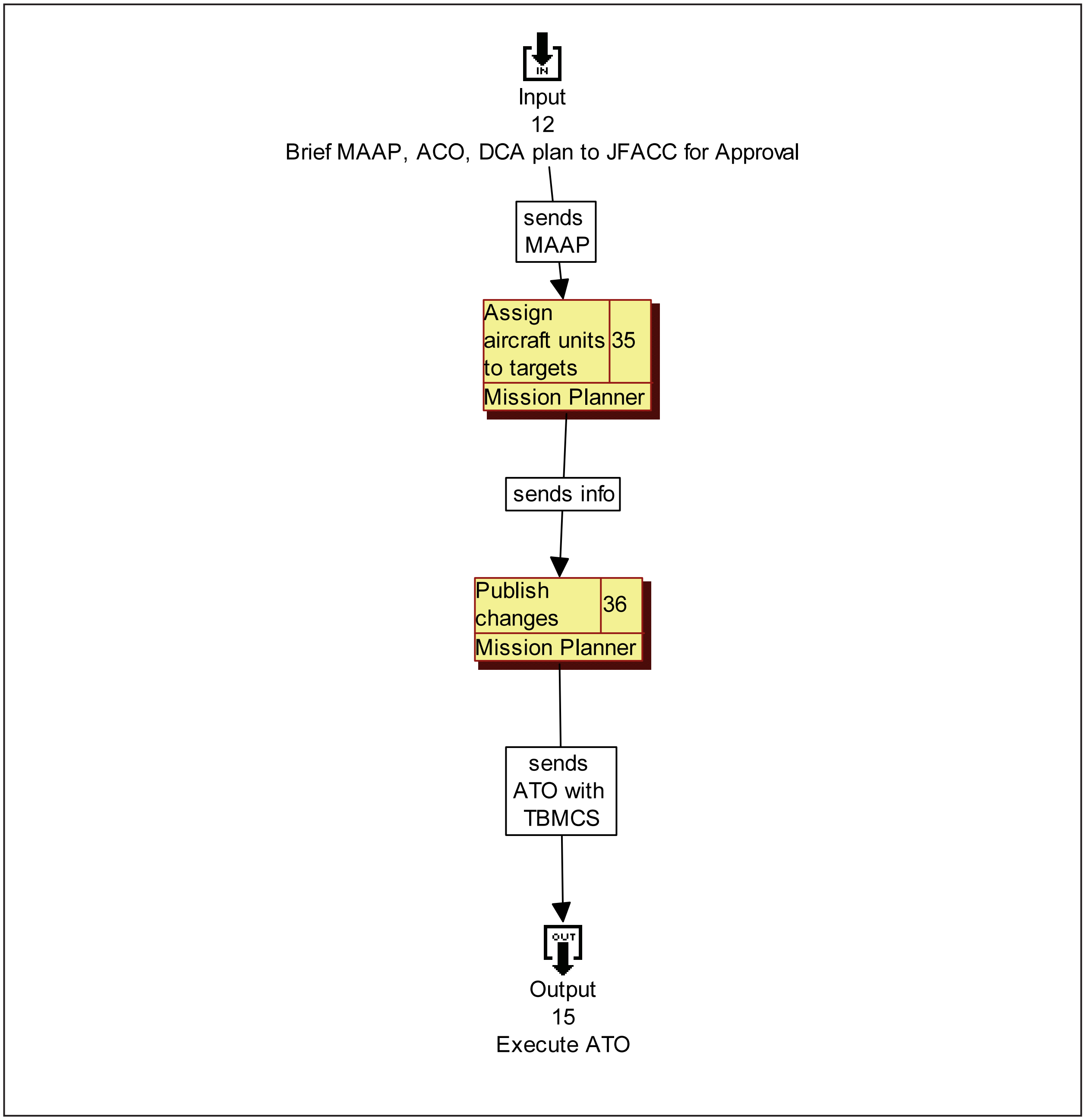


Figure 6-22. Operational Event/Trace Description (OV-6c) for Final ATO Generation

Operational Views and Executable Architectures

As shown in the detailed graphics provided in this section, the Operational Views, and particularly the OV-6c products, are critical to the development of executable architectures. These executable models are incredibly valuable tools in enabling visualization of complex processes and in supporting development of MOEs and MOPs that can be used in a variety of ways to support trade off studies and analysis. Specifically, executable architectures can be used to support doctrine and TTP evolution; process analysis and reengineering; identification of IT support redundancies, shortfalls, and integration opportunities; staffing analysis; split-base analysis; Network Centric Operations; theater bandwidth/resource allocations; training, exercise, and experimentation development; and POM development.

JCC(X) Systems View

The Systems View describes how the process and information capabilities identified in the Operational View are to be implemented. The JCC(X) Systems View provided functional node descriptions to support the development of the JCC(X) C4ISP and the JCC(X) Joint Mission Package Performance Specifications. Additionally, the JCC(X) Systems View identified and depicted the DoD system-type requirements to support security, interoperability, and reach-back needs. Since the actual systems that would be in use at the time (the year 2011) when JCC(X) was expected to be fielded could not be defined, the term "System Type" was used in place of the actual names of systems. System Types were used as generic descriptors of system functionality that enabled architects to avoid presupposing that a specific system known today would be used on the JCC(X). The architects did assume that the Global Information Grid (GIG) or a similar system would provide the infrastructure necessary to support the connectivity required by the JCC(X). Accordingly, the architects developed the Systems View within the GIG context. A System Interface Description (SV-1) for JCC(X) is provided in Figure 6-23.

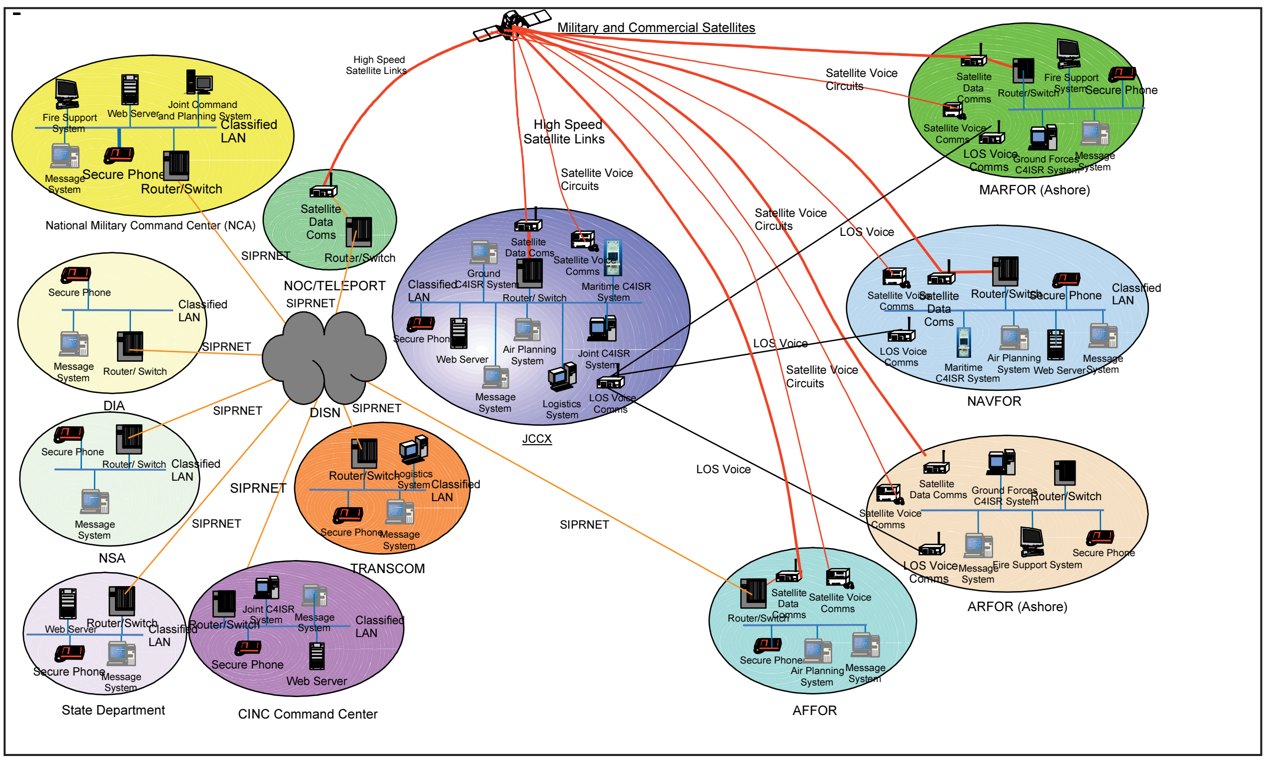


Figure 6-23. JCC(X) System Interface Description (SV-1)

JCC(X) Technical View

The Technical View identifies the standards or "building code" to be used in development. A major element of the Technical View is the Technical Architecture Profile (TV-1), which references the technical standards that apply to the architecture and how they need to be or have been implemented. The C4ISR Architecture Framework, Version 2.0, requires the Technical View to contain a matrix of specific services and standards, and Interim Regulation DoD 5000.2-R (Section 2.7.2.1) states that the JTA will serve as the foundation for the development of the mission architecture (i.e., the Technical View). The JCC(X) architects understood the requirement to develop the JCC(X) Technical View and identified the standards required to support the interoperability interfaces for JCC(X), but they also recognized that the JTA services and standards were based on today's technology and might not apply to the JCC(X) since it was not expected to be delivered until the 2011 time frame. Accordingly, the JCC(X) architects chose to use the GIG and its associated interfaces, which are known as KIPs, in combination with the JTA to develop the Technical Views for JCC(X). The JTA services and standards and the GIG KIPs were identified at the interfaces between all of the JCC(X) node pairs depicted in the System Interface Description (SV-1) developed in the Systems View. Table 6-1 provides a representative Technical Architecture Profile (TV-1) highlighting the use of both the GIG and JTA in developing the Technical View.

Table 6-1
JCC(X) Representative Technical Architecture Profile (TV-1) for External Links

From JCC(X) to/from	**JTA Service View**	**GIG KIP View as JCC(X) Technical View**
	JTA Services	***GIG KIPS***
AFFOR	1, 2, 3(all), 4, 6, 8, 9, 10(A,B), 12(D,E), 13, 14	1, 2, 8, 10, 11
ARFOR	1, 2, 3(all), 4, 6, 8, 9, 10(A,B), 12(D,E), 13, 14	1, 2, 8, 10, 11
NAVFOR	1, 2, 3(all), 4, 6, 8, 9, 10(A,B), 12(D,E), 13, 14	1, 2, 8, 10, 11
MARFOR	1, 2, 3(all), 4, 6, 8, 9, 10(A,B), 12(D,E), 13, 14	1, 2, 8, 10, 11
NIMA	1, 2, 3(A,C,D,E), 6, 8, 9, 10(A,B), 12(D,E), 13, 14	2, 4, 8, 10, 11
CINC	1, 2, 3(all), 4, 6, 8, 9, 10(A,B), 12(D,E), 13, 14	2, 4, 8, 10, 11
NSA	1, 2, 3(A), 6, 8, 9, 10(A,B), 12(D,E), 13, 14	2, 4, 8, 10, 11
TRANSCOM	1, 2, 3(A), 6, 8, 9, 10(A,B), 12(D,E), 13, 14	2, 4, 8, 10, 11
DIA	1, 2, 3(A,D,E), 6, 8, 9, 10(A,B), 12(D,E), 13, 14	2, 4, 8, 10, 11
NMCC	1, 2, 3(A), 6, 8, 9, 10(A,B), 12(D,E), 13, 14	2, 4, 8, 10, 11
CGFOR	1, 2, 3(A), 6, 8, 9, 10(A,B), 12(D,E), 13, 14	2, 4, 8, 10, 11
State Dept.	1, 2, 3(A), 6, 8, 9, 10(A,B), 12(D,E), 13, 14	2, 4, 8, 10, 11

Summary

JCC(X) as a program has been cancelled, but the C4I mission package that this architecture describes lives on. A command and control variant that will use the JCC(X) architecture to support the requirements process is currently being explored, and the OSD Force Transformation Office has expanded the JCC(X) executable architecture to support training and experimentation.

CHAPTER 7
A COALITION INTEGRATED AIR PICTURE

Purpose

The first four case studies in this part of the book demonstrated the use of the architecture products to support different purposes, including analysis of the ability of an FoS to deliver specific mission capabilities, assessment of alternative systems in building an acquisition plan, and development of architectures to support design of completely new FoSs. The final case study, a Coalition Integrated Air Picture (CIAP), demonstrates how a capability such as an integrated air picture for coalition partners can be used as an operational node within a mission warfare architecture. It focuses on the use of architecture products, including executable architectures, in describing performance and behavior. The results presented in this chapter were a fundamental in influencing Coalition partner decisions regarding how to proceed with the CIAP.

Background

The concept of a CIAP means different things to different organizations. To some, it may imply a centralized location where data from all participating platforms is displayed to provide situational awareness; to others, it may imply a distributed network where all providers of data also receive all data of fire control quality; to still others, it would imply something completely different. When working across organizational and political boundaries, the probability that each user will have a different understanding of CIAP concepts is great. These differences in conceptual understanding lead to differences in methods of implementation. In other words, it is simple for organizations to agree that sharing air track data would be beneficial, but it requires significantly more thought on the part of these organizations to determine and agree upon how this sharing should be implemented.

The Coalition Partners (Australia, Canada, New Zealand, the United Kingdom, and the United States) all provide representation to The Technical Cooperation Program (TTCP) for English speaking countries. The TTCP's Technical Panel Four (TP-4), in recognition of the multi-faceted task at hand, decided to document a CIAP operational concept and its implementation through the use of architectures. The CIAP architecture will provide traceability from the CIAP requirements to the CIAP operational concept and then to physical implementation. The Coalition Partners have chosen the U.S. DoD C4ISR Architecture Framework as the architecture standard for performing this documentation task. The use of architectures and specifically the C4ISR Architecture Framework will give structure to the definition and physical implementation of the CIAP concept.

For a geographically distributed effort such as a CIAP, it is possible to achieve marked acceleration in the development process by working within an established process via a 24-hour accessible collaborative engineering environment[24] to physically instantiate the CIAP concept. Semi-annual meetings among the TP-4 national partners are augmenting this collaborative environment.

CIAP Operational Concept

To describe the CIAP Operational Concept, an Operational View and an Activity Model are being developed. Details on the architecture products being developed to support the CIAP Operational Concept are presented in the following paragraphs.

CIAP High-Level Operational Concept (OV-1)

The architecting process begins with requirements. The Coalition currently has a draft set of Capstone Requirements that are undergoing review.[25] From these underlying requirements, an operational concept can be depicted. The operational concept is graphical in nature but should be supplemented by text describing the operational concept in high-level language. The CIAP Operational Concept is depicted in Figure 7-1.

Figure 7-1. CIAP High-Level Operational Concept (OV-1)

Activity Model

From the operational concept, the activities required to enable the concept can be derived. These activities are presented in Figure 7-2 within the context of Theater and Air Missile Defense operations. The activities are combinations of operator actions, supporting system functions, and automated system functions. For example, an operator action is to "Prepare Courses of Action" (see A3.1 from Figure 7-2). A system may support the operator by presenting alternative courses of action. If alternatively, the course of action was chosen by the system and acted upon without operator intervention, then that activity would be fully automated. From the Activity Model, the logical relationships between activities can be derived. Figure 7-3 shows the logical relations within the Theater Air Defense Activity Model.

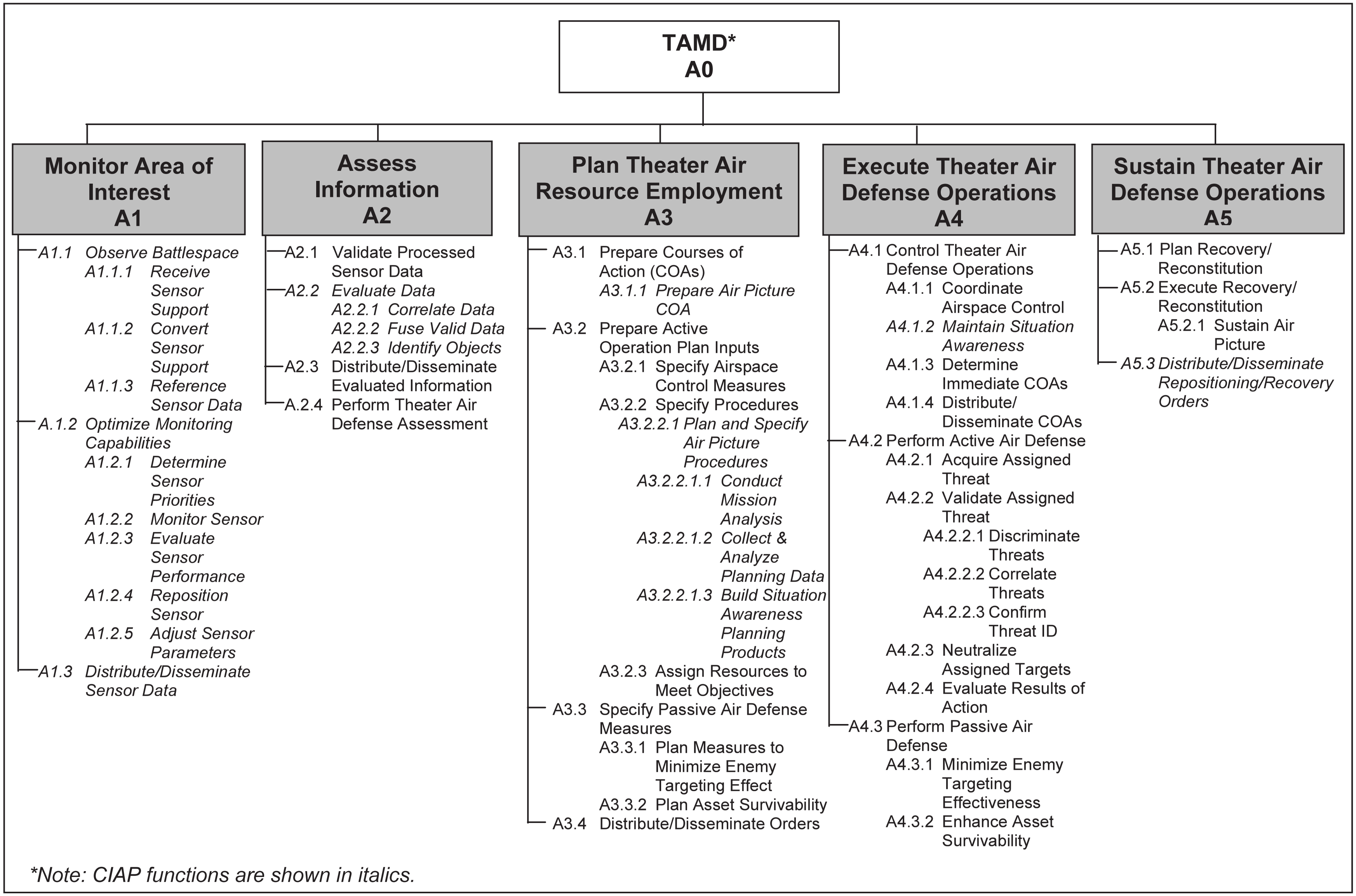


Figure 7-2. U.S. Navy TAMD Operational Activity Model (OV-5) with CIAP Decomposition

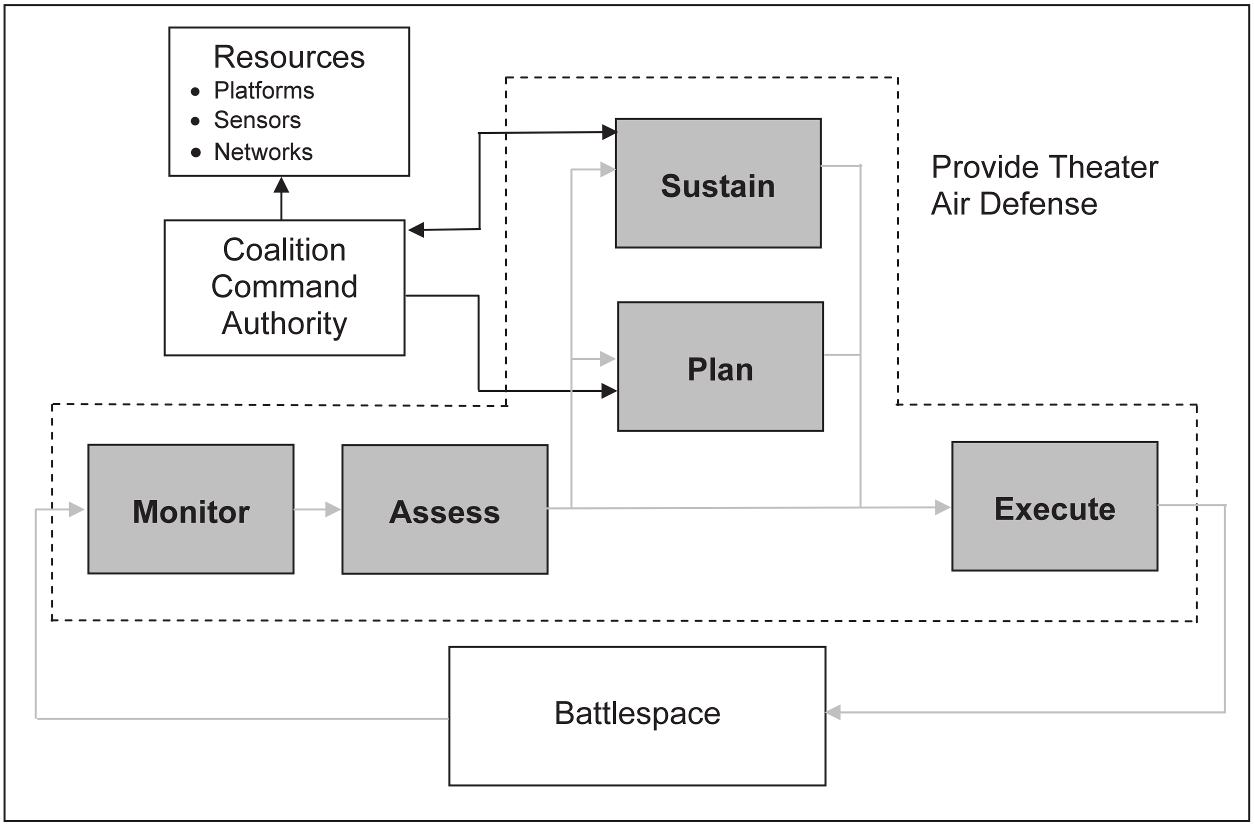


Figure 7-3. Logical Relations of the Theater Air Defense Activity Model

CIAP System Functional Mapping

Proposed CIAP system functions are shown in italics in Table 7-1, Theater Air Defense System Function List (SV-4), and are shown in purple in Figure 7-4, Theater Air Defense System Functional View with CIAP Decomposition (SV-4). Their supporting relationships to the CIAP activities are shown in Table 7-2, CIAP Function Traceability to CIAP Operational Activities (SV-5).

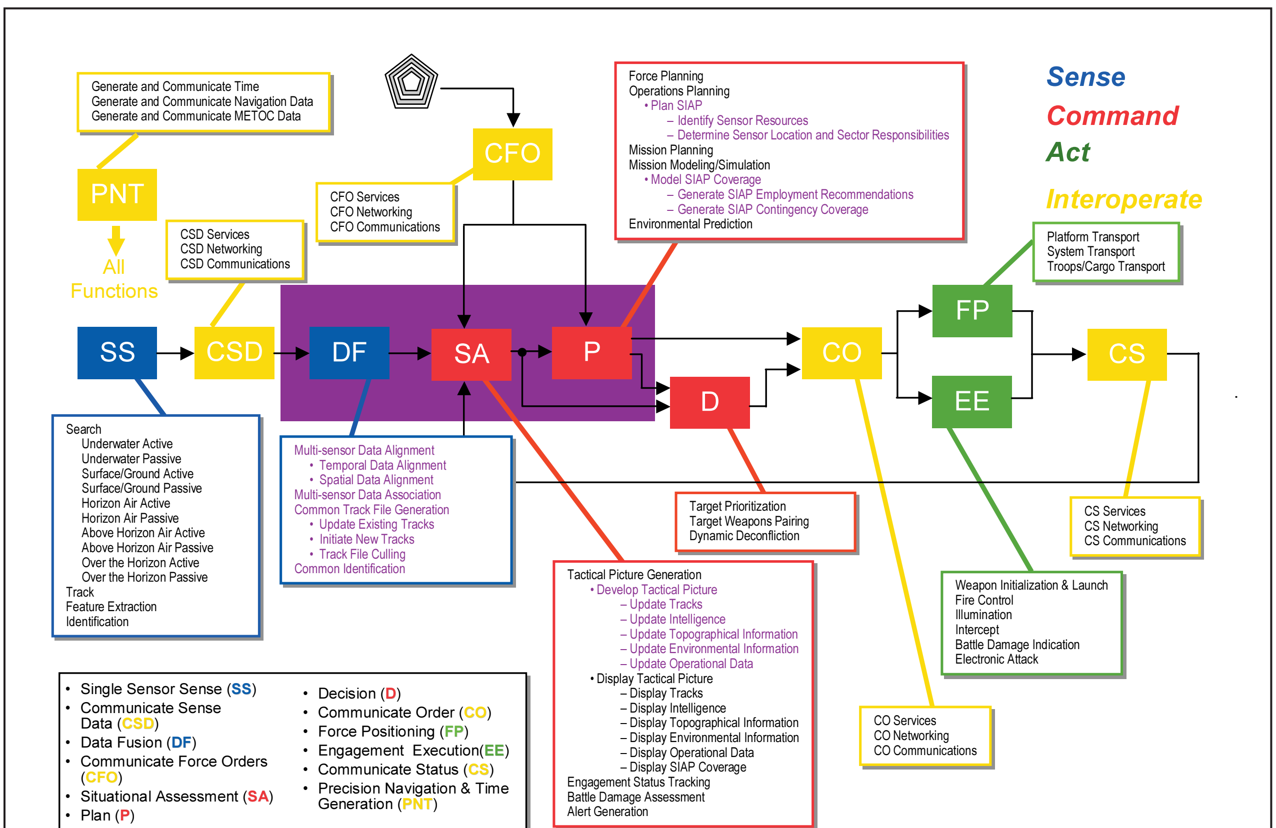
Table 7-1*
Theater Air Defense System Function List (SV-4)

First-Level Functions	Second-Level Functions	Third-Level Functions	Fourth-/Fifth-Level Functions
Sense	Single Sensor Sense	Search	Underwater active
			Underwater passive
			Surf/ground active
			Surf/ground passive
			Horizon air active
			Horizon air passive
			Above horizon air passive
			Above horizon air active
			Over the horizon passive
			Over the horizon active
		Track	-
		Feature Extraction	-
		Identification	-

Sense	Data Fusion	*Multi-sensor data alignment*	*Temporal data alignment*
			Spatial data alignment
		Multi-sensor data association	-
		Common track file generation	*Update existing tracks*
			Initiate new tracks
			Track file cutting
		Common identification	-
Command	Situational Assessment	Tactical picture generation	*Develop tactical picture*
			- Update tracks
			- Update intel
			- Update topo. data
			- Update env. data
			- Update ops. data
			Display tactical picture
			- Display tracks
			- Display intel
			- Display topo. data
			- Display env. data
			- Display ops. data
			- Display CIAP coverage
		Battle damage assessment	-
		Engagement status tracking	-
		Alert generation	-
	Plan	Force planning	
		Operations planning	*Plan CIAP*
			- ID sensor resources
			- Determine sensor location, sector responsibility
		Mission planning	-
		Mission modeling/simulation	*Model CIAP coverage*
			- Generate CIAP employment recs.
			- Generate CIAP contingency coverage
		Environmental prediction	-
	Decision	Target prioritization	-
		Target weapons planning	-
		Dynamic deconfliction	-
Act	Engagement Execution	Weapon initialization/launch	-
		Fire control	-
		Illumination	-
		Intercept	-
		Battle damage indication	-
		Electronic attack	-

Act	Force Positioning	Platform transport	-
		System transport	-
		Troops/cargo transport	-
Interoperate	Communicate Sense Data	CSD services	-
		CSD networking	-
		CSD communications	-
	Communication Force Orders	CFO services	-
		CFO networking	-
		CFO communications	-
	Communicate Status	CS services	-
		CS networking	-
		CS communications	-
	Communicate Order	CO services	-
		CO networking	-
		CO communications	-
	Precision Navigation & Time Generation	Gen. & comm. time	
		Gen. & comm. nav. data	
		Gen. & comm. METOC data	

**Note: CIAP functions are shown in italics.*



Note: CIAP functions are shown in the purple shaded box and in the purple text.

Figure 7-4. Theater Air Defense System Functional View with CIAP Decomposition (SV-4)

Table 7-2*
CIAP Function Traceability to CIAP Operational Activities (SV-5)

System Functions				TAMD Operational Activities				
				A1 Monitor	**A2 Assess**	**A3 Plan**	**A4 Execute**	**A5 Sustain**
Single Sensor Sense (SS)	Search	Horizon Air Active		A1.1.1			A4.2.1	
		Horizon Air Passive		A1.1.1			A4.2.1	
		Above Horizon Active		A1.1.1			A4.2.1	
		Above Horizon Passive		A1.1.1			A4.2.1	
		OTH Active		A1.1.1			A4.2.1	
		OTH Passive		A1.1.1			A4.2.1	
	Track			A1.1.2, A1.1.3			A4.2.2.1	
	Feature Extraction			A1.1.3	A2.2.3		A4.2.2.2	
	Identification			A1.1.3	A2.2.3		A4.2.2.2	
Multi-Sensor Sense (MS)	*Multi-Sensor Data Alignment*				A2.2.1			
		Temporal Data Alignment			A2.2.1			
		Spatial Data Alignment			A2.2.1			
	Multi-Sensor Data Association				A2.2.1			
	Common Track File Generation				A2.2.2			
		Update Existing Tracks			A2.2.2			
		Initiate New Track			A2.2.2			
		Track File Culling			A2.2.2			
	Common ID				A2.2.3		A4.2.2.2	
Situational Assessment (SA)	*Tactical Picture Generation*							
		Develop Tactical Picture					A4.1.2	A5.2.1
			Update tracks				A4.1.2	
			Update intel				A4.1.2	
			Update topo. info.				A4.1.2	
			Update env. info				A4.1.2	
			Update ops. data				A4.1.2	
	Engagement Status Tracking						A4.1.2	
	Battle Damage Assessment						A4.2.4	
	Alert Generation				A2.4		A4.1	

Plan (P)	Force Planning					A3.1		
	Operations Planning					A3.2, A3.3		A5.1
		Plan CIAP				A3.2.2.1		
			Identify sensor resources			A3.2.2.1		
			Deter-mine sensor locations & sector responsi-bilities	A1.2		A3.2.2.1		
	Mission Planning			A1.2.2				
	Mission Modeling/Simulation					A3.2, A3.3		A5.1
		Model CIAP Coverage				A3.2.2.1		
			Generate CIAP emp. recs.			A3.1.1		
			Generate CIAP contin-gency coverage			A3.1.1		
	Environmental Prediction					A3.2		
Decision (D)	Target Prioritization						A4.1.3	
	Target-Weapons Pairing						A4.1.3	
	Dynamic Deconfliction						A4.1.1	
Force Positioning (FP)	Platforms Transport							A5.2
	Systems Transport							A5.2
Engagement Execution (EE)	Weapon Initialization & Launch						A4.2.3	
	Fire Control						A4.2.3	
	Illumination						A4.2.3	
	Intercept						A4.2.3	
	Battle Damage Indication						A4.2.3	
	Electronic Attack						A4.2.3, A4.3.1	

Interoperate	CSD	CSD Comms	A1.3	A2.3			
		CSD Networking	A1.3	A2.3			
		CSD Services	A1.3	A2.3			
	CFO	CFO Comms			A3.4		
		CFO Networking			A3.4		
		CFO Services			A3.4		
	CO	CO Comms				A4.1.4	A5.3
		CO Networking				A4.1.4	A5.3
		CO Services				A4.1.4	A5.3
	CS	CS Comms				A4.3.3	
		CS Networking				A4.3.3	
		CS Services				A4.3.3	
	PNT	Gen & Comm Time	A1	A2	A3	A4	A5
		Gen & Comm Nav	A1	A2	A3	A4	A5
		Gen & Comm METOC	A1	A2	A3	A4	A5

**Note: CIAP functions are shown in italics.*

CIAP System Interface Mapping

The physical instantiation of the architecture is the next step for the Coalition. Each Coalition Partner is identifying the systems and platforms that will be CIAP compatible. From this data, a system-to-functions mapping will be developed, as well as system-to-system mappings and system interface mappings identifying connectivity, data content, data format, and link protocol. An example of such system mappings (SV-3) for a selected set of U.S. Navy systems is provided in Figure 7-5. This figure illustrates three types of system mappings:

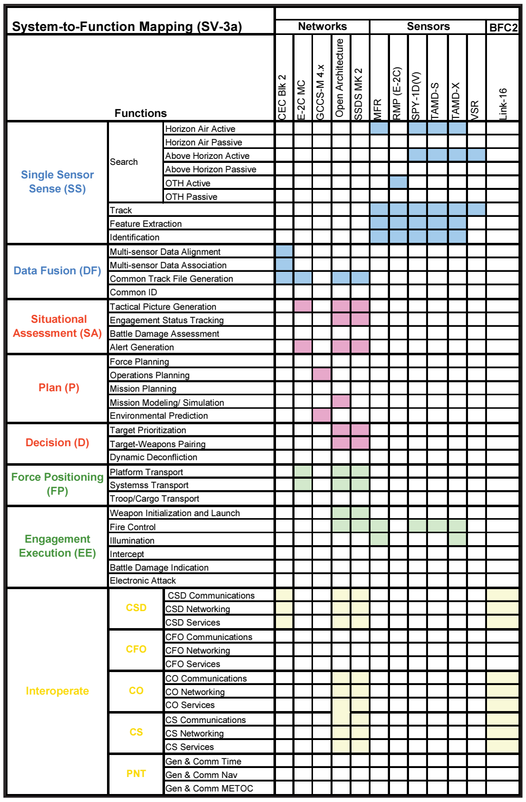
- System-to-system mapping (SV-3a)
- System-to-platform mapping (SV-3b)
- System-to-system mapping (SV-3c)

Figure 7-6 is a graphical representation of the system interfaces.

Architecture Performance and Behavior

An executable model of the architecture will be developed to validate the CIAP concept and to provide an early demonstration that the physical instantiation will meet the Capstone Requirements. The executable model at the highest level will have the logical connectivity depicted previously in Figure 7-3, the Logical Relations of the Activity Model. The high-level activities will be decomposed into operator models or system models and executed in use cases. If a common database representing the CIAP can be created and assessed against the Capstone Requirements using the executable architecture, then the Coalition could begin design and development. Limitations and issues including available communication bandwidth, inaccurate time references, or inaccurate platform positional accuracies can be addressed using the executable architecture before proceeding with more costly design, development, and experimentation efforts.

The executable model provides the ability to determine if the architecture will function under simulated real-world conditions. Before undertaking development of an executable model, it is critical to review the static views of the architecture of the proposed implementation to verify the following considerations:



CIAP System-to-Platform Mapping (SV-3b)

Systems	CG(X)	CVN	DDG 51	E-2C
	Platform Types			
AN/SPY-1D(V)			X	
CEC Block 2	X	X	X	X
E-2C MC				X
GCCS-M 4.x	X	X	X	
Link-16	X	X	X	X
MFR		X		
Open Architecture	X		X	
RMP (E-2C)				X
SSDS MK 2		X		
TAMD-S	X			
TAMD-X	X			
VSR		X		

CIAP System-to-System Mapping (SV-3c)

	GCCS-M 4.x	Open Architecture	CEC Block 2	E-2C MC	SSDS MK 2
GCCS-M 4.x					
Open Architecture	●				
CEC Block 2		●	● (purple)		
E-2C MC		● (blue)	●		
SSDS MK 2		● (blue)	●	● (blue)	
MFR					●
RMP				●	
SPY-1D(V)		●			
TAMD-S		●			
TAMD-X		●			
VSR					●

● Direct
● (blue) Link-16
● (purple) CEC/DDS

Figure 7-5. System Mappings (SV-3), U.S. Navy Systems (circa 2019)

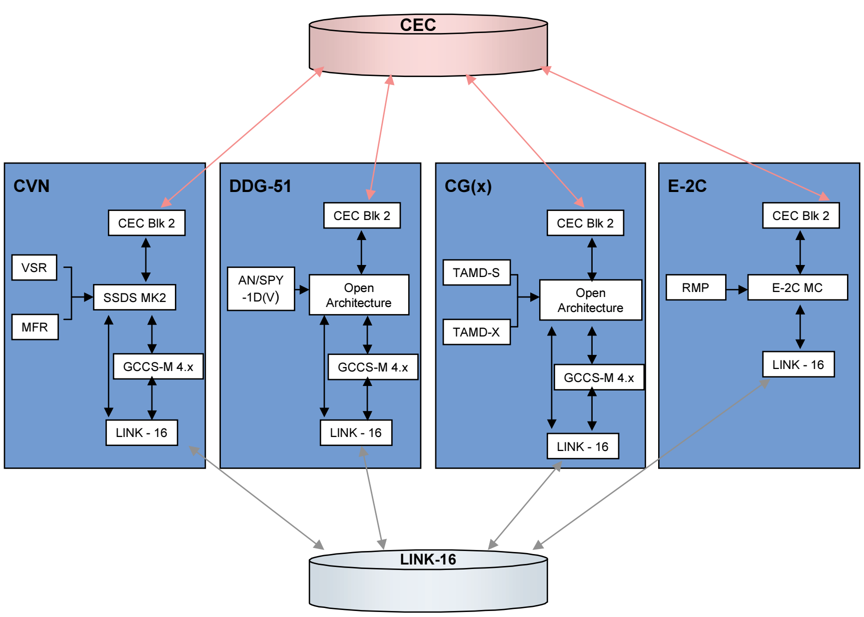


Figure 7-6. System Interface Description (SV-1)

- Required system interfaces exist and the architecture adequately defines these interfaces
- Required data is being passed from system to system at these interfaces to support system-of-system mission functionality
- The flow-down of requirements is clear and that the overall system-of-system requirements can be successfully achieved through the requirements of individual systems
- Interoperability between systems is adequately defined and supported by the system architecture
- The impact of functionality that is redundant across multiple systems is clearly understood
- Required functionality that is omitted is identified and corrective actions are taken
- Coordinating functionality critical to FoS performance is identified

Once the implementation is verified, development of an executable model will begin.

The CIAP executable model will validate that the architecture is functional. In order to accomplish this validation, the CIAP architecture must be placed in a use context. Specifically, the use context for CIAP is Theater Air Defense; in other words, CIAP exists for the expressed purpose of enabling Theater Air Defense. Consequently, the evaluation of CIAP requires that Theater Air Defense be modeled in the executable.

The OV-6c for Theater Air Defense is provided in Figure 7-7. CIAP functionality is resident in the purple shaded blocks of the figure. This OV-6c will be represented in a UML model. The model will be structured and of sufficient fidelity to determine the effect on engagement success of the following issues:

- Inter-platform bandwidth limitations
- Inter-platform communication network QoS policy
- Targeting data routing from sensor to shooter
- Latency delays due to human interpretation of combat ID vs. automatic target ID
- Target loading on the communication network
- Interceptor/Weapon time of flight

The first, second, third, and fifth items are directly related to CIAP performance.

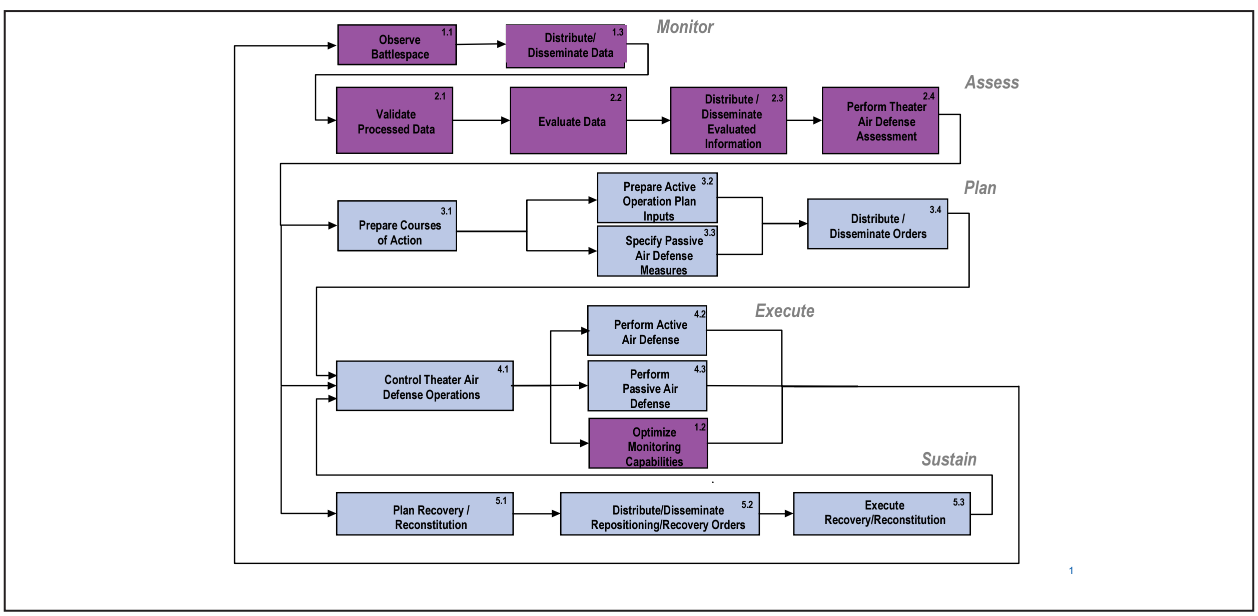


Figure 7-7. Theater Air Defense OV-6C

The executable model will be used to support the following specific purposes:

- Generation of data on the dynamic interactions of the component portions of the Theater Air Defense system (e.g., sensor, communication link, weapon) and the overall system response time performance
- Identification of the interactions and/or components that have the greatest impact on overall Theater Air Defense system response time performance
- Determination of the expected impacts on Theater Air Defense performance from changes (such as a different mix of platforms or platform placement) or enhancements (such as faster interceptors/weapons, automation of target ID, or increased bandwidth)

Approach

An active agent executable model will be developed in an iterative, hierarchical fashion using Rational Rose Real-Time. The model will portray the Theater Air Defense operational architecture and Theater Air Defense system architecture starting at a high level. Detail will be added to the model as needed in order to address system performance. System performance data for each modeled system will be documented in a System Performance Parameters Matrix (SV-7). The model will represent the sensor-shooter-target sequence using agents to portray the major system components: ship platforms, communications links, weapons/interceptors, and decision makers. Functions and or activities performed within an agent are to be initially portrayed as passive objects having a time delay and subsequently as active objects modeling the propagation of targeting errors. The model is notionally shown in Figure 7-8.

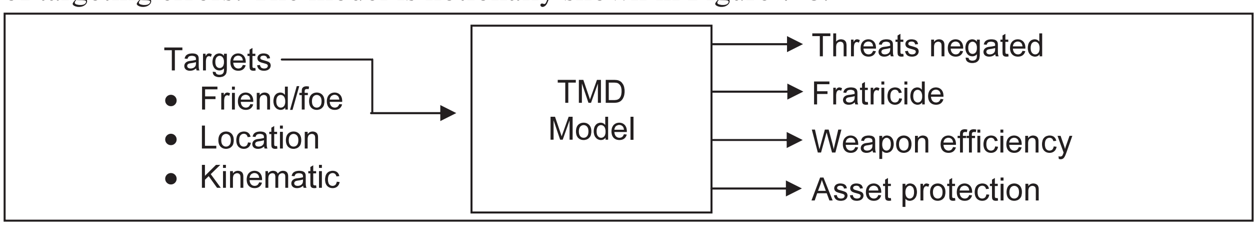


Figure 7-8. Notional Active Agent Executable Model for CIAP

Functions will be modeled as a data transform f (x) with a time delay. The least level of fidelity will be modeled to represent the data transform adequately. Figure 7-9 illustrates the method for modeling functions.

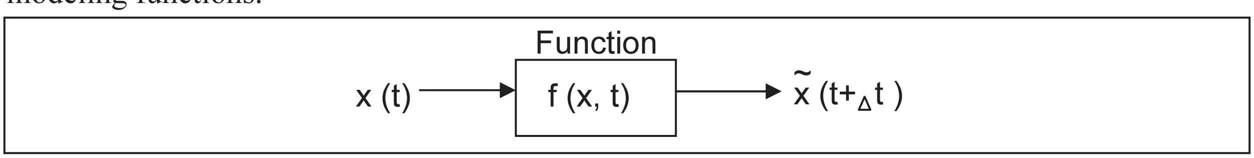


Figure 7-9. Method for Modeling Functions

Activities will be modeled as data transform g (y) with a time delay. Figure 7-10 illustrates the method for modeling activities.

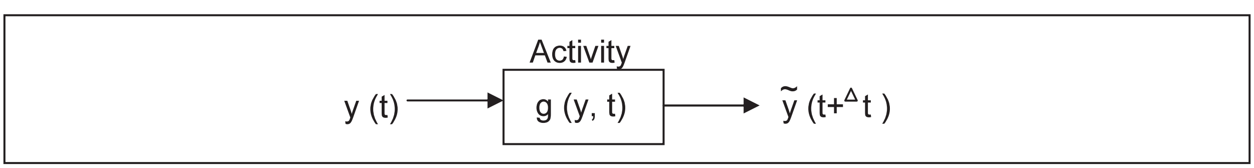


Figure 7-10. Method for Modeling Activities

Various characteristics of system components will be addressed in the model. These characteristics are identified by system component in Table 7-3.

Table 7-3
System Component Characteristics to be Addressed in the Model

System Component	Characteristics
Sensor	Target state error estimation due to sensor measurement error and sensor registration errors
Communications Link	Data transfer times arising from congestion, satellite visibility and bandwidth limitations as well as QoS policies
Launch Platform	Launch platform registration errors and time required to maneuver to launch position
Weapons	Weapon registration errors, sensor measurement and/or guidance errors, and time-of-flight
Control Platforms	Control platform registration errors, sensor fusion errors, and the time required to interpret sensor data and determine an engagement order

The model will be configured to evaluate the stochastic effects of network loading. These effects will be evaluated by developing a scene generator that will include parameters including a minimum and maximum number of targets, spatial and temporal distribution, and spatial and temporal visibility. Sensor parameters, including probability of detection as a function of target visibility and spatial and temporal coverage, will also be developed. The model will also include minimum and maximum numbers of launch and control platforms and spatial and temporal distributions.

Data collected during execution of the model will be used to produce graphs and plots that will portray system behavior and performance. To support analysis, the model will produce the following products:

- Time line of activities
- Latency from sensor to weapon impact
- Error propagation from sensor to weapon
- Probability of engagement success in the following categories:
    - Target not visible
    - Target visible, but latency of engagement was too great
    - Target visible, engagement prosecuted, but targeting error was too great
    - Target visible, engagement a success
    - Weapon efficiency

Specific CIAP metrics will be derived that show the effect of the CIAP's accuracy on each of the listed Theater Air Defense performance metrics. While this approach requires the development of an executable that will be much more complicated than an executable of just the CIAP process, this approach is necessary to place the value of the CIAP in context. For example, if CIAP accuracy can be increased 20 percent but has minimal effect on Theater Air Defense engagement success, time and funding that increase CIAP accuracy to that level may be better spent elsewhere. In this context, a CIAP is a means to an end, not an end in itself.

Summary

The CIAP architecture development, while in its infancy, has proven to be a worthwhile tool for instantiating the CIAP concept. The use of standardized views of the architecture accessible via a collaborative engineering environment has enabled a worldwide coalition to greatly accelerate the CIAP systems engineering process despite the wide geographical and time differences among the partners.

PART III
CAPABILITIES-BASED ACQUISITION

This final part of the book focuses on the methodology for using the Architecture Framework to support research, development, and acquisition, and particularly capabilities-based acquisition. The first chapter in this part of the book provides the history of the Architecture Framework and the relevance of that history to mission capability acquisition. It then continues with a discussion of the rationale behind the move to capability-based acquisition and provides information on the conditions under which the pursuit of FoS interoperability can offer performance and cost-effectiveness benefits. The second and final chapter in this part of the book addresses the data management aspects of the architecture-based systems engineering methodology. As seen in the case studies provided in Part II of the book, the complexity of the FoS combined with the diversity of the stakeholders demand the use of automation and standards in the data management of the architecture products. This chapter provides methodology and tools for incorporating data management in the mission capability acquisition process.

CHAPTER 8
CAPABILITY-BASED ACQUISITION: WHY, WHEN, AND HOW?

Purpose

The previous chapters demonstrated how the architectural methodology can be applied to specific FoS systems engineering initiatives focused on increasing mission capability. This chapter provides information on the architecture framework history and the relevance of that history to mission capability acquisition today. It describes the reasons for pursuing capability-based acquisition and recognizes that the failure to achieve the synergy possible through FoS systems engineering can lead to degradation in combat effectiveness. It also introduces challenges associated with using an FoS approach to acquire integrated systems focused on achievement of defined mission capabilities and notes that it is not always feasible or cost effective to force system interoperability into an FoS. Because providing interoperability may require development of costly solutions, the resulting performance gains sought from the interoperation of systems must be significant in order to justify the investment. Finally, it introduces a basis application of architectures: documentation of a blueprint for FoS development.

Architecture Framework History and Relevance to Mission Capability Acquisition

In 1996, the OASD for C3I (today called NII) sponsored an effort to develop an Architecture Framework Document in order to establish a standard means for the department to describe integrated systems. In seeking to provide joint and interoperable systems, the department believed the first step should be development of a common lexicon and approach that could be used to describe integrated architectures across disparate organizations. The Services, Joint Staff, Office of the Secretary of the Defense, and agencies across the department worked together to develop this lexicon and approach document. Because the effort was sponsored by the OASD for C3I, however, the resultant document, the C4ISR Architecture Framework Version 1.0, focused entirely on architecture views that would be used to describe the integration of C4ISR systems. The architecture views provided in the document were derived primarily from selected views that were used across the department to describe information systems and information networks. Despite the fact that the end-product from this exercise had a somewhat narrow focus, the attempt to organize common views across organizations that were dealing with requirements, engineering, and acquisition was a step in the right direction.

The C4ISR Architecture Framework Version 1.0 included various views, categorized as operational, system, or technical, that could be used or modified to support design of interoperable and integrated systems of systems. The views are illustrated in Figure 8-1. They are similar in many ways to the classic systems engineering views of the Institute of Electrical and Electronics Engineers (IEEE) Standard 610.12[26] in that both use functional and physical views to capture requirements and identify designs for improving performance. The difference in the C4ISR Architecture Framework was its focus on the improvement of C4ISR interoperability.

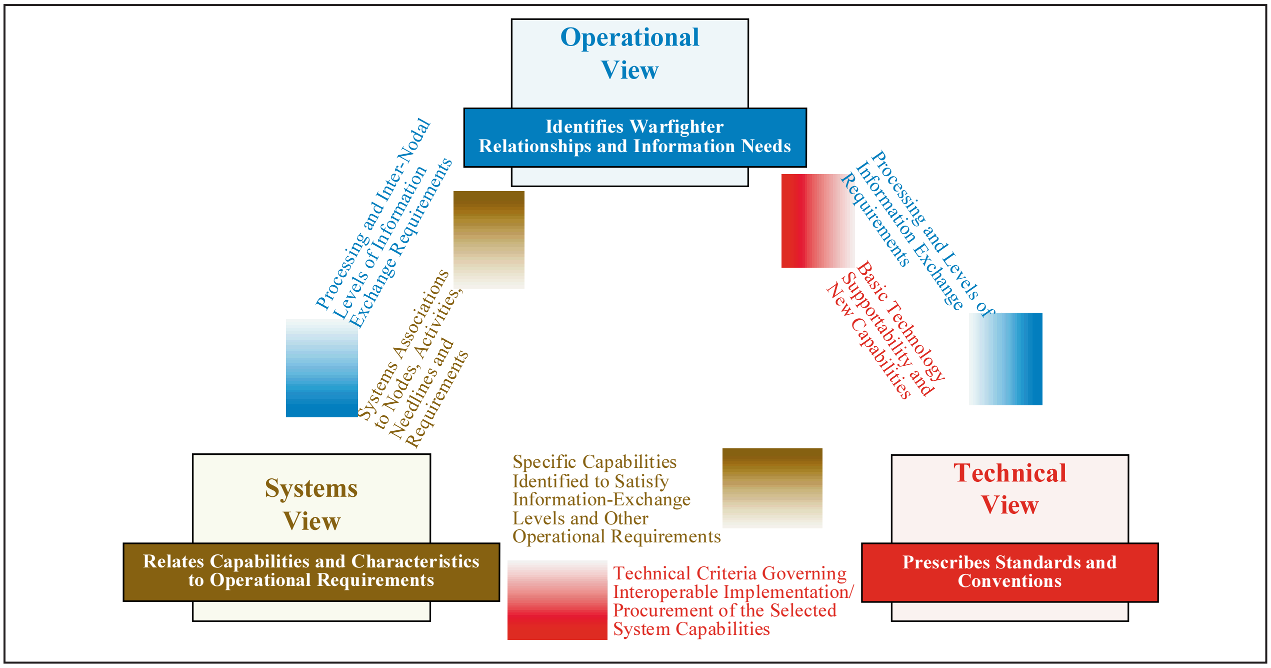


Figure 8-1. Architecture Framework's Common Language and Standard Format, including Operational, Systems, and Technical Views

In December of 1997, the second version of the C4ISR Architecture Framework was published and eventually led to the convening of the DoD Architecture Working Group in June 2002. This group developed definitions, guidelines, and references (Volume I), products and data descriptions (Volume II), and supplementary guidance, sample products, and use (Volume III) for the DoD Architecture Framework (DODAF). The major new features of the DODAF are summarized in the following bullets:

- Based on intended use of the document across three major disciplines
- Mapped to the Federal Enterprise Framework
- Removes concept of Essential and Supporting Products
- Incorporates data-centric perspective
- Provided Object-Oriented and NCW approaches

The drafts of the three volumes of the DODAF were submitted for review in early 2003.

Mission capability based acquisition relies on the establishment of an architecture framework within which individual programs can be evaluated against requirements. Operators must create operational views to capture integrated requirements, and engineers and systems acquisition professionals must use systems and technical views to evaluate investment strategies in determining the best methods for satisfying the integrated operational requirements. The OASD for C3I recognized this fundamental need to evaluate what have come to be known as "derived requirements for interoperability and integration." The department established instructions and policies to promote better communication between the operational, engineering, and acquisition communities and their respective disciplines in order to support improved identification of technical and programmatic requirements.

Development of the Architecture Framework Document was the first step toward implementation of a standard process for evaluating interoperability and integration because it created a common approach and language to support the process. Achievement of this goal was subsequently moved forward through establishment of requirements for specific program reviews and direction to use specific common tools across departments to promote standardization in those reviews. For example, the OASD for C3I began requiring the use of operational, systems, and technical views as part of the C4ISPs that were required by the DoD 5000 acquisition directive to be included in program reviews for major acquisition milestones. Figure 8-2 illustrates the C4ISP process. Additionally, the OASD for C3I has established a process for disseminating architecture views for widespread review and analysis. After reviewing each C4ISP, the OASD for C3I staff places the architecture views in the JMAAT. Because JMAAT is networked via SIPRNET through the department, the views are accessible to and reviewable by more than 120 subject matter experts throughout the Services, Combatant Commanders, and agencies. These experts review the views, study and discuss the technical and programmatic issues identified, and determine how they may impact Joint mission areas and any desired capabilities. This process along with the others described in this paragraph point to the emergence of a formal process for addressing critical technical and programmatic issues that affect system interoperability, integration, and mission capability.

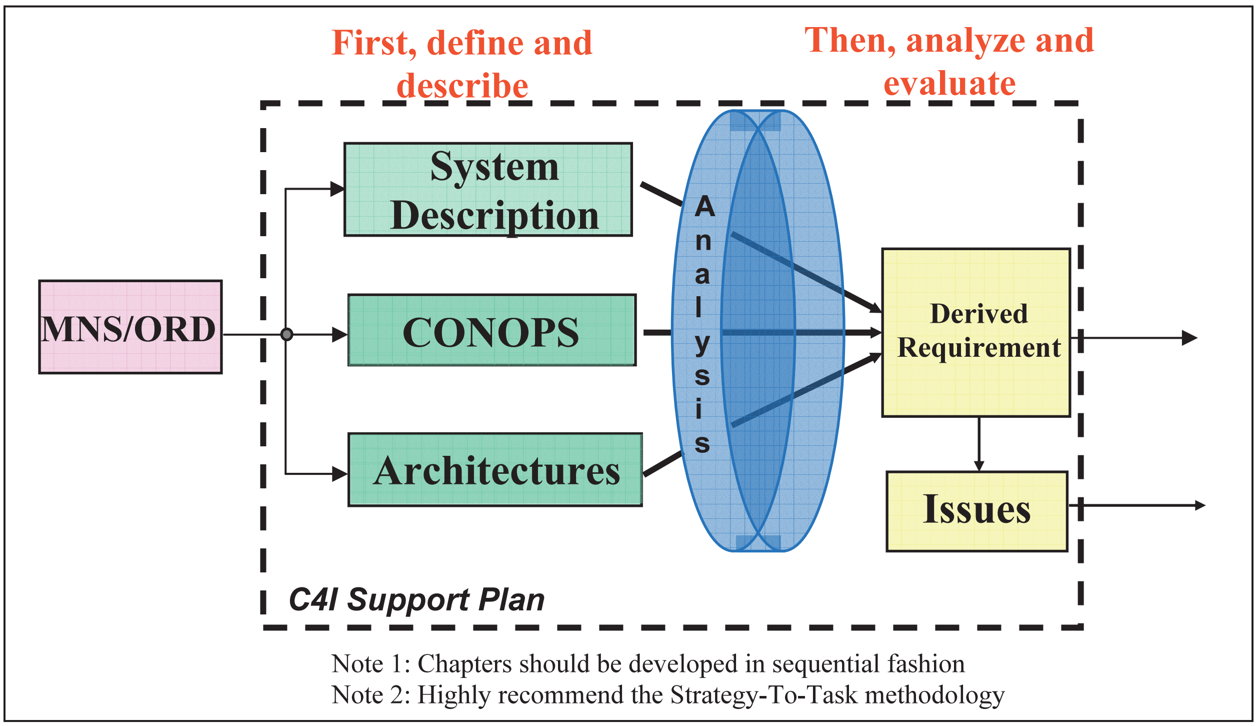


Figure 8-2. C4ISP Process Chart

What is Capability-Based Acquisition?

Single system and platform-centric SoS acquisition has historically focused on defeating a specific threat or related family of threats. Capabilities-based acquisition focuses on achieving mission capabilities, usually through an assembled FoS or through an SoS.

To understand capability-based acquisition, it is important to understand what the terms in the title actually mean. Recall from Chapter 2 that an operational concept is an end-to-end stream of activities that defines how force elements, systems, organizations, and tactics combine to accomplish a military task. Within a scenario or tactical situation, a course of action (COA) is a possible plan available to an individual or commander that would accomplish or support a mission. A capability then, as defined by Joint doctrine, is the ability to execute a specified COA. COAs are simply sequences of operations that can be executed to support or accomplish a mission, so mission capability can be defined as the ability to execute the collective COAs necessary to accomplish the overall mission. It is for this reason that every case study in Part II of this book includes an Operational Event/Trace Description (OV-6c) that provides the operational concept for the mission capability. Capability-based acquisition can then be defined as the acquisition of an interoperable FoS or SoS that enables the execution sequence described in the OV-6c for a specific mission or mission task.

Why Capability-Based Acquisition?

The background information provided in the previous two sections of this chapter offers some insight on the rationale behind capability-based acquisition, but the bottom line is that full mission capability can only be achieved when systems are fully integrated, interoperable, and combined with appropriate DOTMLPF components. Failure to achieve this synergy can degrade combat effectiveness. The FoS engineering and acquisition process is designed to enable capabilities from an assemblage of systems designated to support mission objectives. Realizing the criticality of full systems integration in combat operations for specific mission areas, the DoD began exploring the possibility of using a mission capability-based acquisition process to develop new investment strategies that would satisfy integrated requirements with analytically based program decisions.

Degradation in Combat Effectiveness

Degradation in combat effectiveness can be caused by many contributing factors, one of which is undeniably poor or non-existent integration or interoperability. The inability of systems to work collaboratively may make the systems unable to perform functions that are essential to the support of operator activities. Because integration and interoperability are so critical to combat effectiveness, the entire FoS must be considered in the engineering and acquisition process if decision makers are to choose the most operationally sound, technically feasible, and cost effective program investments.

Evidence of the need for an FoS approach to the engineering and acquisition process is unfortunately abundant. In recent combat missions, the lack of integrated systems and their inability to perform vital functions in a coherent fashion have contributed to difficult situations and significant problems in executing military operations. A primary symptom of poor integration and interoperability is the inability of systems to provide and share timely and accurate information among key system components. This inability frequently leads to a failure in providing the right information at the right place and time, which in turn can lead to incorrect decisions, mistaken identifications, and slow response times. Lessons learned from recent military operations have highlighted information distribution problems that led to catastrophic and fatal errors including friendly fire incidents, the shooting down of neutral forces, and the loss of U.S. forces from enemy attacks that may have been prevented if friendly forces had been provided with more timely and accurate warnings.

While the need for an FoS approach to acquisition and systems engineering may be clear, difficulty exists in moving from the way systems are acquired and engineered today to the end state desired. The dilemma is illustrated and described in Figure 8-3.

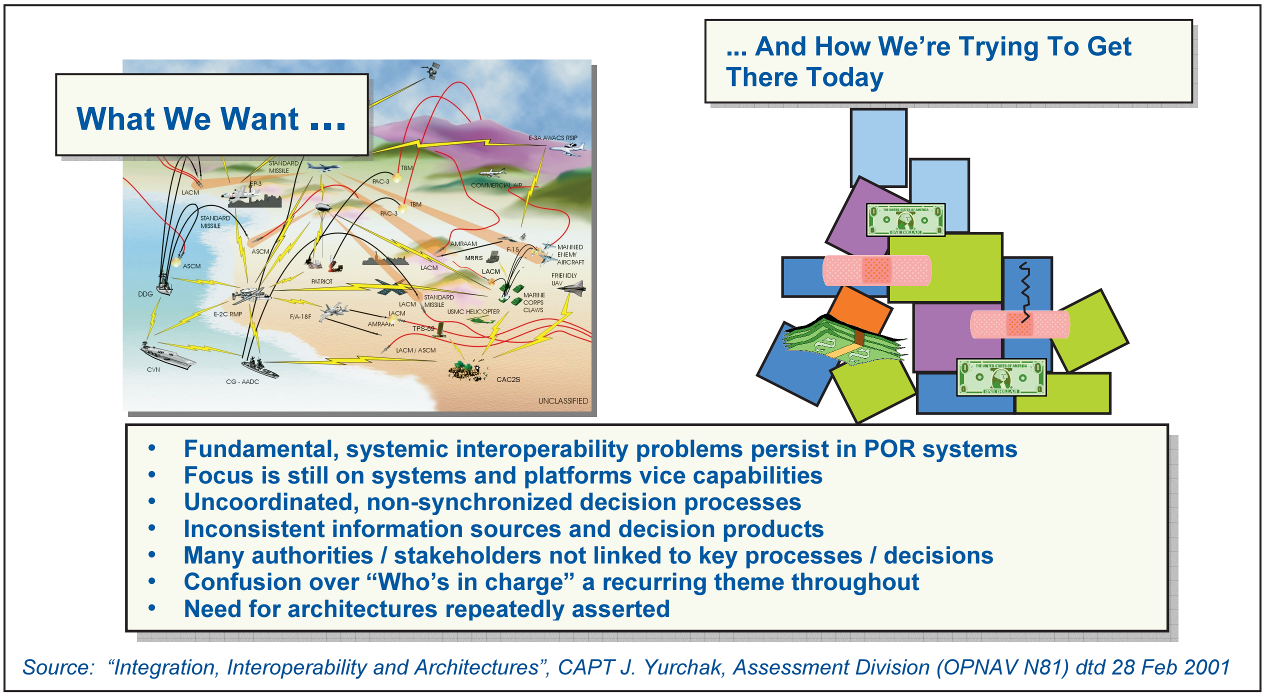


Figure 8-3. The Dilemma Chart

A variety of technical issues and problems have prevented not only the integration of emerging multiple systems that provide related functions but also the satisfaction of newly evolving requirements for legacy systems that were not initially designed to operate together. Examples include the inability to put multiple tracks from various systems together in a single integrated tactical picture (as shown in Figure 8-4) and the confusion and errors in plotting locations and positions caused by the delivery of specific information to receiving units using different metrics and standards. In other examples, root cause analysis has shown that the inability to integrate various communications links led to delays in the speed of command and contributed to confusion in the tactical pictures. In short, there can be no doubt that the failure to employ an FoS approach to the engineering and acquisition process has led to both degradation in mission capability and catastrophic consequences.

The failure to use an integrated systems planning, design, and acquisition process creates additional problems beyond critical operational errors and challenges. It also significantly increases the cost of providing associated and essential capabilities necessary to support systems and processes across all service branches. Specifically, the cost of installing, maintaining, and providing training on duplicate systems designed to perform overlapping functions in support of required operator activities is a poor investment of funds that could be applied to other, more critical priorities.

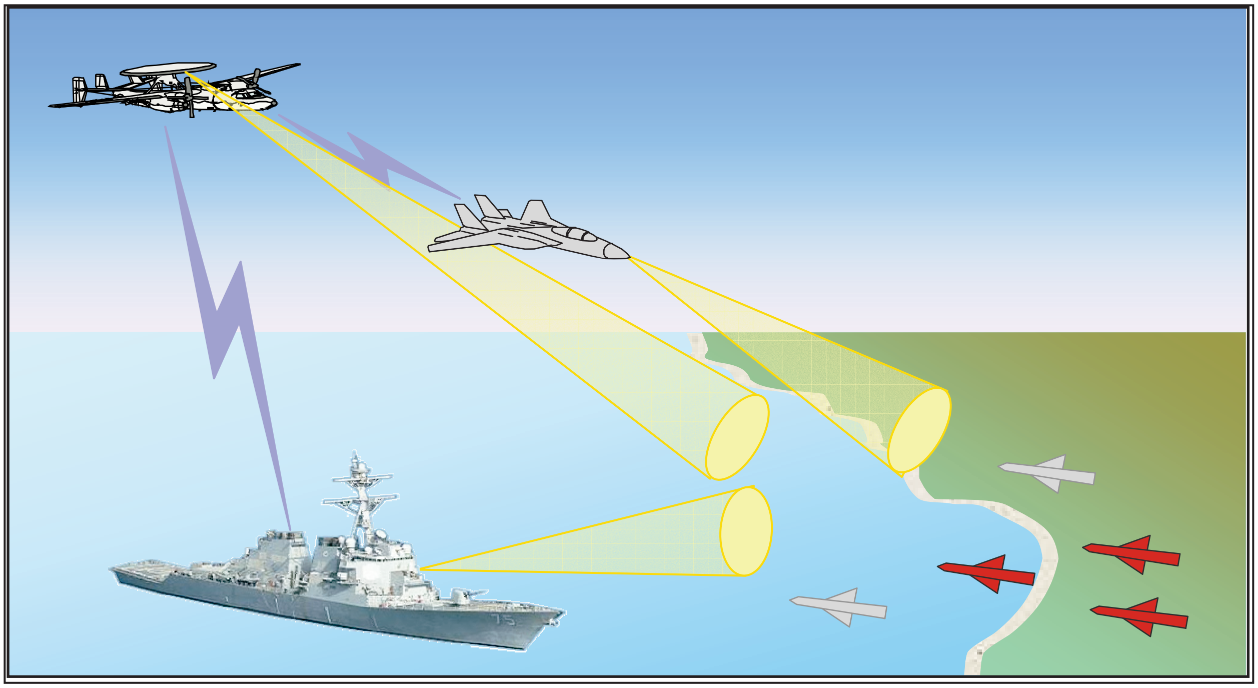


Figure 8-4. Multi-Track on Single Target Chart

In studying the integration and interoperability problems DoD faces, an alarming trend has become apparent. This trend indicates the DoD's tendency to invest funds into systems development aimed at extending capabilities already provided by existing systems. In many cases, these development efforts have been undertaken even when the development effort will yield only limited functional improvement while imposing significantly increased costs for training, maintenance, and installation of essentially duplicative systems. The trend also shows a simultaneous avoidance of investment in systems that are not completely developed but offer potential solutions to identified capability gaps. Because the systems are not fully developed, they are higher risk projects and their technical objectives are more difficult to achieve, yet it is only through investment in these types of projects that total system capability gaps can be addressed. To reverse this trend of investing in duplicative systems and ignoring identified capability shortfalls, it is necessary to approach the acquisition and engineering process with a goal of gaining an integrated FoS that can deliver specific mission capabilities.

What is a Mission Capability Package?

To address the need to provide integrated FoSs designed to deliver a specific set of capabilities, Mission Capability Packages were created. Mission Capability Packages include portfolios of analytically backed programs combined with the necessary DOTMLPF components to allow satisfaction of integrated requirements. These packages are developed to identify systems and support elements needed to meet mission objectives defined and validated by the operators.

Developing a Mission Capability Package requires use of an integrated progression of assessment processes and architecture products. These processes and products build upon each other to provide the best and most achievable evolution plan and business case for the required capability objectives that support the specified mission areas. A complete Mission Capability Package accounts not only for the systems but also for the DOTMLPF required to obtain a desired joint mission area capability. Figure 8-5 provides further definition of an MCP.

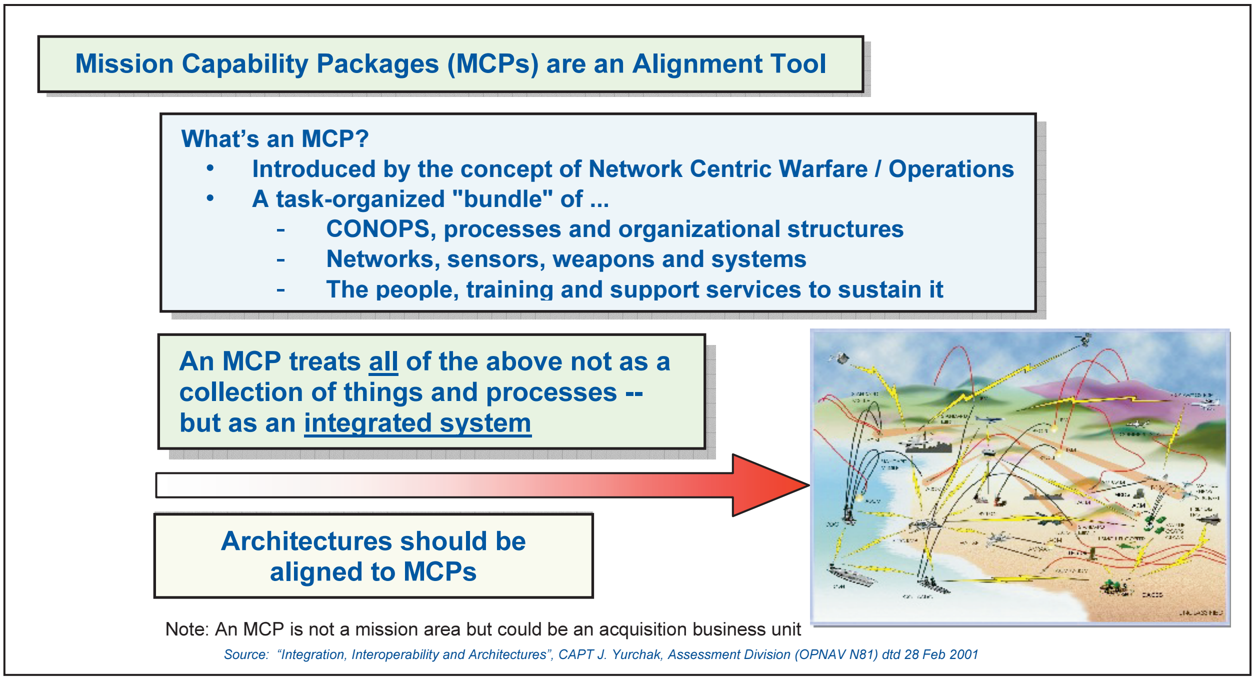


Figure 8-5. MCP Definition Chart

One of the primary DoD objectives outlined by the Joint Staff in the Joint Vision 2010 and 2020 documents and other DoD planning and policy documents during the past 10 years has been to acquire joint, interoperable FoSs that improve mission capability and increase combat effectiveness and efficiency. More recently, the Navy and the Air Force have begun to develop processes for evaluating their POM investment strategies through the use of Mission Capability Packages. These services are using the packages to identify and eliminate gaps and duplications in program investments and to make better investment decisions that will provide the end-to-end processes and equipment necessary to improve military operational capabilities.

The U.S. Navy's Mission Capability Package process is outlined in the Chief of Naval Operations N70 POM-06 Process. The process, which is graphically outlined in Figure 8-6, is a process for standardizing scenarios, capability objectives, and metrics to assess acquisition decisions. It describes the processes for developing Mission Capability Packages and the organizations responsible for creating them. The process was initiated by the CNO and conducted by the office of Integrated Warfighter Requirements (OPNAV N70). The packages developed using the process will be used in building an Integrated Sponsor Planned Program (ISPP) that will guide acquisition decision-making in the POM.

The RDA CHENG applied the architectural methodology to support the N70 POM 04 build. The methodology was used in six of the N70 MCPs to various levels. In supporting the N70 POM 04 build, a cost analysis was performed on the various Programs of Record based on program lines and lifecycle costs. The cost analysis was followed by a Multi-Attribute Utility Analysis, as described in Chapter 5. The Multi-Attribute Analysis was used to develop organizing exhibits at the early stages of planning for POM 04, although the exhibits were not used in the final decision-making process. The ASN(RDA) CHENG did use the Multi-Attribute Utility Analysis to advise ASN(RDA).

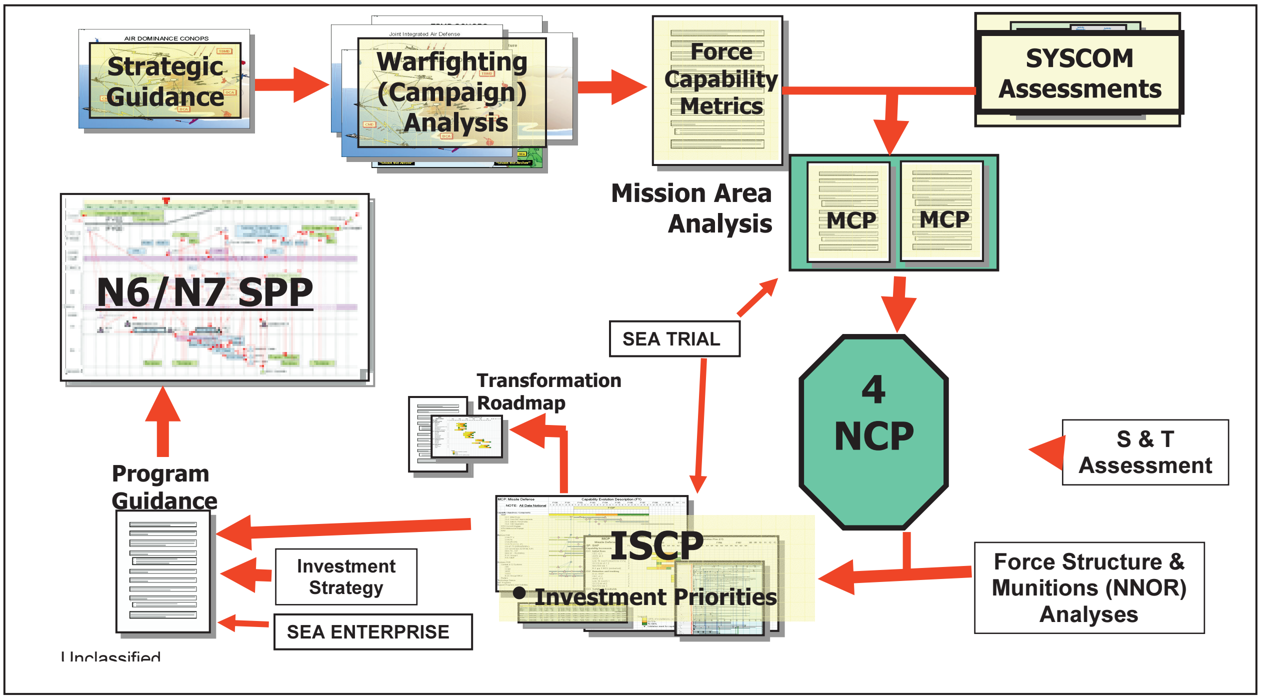


Figure 8-6. N70 POM-06 Process

Figure 8-7 shows the current process being proposed at the Joint level by CJCS J8. This process is clearly architecture-based and maps acquisition planning and DOTMLPF into capability evolution, as shown in the lower half of the figure. The figure also illustrates the concept of identifying capabilities as bundles of tasks and of associating multiple systems with capabilities.

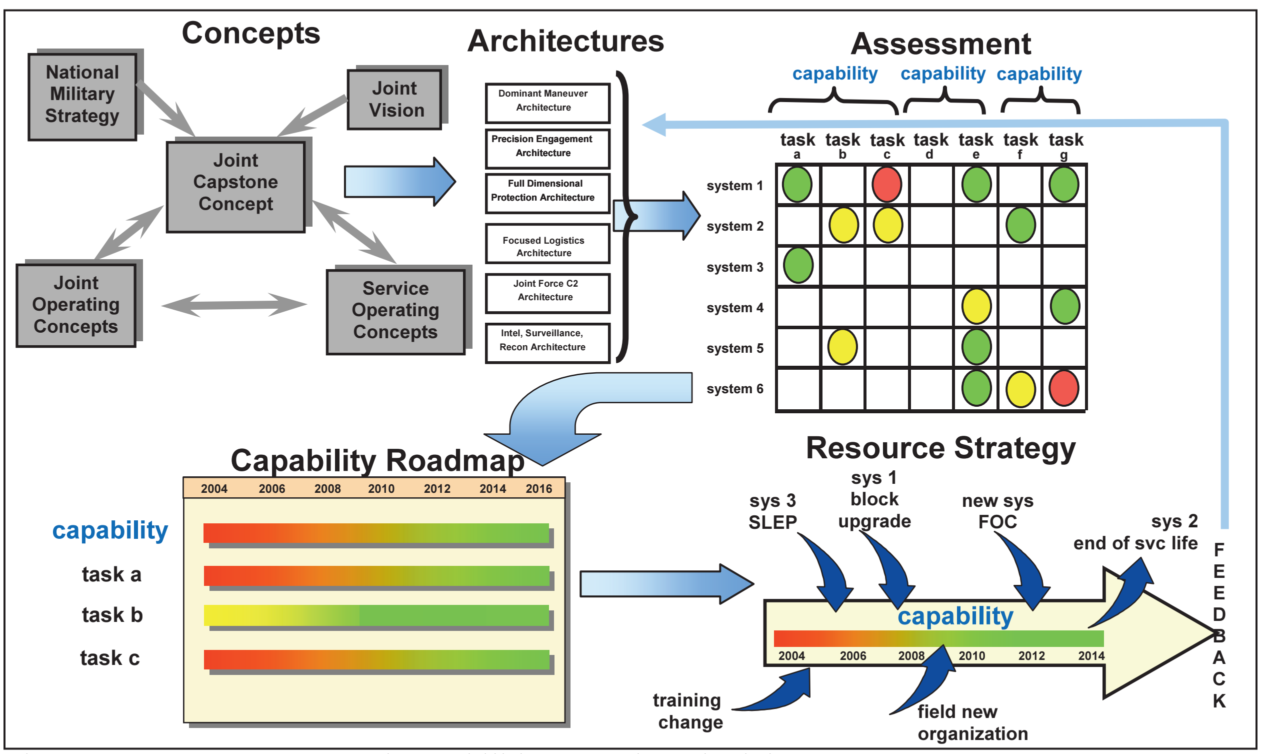


Figure 8-7. CJCS J8 Proposed Capabilities-Based Methodology

Why Change the Process?

As noted throughout this chapter, the current acquisition process does not address methods for acquiring integrated FoSs that can meet specific mission objectives. Current requirements generation processes generally fail to produce an integrated FoS view that can identify all systems and support elements required for successful execution of operator activities. The process focuses on improvements to individual systems and platforms as opposed to integration and interoperation of systems and platforms to produce desired capabilities, which inevitably leads to continued acquisition of and investment in programs with systemic interoperability problems. The problem is exacerbated by the fact that the decision process is frequently uncoordinated and out of sync with related decision-making activities, so it often fails to put the right piece of the solution in service at the right time. Simply put, DoD cannot meet interoperability objectives by merely establishing or enforcing policies or standards, including key performance parameters in ORDs or Capstone Requirments Documents (CRDs), or even by applying sound engineering and computer science practices. Only through the use of an acquisition decision making process that specifically addresses integrated FoS mission capability can DoD begin to meet its interoperability goals.

The need to make results-based acquisition decisions serves as an effective forcing function for changing the process. The use of Mission Capability Packages, which include the architectural views and assessment processes for considering the integrated requirements and associated DOTMLPF components needed to provide and field the desired capabilities, will enable DoD to make better acquisition decisions focused on mission objective achievement.

What Needs To Be Done?

Changing the acquisition process to address mission capability will involve a collaborative effort among operators, engineers, and acquisition specialists to perform the following key steps:

- Develop a framework and language that will assist operators, engineers, and acquisition specialists in identifying integrated solutions that provide a balance between platform and system capabilities and force capabilities
- Determine integrated requirements and perform gap analysis based on the architecture framework that is developed
- Ensure the architecture framework is integrated throughout the services to facilitate and motivate collaboration and information sharing
- Integrate key decision processes affecting the end state and track progress through use of collaborative tools
- Provide links between the assessment process and the oversight process and among program milestones, resource decisions, and architecture compliance

Accomplishing these steps in the manner illustrated in Figure 8-8 will yield a process for acquiring distributed, highly networked sensor, weapon, combat, and support systems that will be designed to deliver the critical integration and interoperability necessary to meet mission objectives.

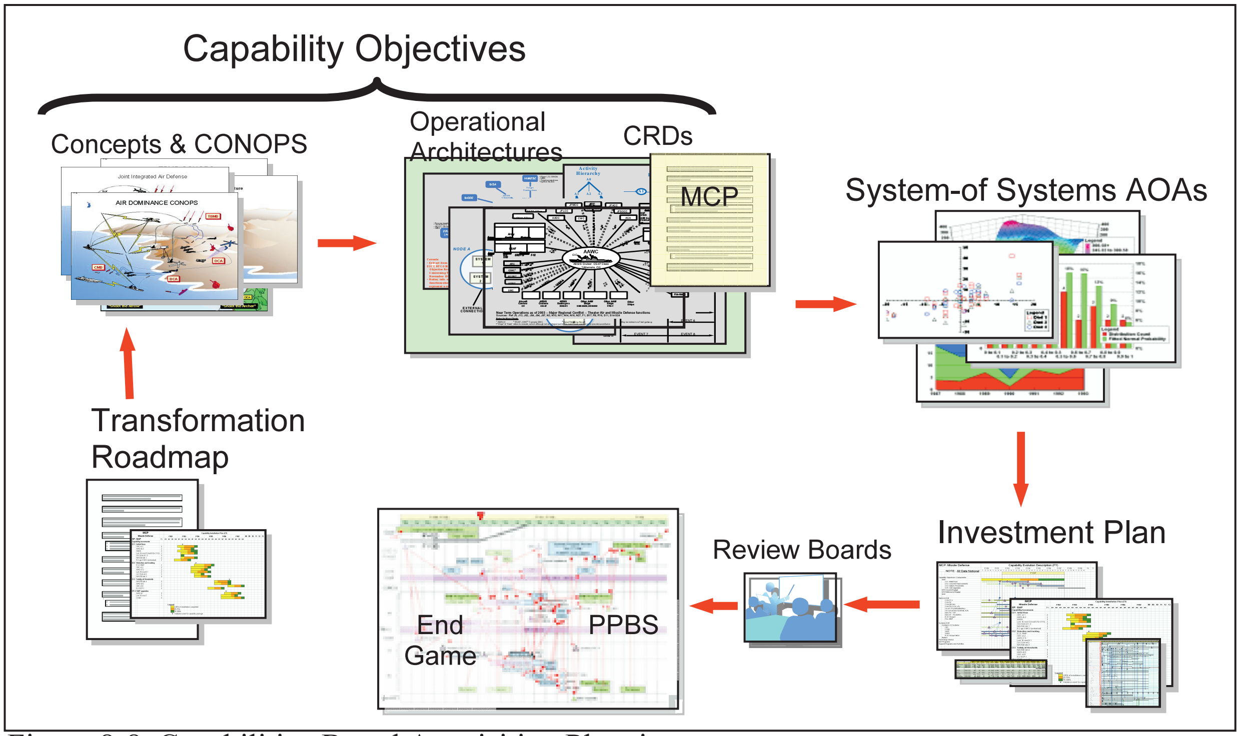


Figure 8-8. Capabilities-Based Acquisition Planning

When Does FoS Interoperability Present Performance and Cost-Effectiveness Benefits?

The previous section discussed the need for an acquisition process that focuses on delivery of mission capability from interoperable FoSs, but it is important to note that not all operational concepts benefit from system interoperability. It is not always feasible or cost effective to force system interoperability into an FoS. Interoperability has been shown to be a force multiplier in cases where systems already offer inherent mission capability. In cases where no inherent capability exists, however, making systems interoperable may simply result in a more costly but still ineffective system. Compounding the difficulty of creating interoperability among existing systems is the fact that legacy systems can be poor candidates for inclusion into an interoperable FoS. Problems associated with re-engineering legacy systems to provide interoperability include obsolete technology that cannot be easily modified; complications caused by deploying multiple variations of the same basic system; and the impact of taking systems and platforms out of service while modifications are being made. Because providing interoperability may require development of costly solutions, the resulting performance gains sought from the interoperation of systems must be significant in order to justify the investment.

The Three Myths of Interoperability and Integration

To distinguish between myth and reality in the areas of interoperability and integration, it is first necessary to clearly define the terminology. The DoD technical community frequently confuses the meanings of the following terms: interfaced, networked, interoperable, and integrated. Systems are interfaced if a communications bridge has been established across a boundary between two systems. While an interface is necessary for systems integration, it is not a sufficient means for realizing the full performance potential of an FoS. If an interface has been established between the systems and a network structure, the systems are considered to be networked. Identifying systems as networked does not imply that the systems are either interoperable or integrated. Systems are described as interoperable when they can function together within an FoS, but systems are only described as integrated if they can guarantee accurate and timely transfer of necessary data between systems within an FoS. A distinction must be drawn between a system that has been *interfaced into* an FoS and one that has been *integrated into* an FoS. They can both provide interoperability, meaning they can function within the FoS, but the performance capabilities of the integrated system are potentially far greater than those provided by the interfaced system.

There are at least three myths associated with integration and interoperability. The first is that distributed functionality always provides increased performance, cost effectiveness, and redundancy. The second is that interoperability equates to force multiplication. The third is that integration of multiple systems can somehow forge a capability where none existed before. Each of these myths is discussed in the following paragraphs.

Myth 1 is the fallacy that distributed functionality always provides increased performance, cost effectiveness, and redundancy. Admiral Art Cembrowsky, U.S. Navy (retired), was one of the first to debunk this myth. His argument revolved around the critical difference between platform networking and platform integration. He noted that a group of networked platforms could continue operating with full functionality even if they were separated from the network, although their performance would lack the force multiplier effects of being connected. He cautioned against dependence on integrated functions distributed across multiple platforms because the distributed functions resident on a single platform and distributed via the network would be unavailable to the force as a whole if that one platform was separated from the network. To state the problem simply, suppose each of three platforms in a network had sensors, weapons, and a command and control system. These platforms could be networked and operate together, providing a force multiplier. If, however, one platform provided sensor functionality, the second provided command and control functionality, and the third provided weapon functionality and these capabilities were available to all platforms via integration, it would be devastating to the group if any of the three were destroyed or otherwise separated from the network. In Admiral Cembrowsky's view, distributing functions over the network was sub-optimal because it deprived the platforms of the ability to operate with full autonomy.

Distributed functionality can have benefits, but total distribution, as described in the previous paragraph and as shown in Figure 8-9, designs multiple single points of failure into the FoS. This is an important concept to understand, especially because DoD is currently attempting to move away from large, capital-intensive platforms that provide autonomous capabilities. Instead, DoD is moving toward acquisition of platforms with less inherent functionality that will have to be present in greater numbers to avoid single points of failure. Referring back to the example provided in the previous paragraph, DoD would require multiple land-based, ship-based, and air-based systems to provide redundancy and remove the single points of failure posed by the use of integrated capabilities resident on distributed platforms.

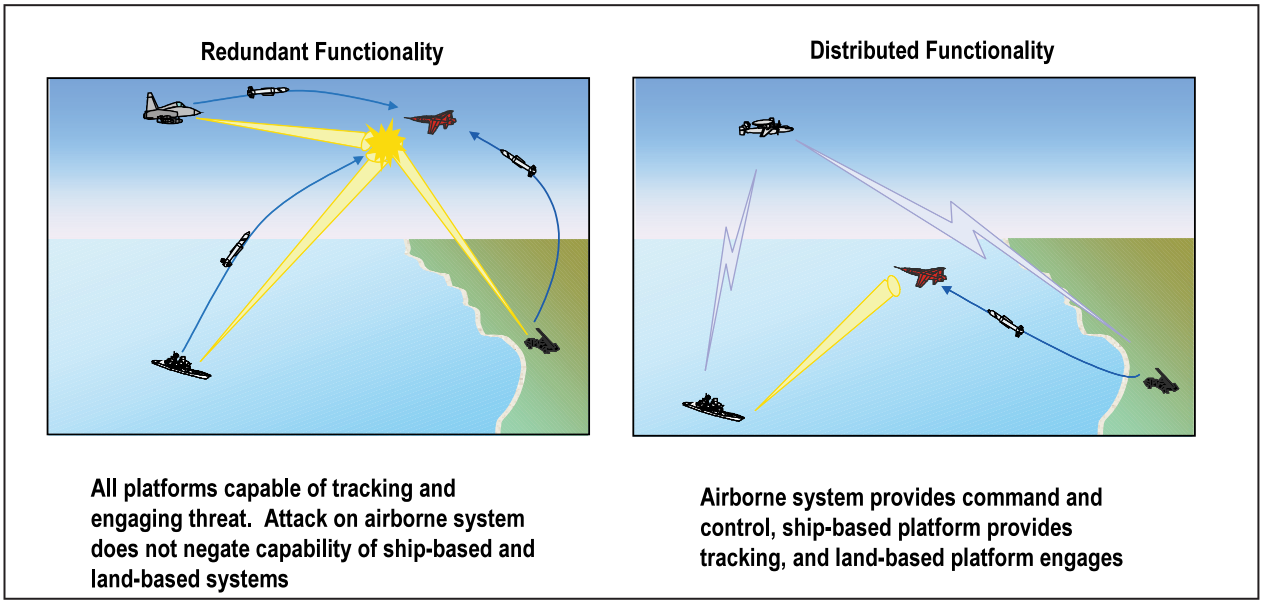


Figure 8-9. Redundant Functionality versus Totally Distributed Functionality

Myth 2 is the assumption that interoperability equates to force multiplication. Force multiplication will not be achieved through interoperability if threats attack in sectors. As shown in Figure 8-10, a platform-centric architecture is completely adequate as long as threats remain in a sectored battlespace. When threats amass in one sector, however, significant force multiplication is gained through integration. The fact is that the force multiplication advantages of interoperability are dependent upon the scenario and the threat, and the probable types of scenarios and threats platforms may face must be considered in determining the significance of the advantage that would be gained through achievement of interoperability.

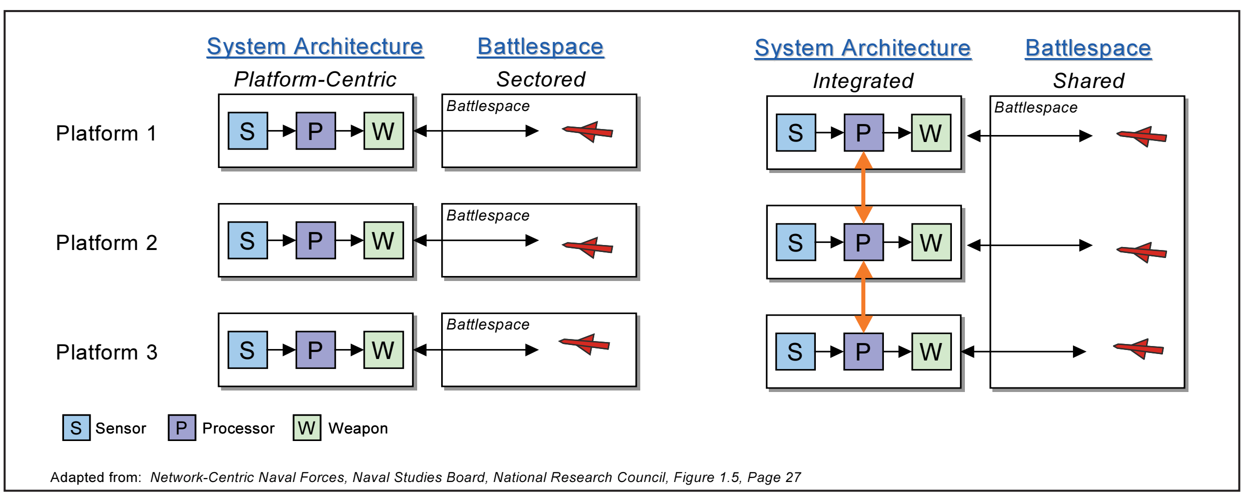


Figure 8-10. Effect of Scenario on Force Multiplication

Myth 3 is the incorrect assumption that integrating systems can provide a capability where none existed before. If the inherent capability to perform a function does not exist in an FoS, then integration will not forge that capability. For example, a group of distributed airborne surveillance sensors, each with the capability to detect a certain threat at 200km, may have surveillance coverage similar to what is represented in Figure 8-11. Netting these sensors together will not enable them to detect targets that they individually could not detect. As indicated by the red line, the combined surveillance coverage provided by the networked sensors will increase to the sum of the parts, allowing a larger area to be surveyed for targets the individual systems can detect. But if a target is below an individual sensor's detection threshold, it will remain below the networked sensors' detection threshold. Put another way, integration and interoperability do not allow an FoS or an SoS to violate the laws of physics.

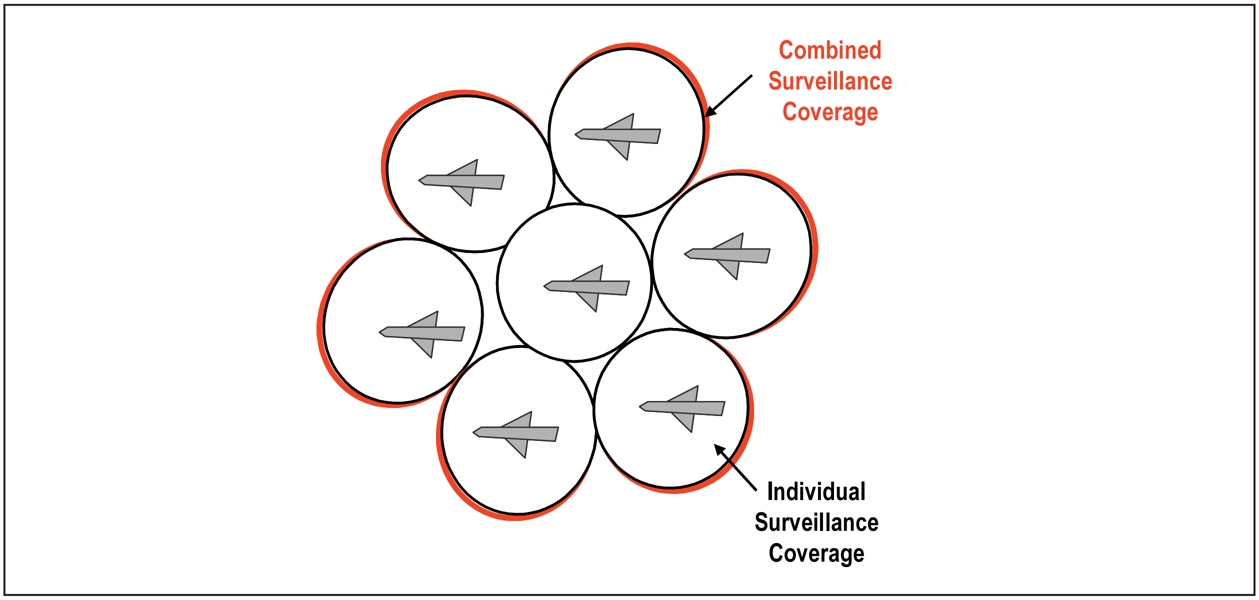


Figure 8-11. Effect of Sensor Netting on Increased Surveillance Coverage

It should be noted, however, that integration and interoperability can allow improvement in information utility. For example, in Figure 8-11, the individual surveillance coverages limit the tracking capabilities (ranges) of the individual sensors. But consider the fact that tracking is an aggregation of detection data. Therefore, if the individual sensor's track data can be accurately geospatially registered and time-aligned, the family of sensors will then enjoy a greater (aggregate) track range than the individual sensors.

Legacy Systems: Not Necessarily Suitable Candidates for FoS Engineering

In assessing the potential returns to be gained in implementing FoS interoperability, it is necessary to consider if and how legacy systems can be integrated into the FoS. The challenges associated with integrating legacy systems into an FoS are numerous. First, these systems frequently employ outdated technology that is difficult or impossible to modify. Legacy systems, especially those fielded before 1990, are designed with specialized computer hardware and programming techniques that are primitive by today's standards. Interfacing these systems directly to current or emerging hardware can be extremely challenging. Legacy system data may not be available at an established input/output port, a fact that will require internal modification of the system without any resultant negative effects on system performance or real-time operations. Additional problems will arise if hardware schematics are incomplete and the system designers are retired or otherwise unavailable, a situation that will require reverse engineering of the hardware component. Integration of software from legacy systems also presents difficulties.

The programming techniques of previous decades do not easily lend themselves to modification. Some programs are written in what are now obsolete programming languages (e.g., CS/2) or assembly languages for processors that have been discontinued for years. The expertise to modify these programs may no longer exist, and even if it does, integrating software written in these languages presents risks to system stability and real-time performance.

A second issue associated with integrating legacy systems into integrated FoSs is the existence of multiple versions of similar legacy systems. On many large-capital DoD legacy systems, a spiral development process is used to support continuous development of more and more capable versions of the same system. While this approach has advantages in providing enhanced capability over time, it also yields numerous versions of the same system. The Aegis Computer Program provides an example of a system that has evolved through numerous iterations. In 2002, there were at least five operationally deployed major baselines as well as many other minor baselines of this system. This situation can present serious challenges for the integration of a legacy system into an integrated FoS because the integration effort is not focused on a single system but rather the integration of numerous *separate* legacy systems. Budgets and schedules for integrating legacy systems into FoSs must reflect the possibility that there may be multiple versions of the legacy system.

The third hurdle associated with the FoS integration of legacy systems is scheduling system modifications into the operational deployment schedules of the legacy system. Since many platforms and systems are routinely scheduled for maintenance and upgrade intervals, this issue is frequently resolvable; however, additional scheduling conflicts can arise if components requiring specialized testing and qualifications (e.g., live-fire missile exercises) are modified. Again, these issues must be considered in assessing the viability of integrating legacy systems into an FoS.

A final consideration associated with legacy system integration into an FoS is the calendar time required to modify each particular system. The modification period required to support integration can span several years. During that time, newer versions of a particular system may be placed in service, and plans may be made to retire older platforms and systems. Accordingly, it is critical to assess the calendar time required to deploy a modified legacy system in relation to both the expense of the modification and the amount of time remaining in the system's service life.

The Cost of Integration and the Need for an Offsetting Payoff

Each paragraphs of this section has emphasized the need for careful consideration of the anticipated advantages to be gained through integration in relation to the costs and challenges associated with accomplishing that objective. As one might expect, integrating systems is not inexpensive. For an integration effort to be cost-effective, it must deliver an increase in capability that is less expensive to achieve through integration than through design of new systems or procurement of multiple copies of existing systems. Figure 8-12, for example, shows that it may be less expensive to develop a longer-range missile to meet longer range engagement requirements than it would be to integrate fire control functions across multiple platforms in order to accomplish the same objective. While it is typically argued that creating integration and interoperability among existing systems is more cost-effective than new development, this is not always true, and all alternatives should be investigated before a commitment to FoS integration is made.

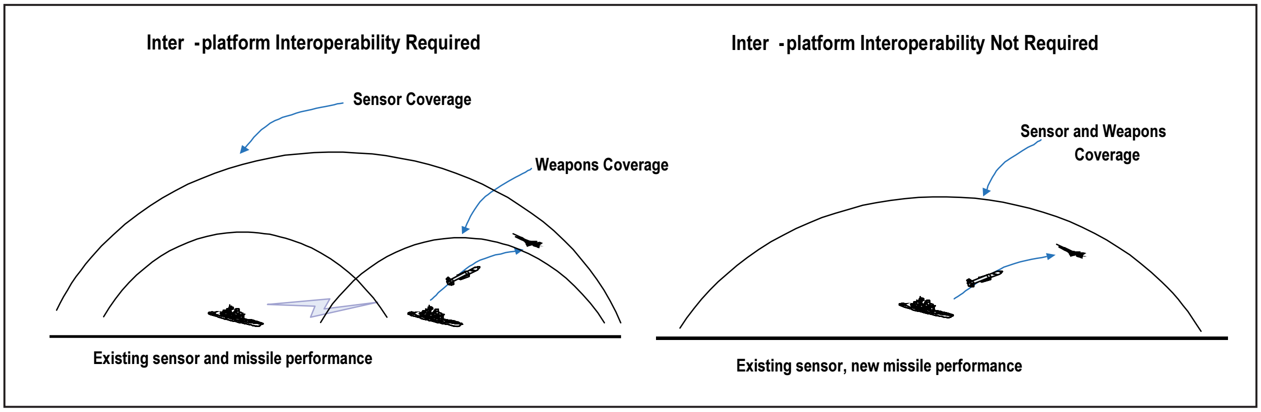


Figure 8-12. Possibility of Substituting New System Design for Interoperability

Costs associated with integration include necessary expenditures in the areas of engineering, test and evaluation, and infrastructure. Engineering costs include research and development, design, fabrication, and installation. Systems integration efforts require changes to system specifications, and these changes must be accomplished using a comprehensive and frequently expensive process that begins with research and development to assess preliminary design alternatives. Once a preliminary design is chosen, further expenditures may be required to fund completion of the necessary drawings or schematics for fabrication of any required parts or modifications. Once the drawings are developed, more costs will be incurred in installing fabricated parts and completing any system modifications. To ensure quality control and configuration management, all of these engineering design steps must be accomplished even for simple modifications, and they are generally both expensive and time-consuming to complete.

While engineering can be expensive, these costs are accompanied by the cost of test and evaluation. After fabrication and installation, the modification must be tested. If the modification is designed to make systems on multiple platforms interoperable, test and evaluation costs may be significantly higher than those that would be incurred in testing capabilities of systems on a single platform simply because more manpower and equipment will be required. For some modifications, test ranges must be scheduled; additionally, if weapons fire is involved, test targets may have to be procured. Obviously, the cost for testing and evaluating modifications can quickly escalate. For example, test and evaluation of baseline upgrades to the Aegis Combat System Computer Program can cost tens of millions of dollars.

Adding to engineering and testing costs are those costs associated with infrastructure to support the integration effort. Examples of infrastructure costs include the expense of increasing bandwidth in an existing communication system and the expenditures necessary to gain more precise or detailed data from existing support systems such as navigation or meteorology. Infrastructure costs are driven by the fact that making systems interoperable involves exponential increases in the number of systems accessing communications and the amount of data being transferred. For example, it is estimated that by 2015, 5,000 U.S. systems will be Link-16 capable. Without a significant infrastructure investment in increasing bandwidth, selection as well as priority criteria may have to be applied to data messages on the link. Further, if large numbers of systems rely on Link-16 to interoperate, it may not be reliable. Another example of the costs associated with providing infrastructure to support interoperability is provided by the Navy's work in developing a CEC. Because the amount of data envisioned to be carried by the CEC was too great for any existing data link, the CEC system was designed with an embedded dedicated data link. The success of the CEC system has outpaced the ability of the dedicated link to transfer data, and the CEC program is now planning a Block 2 variant that will allow more users on the network in the available bandwidth. Other infrastructure costs, including costs for improving the capabilities of support systems, are sometimes overlooked in tallying the costs associated with providing interoperability. Navigation systems provide a good example. It has become apparent that the accuracy of platform system navigation has a profound effect on the accurate fusing of track data from sensors on multiple platforms. In fact, the level of navigation accuracy has sometimes been identified as the limiting factor in developing a fused track picture. Upgrading navigation systems could therefore be viewed as a hidden cost of providing interoperability.

The bottom line, then, is the bottom line. It is critical to assess all the costs associated with an integration effort to determine return on investment prior to committing to the effort.

How Can Architectures be Applied to Systems Development?

The previous sections of this chapter addressed the history, advantages, and limitations associated with using architectures to support acquisition decision-making. This section introduces a more basic application of architectures: documentation of a blueprint for FoS development. Just as a building architect develops blueprints so that individual contractors can determine the scope and requirements of their jobs, the systems architect develops blueprints in accordance with the DOD Architecture Framework so that individual program managers can determine the scope and requirements of their systems. These blueprints – referred to within this book as architecture views – serve to bring all stakeholders a common vision of the solution. They provide a framework for conducting inter-program system engineering discussions and tradeoff analyses, and perhaps most importantly, they deliver a framework for arbitration of issues between various program managers developing or maintaining the FoS. They can and should be a critical tool in creating a new process for conducting systems development and acquisition that focuses on delivering the interoperability needed to support concepts like Network Centric Warfare.

The Challenge of Gaining Common Understanding of Requirements

The DoD series 5000 instructions state that for each milestone review on their respective programs, program managers must develop architectures that meet the Architecture Framework Standard. The architecture that a single program manager develops and submits to the Defense Acquisition Board should not be an independently developed entity; rather, it should be consistent with architectures developed and submitted for other systems within the FoS. At the time of this writing, however, the consistency necessary in architectures for systems within the FoS has not been achieved. Typically, program managers are independently developing architectures to satisfy the DoD requirement. This independent development yields architectures that cannot provide a common understanding of requirements, including inter-program interoperability. Figure 8-13 demonstrates how a documented and consistent architecture can address these problems.

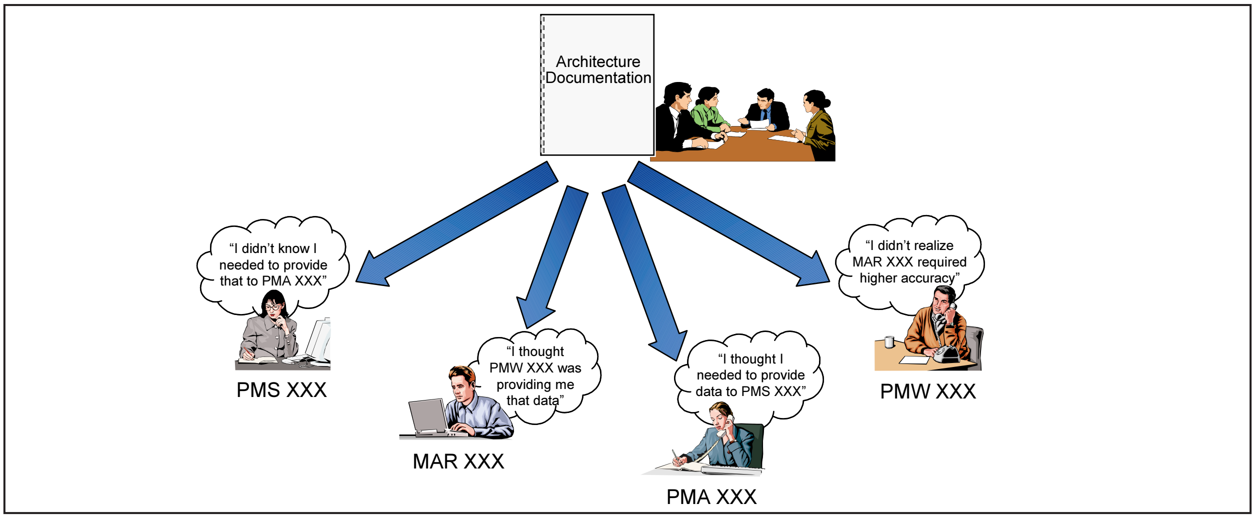


Figure 8-13. Facilitation of Inter-program Communications by a Documented Architecture

The FoS Architecture: A Blueprint for FoS Development

As discussed in previous chapters, the architecture embodies a program's operational concept through the operational views and its functional and physical concepts through the system and technical views. When combined with Capstone and FoS requirements, the architecture will provide all program managers with the necessary information to begin systems development. The relationships of these documents are illustrated in Figure 8-14 and explained below using a hypothetical example of an FoS being developed for ballistic missile defense.

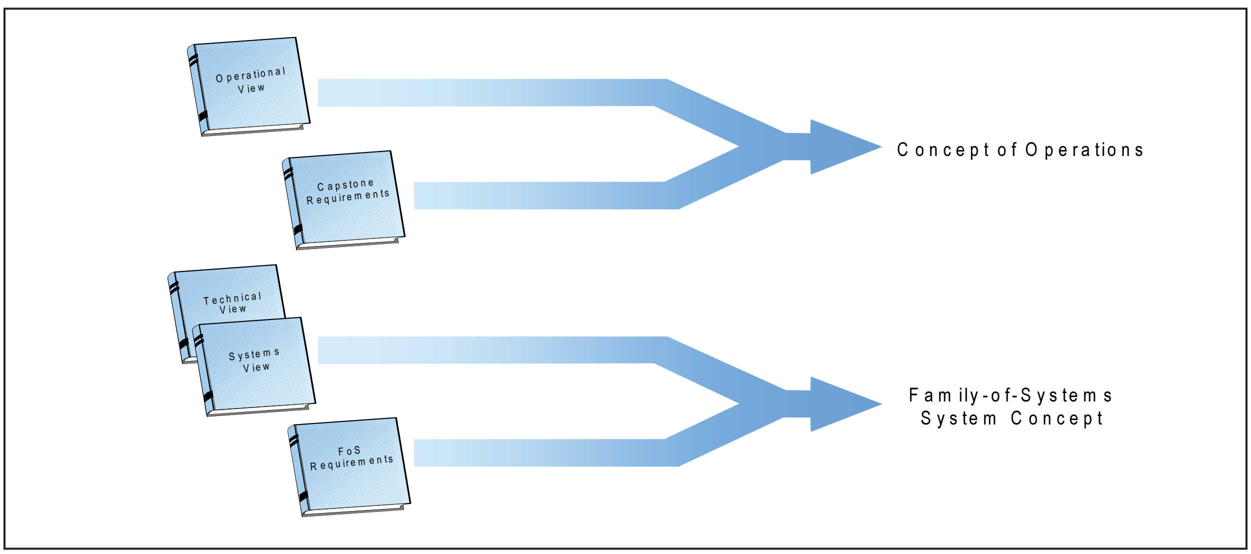


Figure 8-14. Relationship of Architecture and Requirements Documents

Operational views provide the overall concept of operations. For this example, operational views will provide answers to the following questions:

- What platforms will be used?
- What are the expected threats?
- What are the required engagement zones?
- How will different platforms interact to perform the mission?
- What activities must occur to perform the mission?
- How will command be structured?

For the hypothetical Ballistic Missile Defense System (BMDS), the operational concept may be ship-based; must defeat certain types of Theater Ballistic Missiles (TBMs) within a defined number of kilometers inland; and must make space-based cueing available (though it will not always be available). Additionally, under the defined operational concept, authorization for engagement may be delegated to each ship or centralized.

The Capstone Requirements Document formalizes many of the concepts and performance figures identified in the operational views and provides key performance metrics for use in evaluating the FoS. For the BMDS, requirements might be placed on defended area, raid size, threat capabilities, reliability, and training. The operational views and the Capstone Requirements Document can be combined and collectively reviewed since they contain much of the same data. The U.S. Space Command (USSPACECOM) did this effectively in developing the NORAD/USSPACECOM Warfighting Support Systems procurement.

System Views allow activities defined in the operational views to be traced to specific functions, systems, and platforms. They also identify the required data that must be transferred among systems to perform the mission. For the BMDS example, a detect activity may be mapped to the AN/SPY-1 Radar; an engage activity may be mapped to the Aegis Command and Decision System and the Aegis Weapon Control System; and an intercept activity may be mapped to the Standard Missile. Interface diagrams between these systems illustrate required connectivity, data content, data accuracy, and timeliness. Again referring to the BMDS example, missile target acquisition data may be identified as coming from the AN/SPY-1 Radar to the Standard Missile via either 3-, 6-, or 9-state track updates and adhering to a minimum accuracy requirement during an interval defined before intercept.

Technical Views provide the protocols to be used to support data transfer. In the BMDS example, if Link-16 were used to pass track data among ships, the format of the message structure would be provided in the technical views. Alternatively, if the Internet were used to pass information, file transfer protocols and security encryption would be defined.

The System Requirements Document allocates the FoS performance requirements identified in the Capstone Requirements Document to the systems defined in the system views. For the hypothetical BMDS, the system views mapped detection activity to the AN/SPY-1 Radar and intercept activity to the Standard Missile and defined the necessary data that must flow between them to meet operational concept requirements. The System Requirements Document places performance figures and metrics on these systems that will enable achievement of the Capstone Requirements. For the BMDS, defended area requirements may be mapped into detection range requirements for the AN/SPY-1 Radar and fly-out time requirements for the Standard Missile.

There is no reason that the data in the Systems Requirement Document could not be made part of the system architecture, but adding this data to the systems views is not required by the architecture framework.

Applying the Blueprint

Once the blueprint for an FoS is developed, it must be applied to each system within the FoS in order to achieve the architectural consistency that is necessary for interoperability. The Architecture Framework products, which include all the data and requirements for the overarching FoS, would be given to each program responsible for developing a system within the FoS. At that point, each program would develop additional requirements documents or system specification documents that are traceable back to the FoS architecture, Capstone requirements, and FoS requirements. In this manner, systems development would be conducted with a common set of requirements for the entire FoS. Additionally, if for any reason these common requirements could not be met by a specific program, the architecture would provide the framework for adjudicating and resolving conflicts early in the design process.

It is very likely that inter-systems engineering tradeoffs will become a staple made possible by the architecture. Using the BMDS example, assume the interceptor could not achieve the required average velocity. An inter-system engineering tradeoff could be made to require an earlier launch in order to maintain the operational concept. Accepting this tradeoff would require either earlier detection or faster development of a fire control solution due to the reduced time available. These alternatives, along with the alternative of re-engineering the interceptor, must be evaluated from both technical and financial perspectives by the board responsible for maintaining the integrity of the architecture. Once a solution is determined, the architecture would be adjusted and re-issued to the programs. By addressing challenges from an inter-systems engineering perspective, individual programs can avoid trying to fix insurmountable problems independently when a technically feasible, less costly option may be available through an inter-system engineering approach.

Using the architecture as a blueprint for FoS development provide numerous advantages from an interoperability perspective. First, the architecture lets each program know what data it must provide and what data it can expect. Second, if the data will not be available or additional funding is required to develop the interface, the architecture provides a structure for raising and resolving these issues. Finally, if a program manager determines that a requirement cannot be met for any reason, the architecture provides a framework for adjudicating and resolving this conflict. This process is illustrated in Figure 8-15. The smooth process depicted in this illustration brings us back to the DoD 5000 requirement for each program to provide an architecture at its milestone reviews. The development and promulgation of FoS architectures does ease the burden presented by requiring individual programs to develop this data independently, and it offers the opportunity for architectures to be used up front to build interoperability into FoSs. Still, the architecture and any associated problems need to be defined earlier than an initial milestone review, and regular reviews of the architecture need to occur more frequently than milestone reviews. Unfortunately, this need has not been addressed in the DoD acquisition instructions.

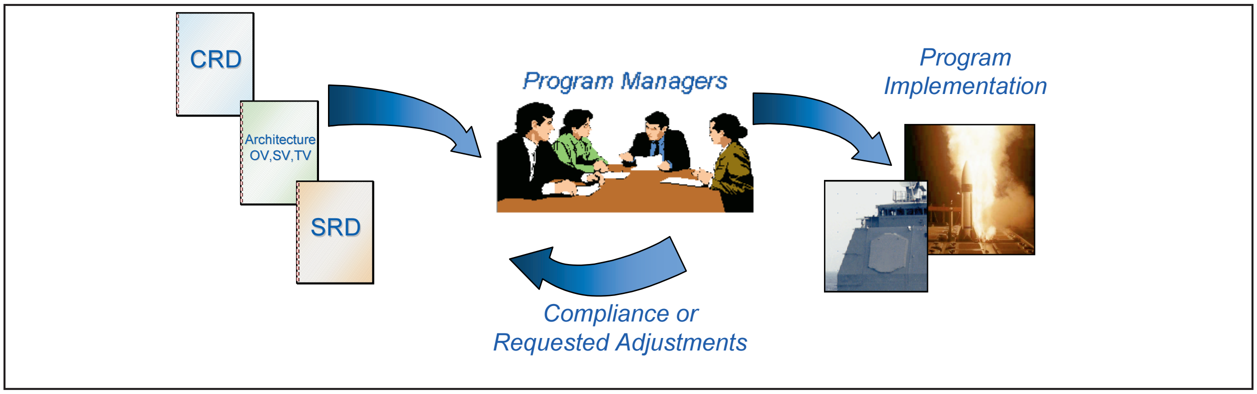


Figure 8-15. Using the Architecture to Augment Requirements in FoS Development

Summary

Although the DoD Architecture Framework products were not originally designed to analyze FoSs derived from programs of record to develop acquisition strategies, they can be and have been adapted to support this function. In fact, these modified architecture framework products have been used successfully to support various DoD projects, as described in the case studies in Part II of this book. Continuing to build and use this new process will require guidance and buy-in from senior leadership and throughout the acquisition, engineering, and operational ranks. The initial time and cost required to continue development of the framework for architectural assessments will not be insignificant. Once the baseline architecture is established, however, it will only require periodic updates and modifications as requirements change. Further, the alternative – continuous investment in system duplications and the failure to fill gaps in mission capability – is simply unacceptable. Even so, it must be remembered that designing and developing interoperable systems is not inexpensive, nor is it always the smartest path to take. Interoperable systems do not necessarily provide better performance; further, performance enhancements can only be realized if the systems within the FoS have an inherent capability to perform mission requirements. A clearly defined payoff should be established before deciding to integrate systems that initially appear to be suitable candidates for inclusion in an FoS. Finally, it is clear that the architecture, Capstone Requirements, and FoS requirements provide all that is necessary to begin documentation of a blueprint for FoS development. After the architecture and requirements are distributed, each program should understand its expected functional, performance, and interoperability requirements. The use of architectures as blueprints for developing FoSs enables programs to avoid at least some of the hidden costs and technical roadblocks associated with FoS development. This process provides one method for addressing the expanding interoperability problems that are affecting the military services.

CHAPTER 9[†]
ARCHITECTURE DATA MANAGEMENT

Purpose

Chapter 2 introduced the Architecture Framework products, and Chapters 3 through 7 provided case studies illustrating how they can be used to support the architecture assessments necessary to define MCPs. The analyses described in the case study chapters depend upon significant amounts of architecture data. This chapter addresses the methods for capturing the data products for systems engineering and acquisition planning, and it describes how MCP data can be managed and synchronized. The chapter also describes some of the tools for quantitative analyses that can be done with architecture data. The chapter concludes with an example of CED data management.

Data Integrity

In order for MCP analysis results to be accurate, the data used to conduct the analysis must have integrity. Data integrity will be most affected by the following two principal factors:

- Accuracy of architecture data
- Consistency among architecture data values and with data values within and beyond a single service (e.g., the Department of the Navy)

This chapter discusses the second of these two aspects of data integrity. The concept of consistency in data values may at first appear very simple, but it becomes challenging in large-scale assessments like MCP analyses because they involve so much complex and highly interrelated data. Without rigorous data management processes, maintaining data value consistency can quickly become unmanageable. Table 9-1 illustrates this effect, showing that even for what most would consider small architectures, large numbers of architecture artifacts result. Without effective data management, the large number of architecture artifacts can lead to consistency problems, and these problems can have significant consequences. Accordingly, any architecture project that plans on using quantitative analyses of the type necessary for MCP assessments must allocate some rigor to the management of collected and developed data.

Quantitative Analysis with Architecture Data

Usually, it is not obvious that a proposed or planned architecture is the best solution for an enterprise. A variety of factors affect an architecture choice or plan. Table 9-2 presents examples of varied enterprise requirements and issues along with potential enterprise measures of merit.

[†]This work is the collaboration of Brian Wilczynski, the DON CIO Enterprise Architect, and Dr. Harrold Crisp, RDA CHENG Director of the Naval Collaborative Engineering Environment.

Table 9-1
Expected Numbers of Artifacts Based on Number of Taxonomic Objects Addressed

Taxonomy Class/Architecture Size	Small	Mid	Large
Operational Nodes	10	100	500
Operational Activities	50	500	2,500
Information Elements	100	1,000	2,500
Events & Triggers	5	50	200
System Functions	25	250	1,000
Systems	10	100	500
Physical Nodes	5	50	250
Performance Characteristics	25	250	750
Technical Standards	25	25	500
Technologies	5	25	150
Approximate Number of Architecture Artifacts	6,000	60,000	250,000

Table 9-2
Enterprise Requirements and Issues along with Potential Enterprise Measure of Merit

Enterprise Requirement/Issue	Associated Measures of Merit	
Info Requirements Satisfaction	• Automated info refinement	• Info delivery/availability
Interoperability - Communications	• Layer 0 – Phys. media compatibility • Layer 1 – Phys. layer compatibility • Layer 2 – Datalink layer compatibility • Layer 3 – Network layer compatibility	• Layer 4 – Trans. layer compatibility • Layer 5 – Session layer compatibility • Layer 6 – Present. layer compatibility • Layer 7 – App. layer compatibility
Interoperability - Data	• Access • Interpretation	• Assimilation and synchronization
Interoperability – Functional	• C4ISR and weapons systems • Enterprise services • Enterprise applications services	• Common support services • Business operations
Security – Communications/ Network	• Access control • Availability • Confidentiality • Dissemination control • Criticality • Integrity	• Non-repudiation producer • Non-repudiation consumer • Protection (type, name, duration, date) • Classification • Classification caveat • Releasability
Manning Impact	• Business process streamlining	• Automation reduction assessment
Logistics Impact	• Maintenance and sparing	
Capacity Planning	• Communications • For a particular ship, exercise, weapon system, FY, location • Commercial SATCOM leasing rqmts. • End-user equipment/Apps/SW	• Growth capacity • Pierside • Commercial trade-off with mil SATCOM • Tech refresh planning
Budget and Cost Analysis	• Cost of an alternative for any time period • Budget/cost by system, platform, etc. • Budget/cost by WBS • Accumulated cost per acquiring org	• Capabilities and requirements impact analysis • WBS analysis • Out-year budget • Budget controls • Variance analysis

Figure 9-1 presents some general relations between tools and architecture data products. As the engineer or analyst moves between the different levels of analysis, consistency between data products must be achieved in order to apply various Modeling and Simulation (M&S) programs. The DoD has invested significant resources in a variety of M&S programs. The data meta model to support M&S programs is the C4ISR Core Architecture Data Model (CADM). It was originally developed not only to model the data of Architecture Framework data products but also to model data for M&S programs designed to perform architectural and interoperability analyses. The advantage of using CADM structures for developing and maintaining measures data is that M&S, analysis, and assessment tools developed or modified to compute the measures based on CADM data are standardized. This means that multiple M&S, analysis, and assessment tools can use the same data sets (providing significant data reuse) and that, over time, a set of M&S, analysis, and assessment tools can evolve to provide a fuller set of measures needed for decision support.

To illustrate this point, consider the example of Network Warfare Simulation (NETWARS), shown in Figure 9-1. NETWARS is a Government Off-The-Shelf/Commercial Off-The-Shelf (GOTS/COTS) tool that models communications throughput using CADM-based architecture data. NETWARS uses IER attributes to assess a variety of parameters (e.g., information element size, frequency, timeliness, security, required format) along with operational node to physical node mappings to estimate bandwidth requirements at physical nodes, predict throughput bottlenecks, and address other communications measures.

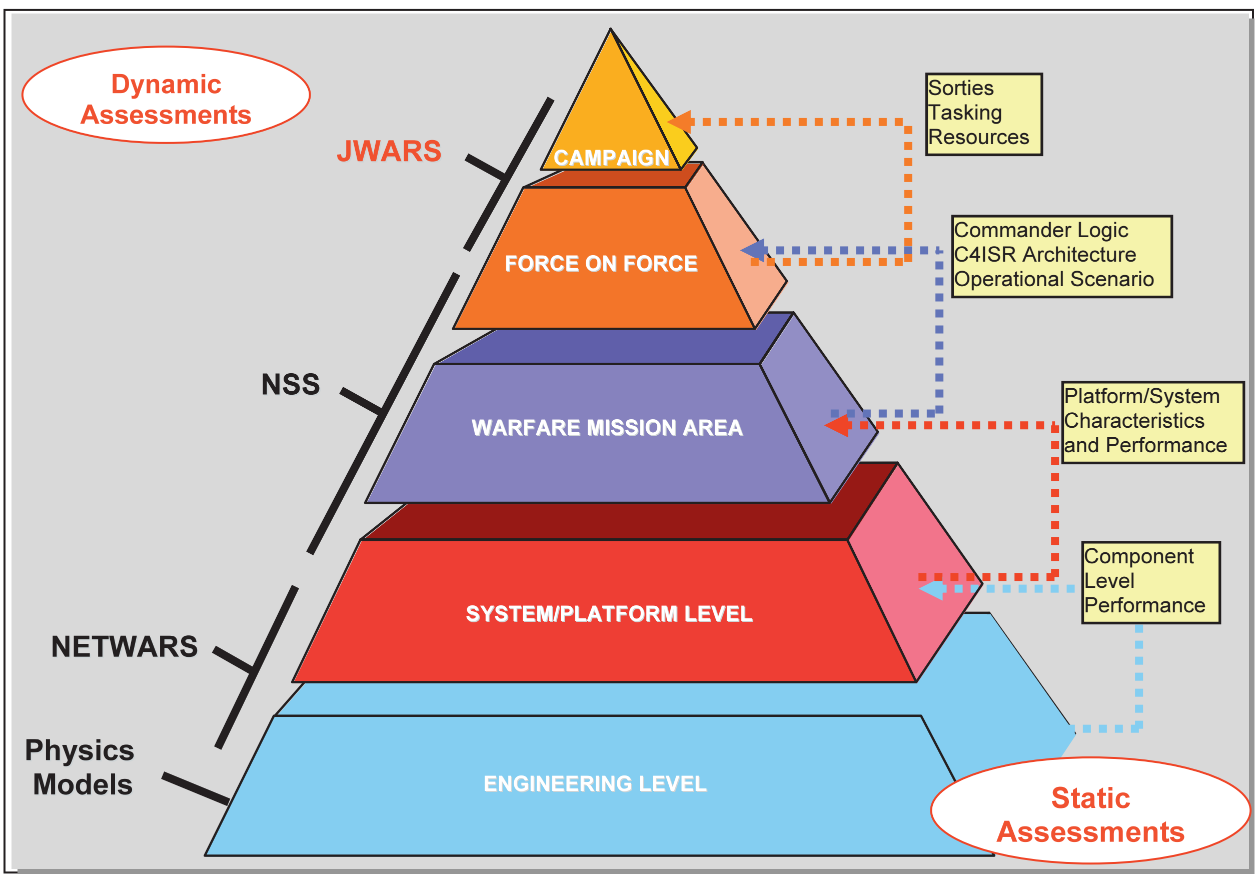


Figure 9-1. Models Pyramid

IER attributes at the operational, functional, and system levels, across time periods, or within "as-is" and "to-be" models are not the only CADM data elements that can be used to compute measures. Task and process-activity man-levels, network architectures, scenario information, performance data, and technical standards like communication protocols can all be input for M&S and analysis tools for measures computation.

Example of Metrics-Based Architectural Analysis

A study by the OSD C3I Decision Support Center (DSC)[27] illustrates both a performance and effectiveness analysis of alternative architectures using architecture data, two levels of metrics, and M&S. In this study, an information requirements model was developed to answer the question, "What are the information needs of soldiers that might be improved by alternative fusion architectures?" or, put another way, "What's a pound of fusion worth?" Thousands of authoritative information requirements were analyzed and categorized based on required information type and quality. Table 9-3 provides a high-level categorization of the object types that pertained to these information requirements. Table 9-4 lists the information groups into which all information requirements could be categorized.

Table 9-3
Multi-INT Fusion Study Object Types

Category	Types of Objects
Platforms and facilities	Ships, aircraft, missiles, vehicles, Special Operations Forces (SOF) units, Strategic Air Missile (SAM) sites, etc. from Company level up to Corps level
Infrastructure	Communications networks, electrical networks/grids, transportation networks, etc.
Politically-related items	National organization, intent, internal conflicts, economic triggers and indicators, etc.

Table 9-4
Multi-INT Fusion Study Information Categories

Category	Types of Information Requirements
Kinematics	Location, velocity, and trajectory (past and predicted), from detection to accuracy sufficient for Precision Guided Munitions (PGMs)
Identification	Broad type to specific unit and with varying certainty
Activity	General to specific plan and with varying certainty
Status	General to specific and with varying certainty
Intent	General to specific and with varying certainty

The information categories and qualities and the object types to which they pertained were used to construct a "knowledge matrix." MOPs were defined, along with a method to compute them, to measure how much more alternative fusion architectures, primarily oriented to Imagery Intelligence (IMINT) and Signals Intelligence (SIGINT) national and tactical sensors, would affect satisfaction of information requirements for different missions. A COTS M&S tool was used to compute the knowledge matrix satisfaction depending upon the fusion algorithm features enabled in the alternative architectures. The M&S tool also provided the fusion results to a GOTS campaign-level M&S tool that operated a full operational scenario and computed mission outcomes so that both measures of requirements satisfaction as well as mission outcome could be presented in the analysis output. This study was briefed throughout the DoD and Intelligence communities and was well received.

Architecture Data Management Principles

To ensure architecture data management in terms of synchronization and consistency, the architecture must incorporate, at a minimum, the principles embodied in the following five data and architecture guidelines:

- Data Development Plan
- Common Architecture Framework
- Common Data Structure
- Common Data Semantics
- Data Synchronization

The principles behind each of these guidelines are described in the following subparagraphs.

Data Development Plan: Architecture Data Collection/Development for Quantitative Analysis

While the Architecture Framework provides a structure for architecture data collection, it is insufficient to develop and collect architecture data without detailed forethought of the quantitative analyses planned for that data. For this reason, the selection of the data and products to be developed must be based on the planned analysis rather than on non-analytical criteria. An analytical approach to architecture data development is illustrated in Figure 9-2.

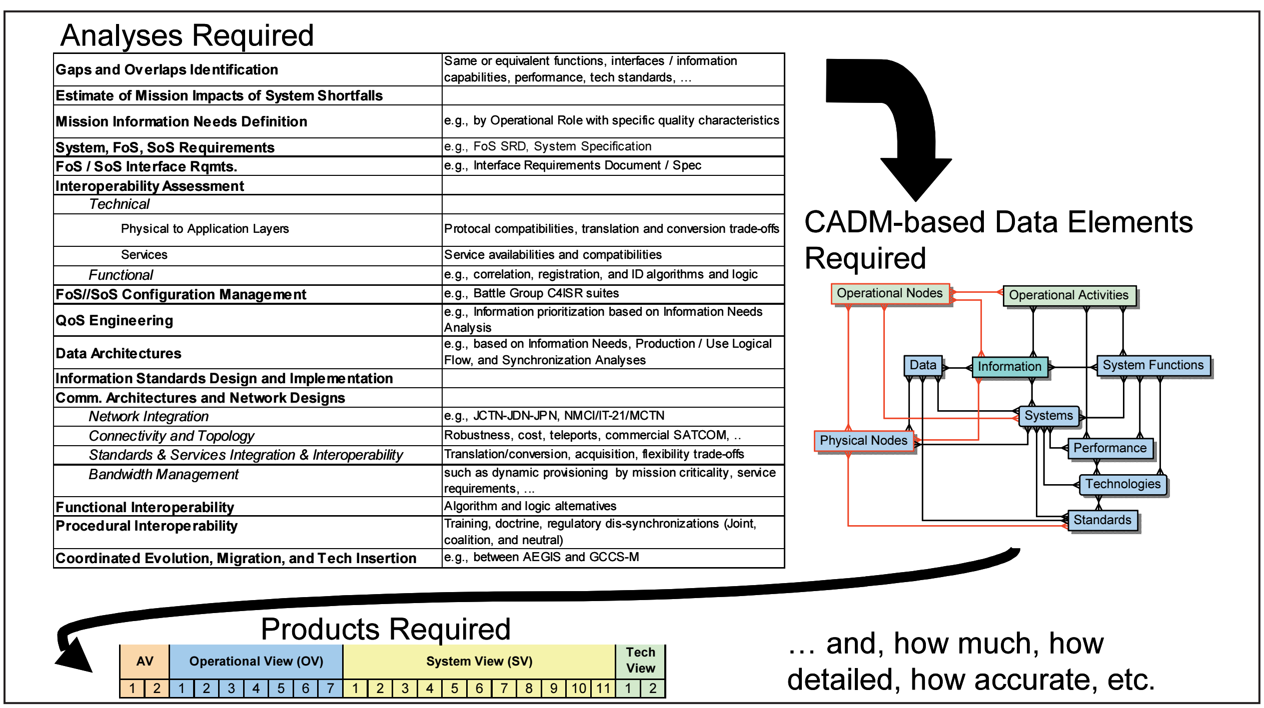


Figure 9-2. Analytical Selection of Architecture Data to Develop and Collect

Common Architecture Framework

In the DoD, the Architecture Framework Document provides a common architecture framework that defines the products, their information, and their associated CADM data elements, as shown in Figure 9-3. The MCP process can be based on the DoD Architecture Framework and uses its constructs to conduct the analyses described in the previous chapters of this book.

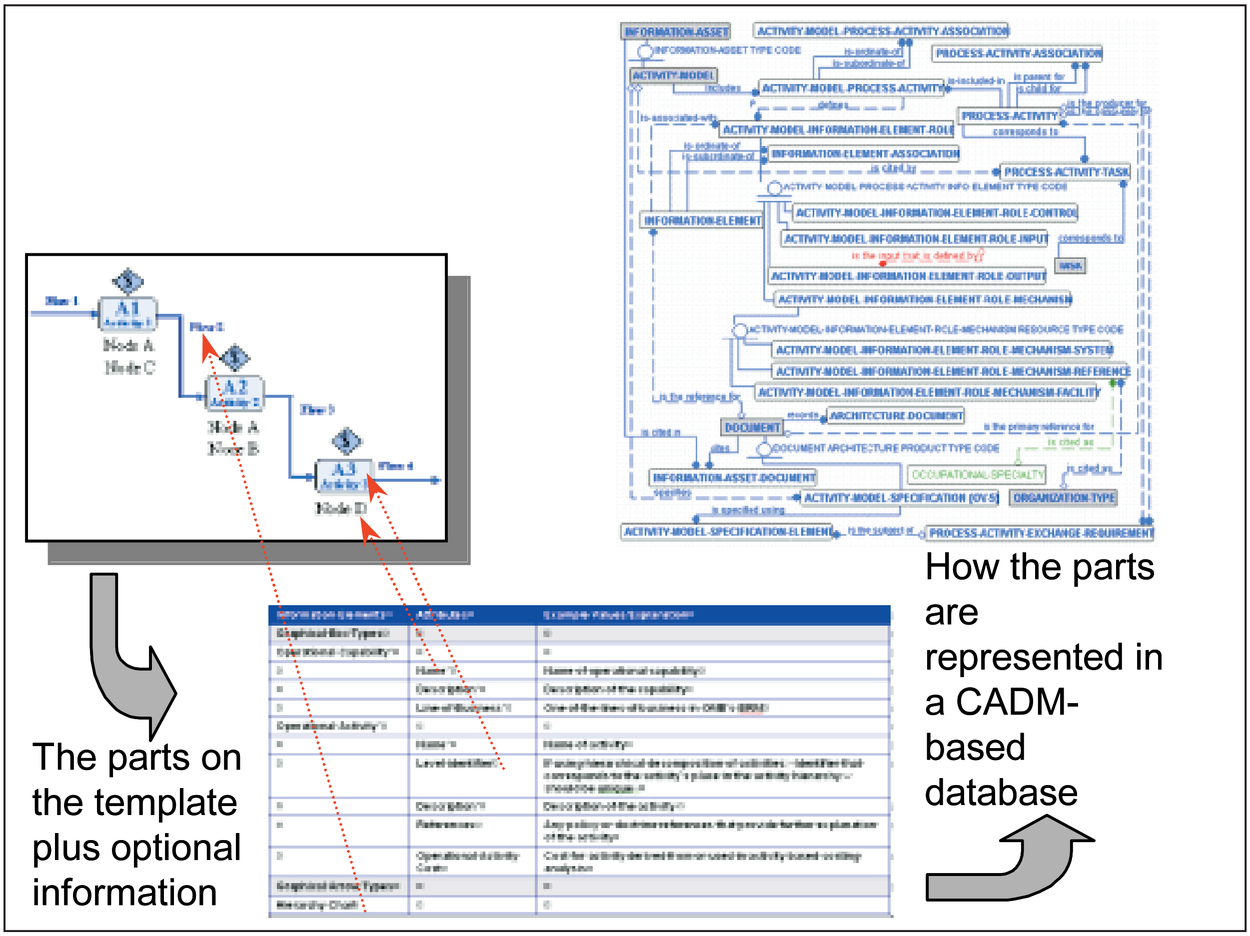


Figure 9-3. Moving from Templates to Components to Database Elements in the Architecture Framework Document

Common Data Structure

As previously discussed, CADM is the common data structure for architecture data. With the CADM, it is possible to represent which operational activities are performed by which operational nodes; what information is required (used by) which operational nodes; how information is related to data; what system functions are performed by what systems; the current and required performance characteristics of systems; and thousands of other types of architecture information. A very high-level CADM overview graphic is shown in Figure 9-4. The Department of the Navy (DON) Integrated Architecture Database (DIAD) is an accurate and complete implementation of CADM.

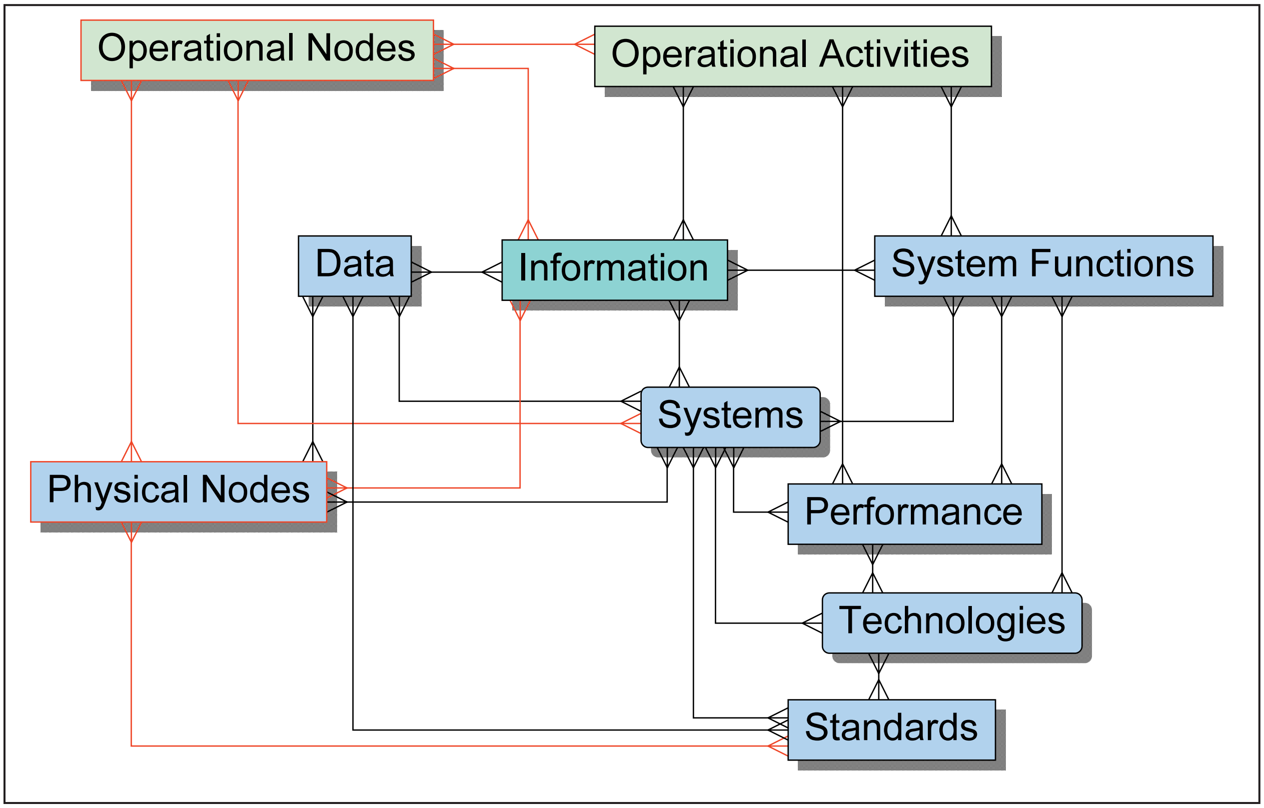


Figure 9-4. High-Level CADM Overview

Common Data Semantics

While a common framework and common data structure are important for data consistency, creating commonality in these two elements alone will not be sufficient for the development of consistent and synchronizable architecture data. The common structure only guarantees common object classes, but quantitative analyses of the types described in this book require common objects. Common objects are necessary to allow analytical threads to extend across the architecture data space continuously. Discontinuities in the threads (e.g., data gaps and inconsistencies) can seriously degrade the analysis results and in many cases preclude any sort of analysis. They can create false assessments of interoperability, cause overestimation of capacity requirements, and mask redundancies. Taxonomies are one method for addressing problems created by data semantics. Taxonomies can be used to support MCP analyses, but they must possess quality features like those identified in Table 9-5.

The DON has been developing taxonomies to support MCP analyses as well as other DON processes for many years. For example, the system function and information element taxonomies can be traced to the CNO Functional Allocation study conducted in 1978. The taxonomies generated by DON are developed and managed DON-wide using the DIAD. Through the years, many lessons have been learned about taxonomy development, and consensus was reached regarding relationships between node definitions and categorizations. These definitions and categorizations are summarized in Table 9-6 along with their corresponding DIAD solutions.

Table 9-5
Quality Features Necessary for Taxonomies Used to Support MCP Analyses

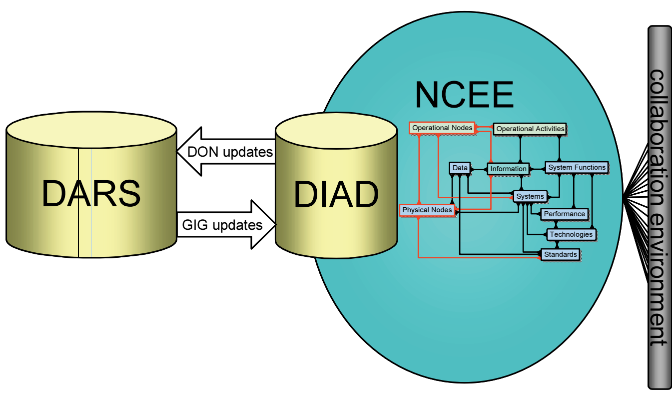
Quality Feature	Sub-Feature	Definition
Completeness	Scope	Addresses whether the taxonomy, in node definitions and structure, covers the taxonomic area of concern for the enterprise
	Detail	Addresses whether the structure is sufficient for the enterprise;
Necessity	-	Somewhat the opposite of completeness in that it addresses whether or not the taxonomy at hand has sufficient significance of structural breadth or depth to warrant enterprise-level visibility and management
Structural Integrity	Membership	Addresses the logical equivalence of the subordinate nodes to a node's description, verifying that the sum of the descendants does not exceed the description of the node and, conversely, does not leave gaps in meeting the description of the node; this feature is essential for logical implications between levels
	Balance	Addresses the leveling of the nodes, so that nodes at the same level in the taxonomy are of equal significance or size
Non-redundancy	-	Addresses requirement that a taxonomy support membership in one and only one node (i.e., creates no ambiguity); without this feature, like objects with different names may exist undetected, thereby sub-optimizing analyses, decisions, and designs
Extensibility and Generality	-	Address whether the taxonomy has been defined in a manner abstract or general enough to enable detailing or elaboration by lower echelon agencies and departments in the enterprise
Well-Definedness	Node Names	Must be reasonably unambiguous and intuitively understandable terms
	Node Definitions	Must be non-self-referential and should provide intuitive understanding of the node meaning

Table 9-6
Required Taxonomy Tool Features and DIAD Solutions

Required Feature	DIAD Solution
Ability to "see" the taxonomy	Use tree, hierarchy
Ability to navigate the taxonomy	Use collapsible and expandable branches
Reconcilability	Merge
Restructurability	Move branches, create trial branch moves
Relatability to local taxonomies or multiple authoritative sources	Use many-to-many mapping
Ability to match up like concepts	Find by various criteria

Data Synchronization

MCP architecture data can be developed using a variety of tools. The Navy Collaborative Engineering Environment (NCEE), developed within the ASN(RDA) CHENG Office, provides the capability to consolidate an MCP data set within its object-oriented data repository. The NCEE objective is to facilitate the transition of architecture data into engineering analysis and M&S tools so that architecture verification and assessment can be tightly coupled with other engineering assessment activities. Ultimately, this MCP architecture data set would reside in the CADM database. As the official implementation of the CADM database, DIAD and DoD Architecture Repository (DARS), the DoD-level, CADM-compliant architecture database, will work in conjunction with the NCEE to synchronize architecture data generated by various architecture tools. This process is illustrated in the overview provided in Figure 9-5. This configuration will address architecture data synchronization on three levels: within an architecture project; across the enterprise's other core process; and to architectures external to the enterprise.



Architecture Product		RR	CORE	DIAD Tools	SA	MS Office
All Views						
AV-1	Objectives, intended usage, and problems addressed; data rqmts, collection plan; analysis plan, measures, and results delivery plan					●
AV-2	Taxonomies *(Op Nodes, Op Acts, IEs, Sys Funcs, Sys, Phys Nodes, Perf Atts, Stds, Tech, Events/Triggers)*			●	⊙	
Operational Views						
OV-1	Overview Concept Graphic					●
OV-2	Op Node Interaction Requirements			⦿	◉	
OV-3	Op Node and Op Activity Information Interaction Requirements			●	◉	
OV-4	Organizational Authorities and Chains of Command				◉	
OV-5	Activity Model	●	●	⦿	◉	
OV-6	Business Rules Model and Activity and Op Node Sequence and State Transition Models	◯	●	◉	◉	
OV-7	Information Requirements Model	⊙	⊙	⊙	⦿	
System Views						
SV-1	Physical Nodes, FoS / SoS / System / Subsystem / Equipment / Applications Interfaces	⊙	⊙	◯	○	
SV-2	Physical Nodes, FoS / SoS / System / Subsystem / Equipment / Applications Communications Links and Protocols	○	○	◯	○	
SV-3	Physical Nodes, FoS / SoS / System / Subsystem / Equipment / Applications Communications Interface Matrix			●	◉	
SV-4	Functional Design and Allocation	◉	◉	◉	◉	
SV-5	Op Activity Automation Support			●	⊙	
SV-6	System Interface Descriptions			●	◉	
SV-7	System Performance Characterisitics			⦿	○	
SV-8	Physical Nodes, FoS / SoS / System / Subsystem / Equipment / Applications Evolution Plan			⦿	○	
SV-9	Technology Insertion Plan				○	
SV-10	State Transition Diagrams	◯	◯	⊙	◉	
SV-11	Information and Data Models	⦿	⦿	⊙	⦿	
Technical Views						
TV-1	Processing, Communications, Data, IA, and HCI Standards			◯	○	
TV-2	Future standards			⊙	○	

Figure 9-5. Overview of DARS/DIAD-to-NCEE Synchronization

Within an architecture project, the NCEE provides the collaboration capabilities to synchronize the efforts of MCP architects working in different locations with different, non-fully-CADM-compliant architecture tools. NCEE includes an infrastructure environment that facilitates the sharing and manipulation of data from numerous tools and data repositories. To support the data exchange and data synchronization among various tools, NCEE provides two essential features:

- Tool plug-in: this feature in the NCEE provides the capability to import and export data from an individual tool or database into Interchange, the NCEE's common data repository. Currently, Interchange has several plug-ins to engineering, architecture, and M&S tools including DOORS, CORE, Excel, and ENVISON/ERGO. Interchange's data structure is highly flexible so that it can be extended to accommodate additional tools and to enable the forward migration of existing data. The basic concept for sharing data among architecture tools is to implement a CADM compliance structure within Interchange and allow the tools to exchange data with each other or with the DIAD tool through the import/export mechanism. As data is imported into Interchange, relationships can be established among the data sets to support complex data analyses. Interchange also has the capability to preserve information specific to the individual tool so the tool would be able to reconstruct its complete model with updated information from other tools. Figure 9-6 illustrates the development concept for tool plug-in.
- Database configuration management: in order to track data that are populated by various tools and users from multiple sources, Interchange provides a sophisticated configuration management capability. This capability includes object-level versioning in which history objects can be viewed, purged, deleted, or reverted to previous versions; configuration management of the schema, model data, and tool/data source plug-ins; user access control that can be assigned down to the attribute level of an object; and a query builder that allows users to create, execute, and store queries and display query results in graphical format.

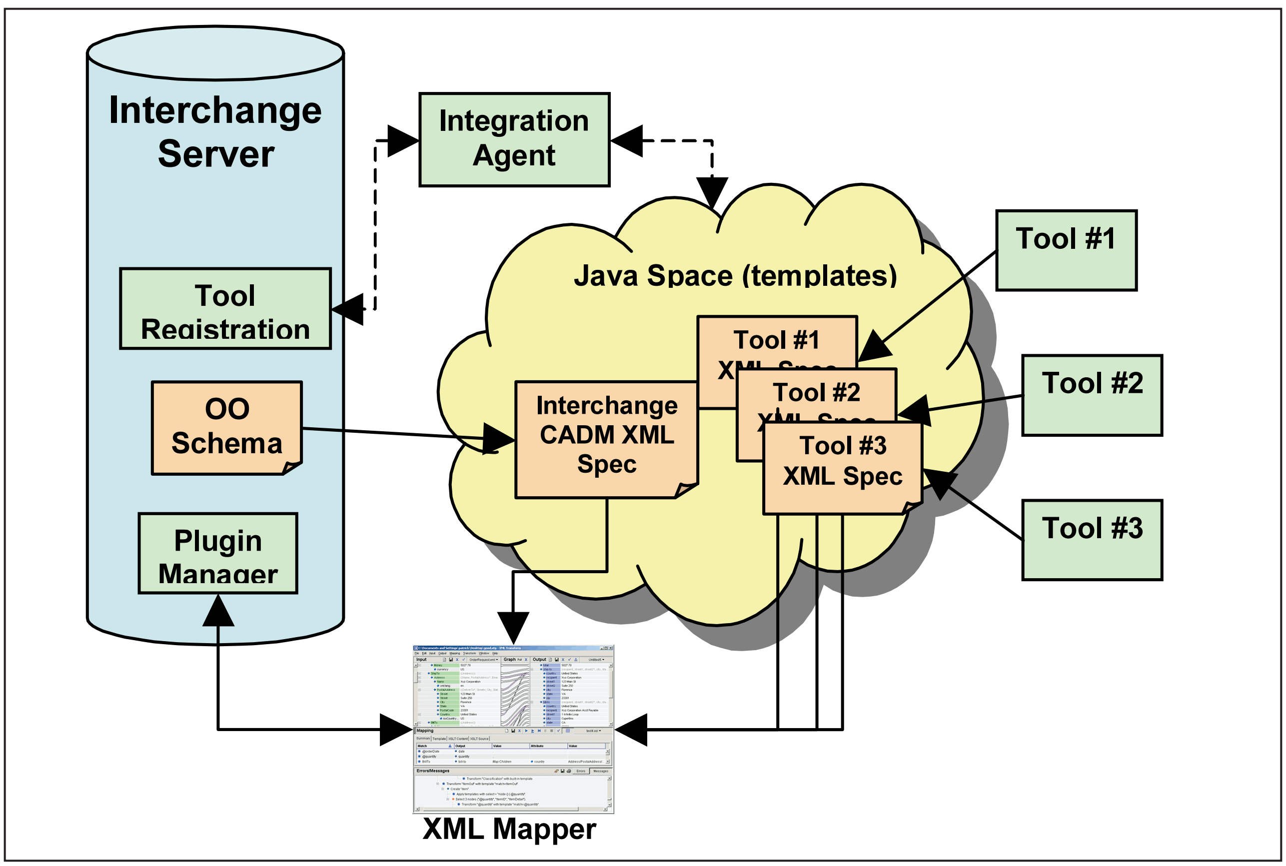


Figure 9-6. Development Concept for Tool Plug-In

Although the NCEE data repository could be extended to support additional complex data synchronization issues, it is logical to continue utilizing the existing DIAD capability and process to support data synchronization across enterprise and external to enterprise. Across core processes, DIAD's standardized CADM data is available for interfacing and replication synchronization. An example exists in the Applications Reduction process being used for the Navy and Marine Corps Intranet (NMCI) project. Although NMCI is not strictly architectural, the DIAD Operational Activity and System Function taxonomies can be used to make synchronization with MCP analyses possible. To support synchronization beyond the DON, the DIAD uses the same data structure as DARS (CADM), which facilitates uploading and downloading from DARS. Through the CADM's key block allocation scheme, key collisions should not occur.

Capability Evolution Description Data Synchronization

The CED is a new set of data that is not currently included in the CADM framework, although efforts to include this data in the CADM are ongoing at the time of the writing of this book. Collecting CED data without an automated capability is a complicated process because there are many architecture data elements involved, and the derived data is based upon dependencies among those data elements. In support of PR-05 MCP data generation, the ASN(RDA) CHENG architecture team strived to compile CED data using a set of templates shown in Figure 9-7 along with additional data existing in the CADM framework. The objective of the template is to enable collection of data that could be used to determine how well a group of systems and platforms (or an FoS) contributes to a set of mission capability objectives within a specific timeframe. If this data is collected for many timeframes, the collected data will indicate how the capabilities of the identified collection of systems evolved over time.

Pillar: SEA STRIKE	FY03 Q1						FY03 Q2						FY14 Q3						FY14 Q4					
MCP: STRIKE		Capability Objective Set						Capability Objective Set						Capability Objective Set						Capability Objective Set				
Mission Component: STRATEGIC STRIKE	System Integration	Lethality	Coverage	Timeliness	Persistence	Surviability	System Integration	Lethality	Coverage	Timeliness	Persistence	Surviability	System Integration	Lethality	Coverage	Timeliness	Persistence	Surviability	System Integration	Lethality	Coverage	Timeliness	Persistence	Surviability
								PA	A	PA	PA	PA												
PLATFORM/SYSTEM NAME																								
CG							OM																	
DDG							OM																	
F/A-18E/F							OM																	
SSN							OM																	
Link-16							OM																	
TTWCS																								
APG-79/AESA																								
JDAM							OM																	
LGB							OM																	
TLAM							OM																	
TTLAM																								
GPS							OM																	
NTM							OM																	
KC-135/KC-10							OM																	

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Pillar: SEA STRIKE	FY03 Q1						FY03 Q2						FY14 Q3						FY14 Q4					
MCP: STRIKE		Capability Objective Set						Capability Objective Set						Capability Objective Set						Capability Objective Set				
Mission Component: AIR INTERDICTION	System Integration	Lethality	Coverage	Timeliness	Persistence	Surviability	System Integration	Lethality	Coverage	Timeliness	Persistence	Surviability	System Integration	Lethality	Coverage	Timeliness	Persistence	Surviability	System Integration	Lethality	Coverage	Timeliness	Persistence	Surviability
								PA	A	PA	PA	PA												
PLATFORM/SYSTEM NAME																								
EA-6B							OM																	
F/A-18E/F							OM																	
Link-16							OM																	
APG-79/AESA																								
JSOW UNITARY																								
HARM BLK 6							OM																	
CONV. BOMBS							OM																	
LGB							OM																	
JDAM							OM																	
GPS							OM																	
KC-135/KC-10							OM																	

• • •

Figure 9-7. CED Template

Mission capability objectives can vary depending upon the mission of interest. If capability objectives are identified in conjunction with the associated metrics related to the collection of data for platforms and systems, then (technically, at least) algorithms can be determined to calculate how well these systems and platforms contribute to capability objectives. In general, however, the associated metrics often depend on analysis and/or M&S results, so it is not feasible at this time to automate the generation of capability objective inputs. Instead, the CED template can be used by the domain expert to provide input of assessment results. For example, in Figure 9-7, the Strategic Strike Mission Component is found under the Strike MCP within the Sea Strike Pillar. Under the "PLATFORM/SYSTEM NAME" column is the list of the systems and platforms that would contribute capabilities to this mission component area. Within each timeframe (measured in quarters within a fiscal year), the domain expert could select from the following assessments of system and platform status:

- O: On-line
- OM: On-line with Minimal Capability
- R: Retired
- EC: Integration Enhances Capability
- DC: Delayed Capability Integration
- MC: Minimal Capability Integration

The domain expert would also select how well (Partially Achieve, Achieve, Not Achieve) the FoSs and platforms contribute to the listed capability objectives (Lethality, Coverage, Timeliness, Persistence, and Survivability).

Figure 9-8 on the following page provides an entity-level CADM subview for CED data. The model shows that mission capability depends upon a variety of factors, including systems, physical nodes, system functions, system migrations/evolutions/P3I, platform migration/evolution/P3I, performance, technology, interfaces, system dependencies, and system status. When these CED data elements are fully identified, the data can be transitioned to project scheduling tools for further GANNT, PERT, and other standard analyses. CED data is also ideal for various multi-attribute analyses. Another prototype capability under consideration is the ability to generate a CED graphical view automatically based on the collected data.

Summary

In order for architecture assessments supporting MCP analyses results to be accurate, the data used to conduct the analysis must have integrity. MCP analysis results will be most affected by two principal data integrity factors: the architecture data values and the consistency among architecture data values and with data values within and beyond a single service (e.g., the DON). To achieve architecture data management in terms of synchronization and consistency, the architecture project team must incorporate, at a minimum, the principles embodied in five data and architecture guidelines: data development plan; common architecture framework; common data structure; common data semantics; and data synchronization. Data synchronization is a key issue since the DoD develops mission architecture data using a variety of tools. The Navy currently plans to use CADM in conjunction with DIAD and NCEE to synchronize architecture data generated by various architecture tools. Efforts to include CED data in the CADM framework are also ongoing at the time of the writing of this book.

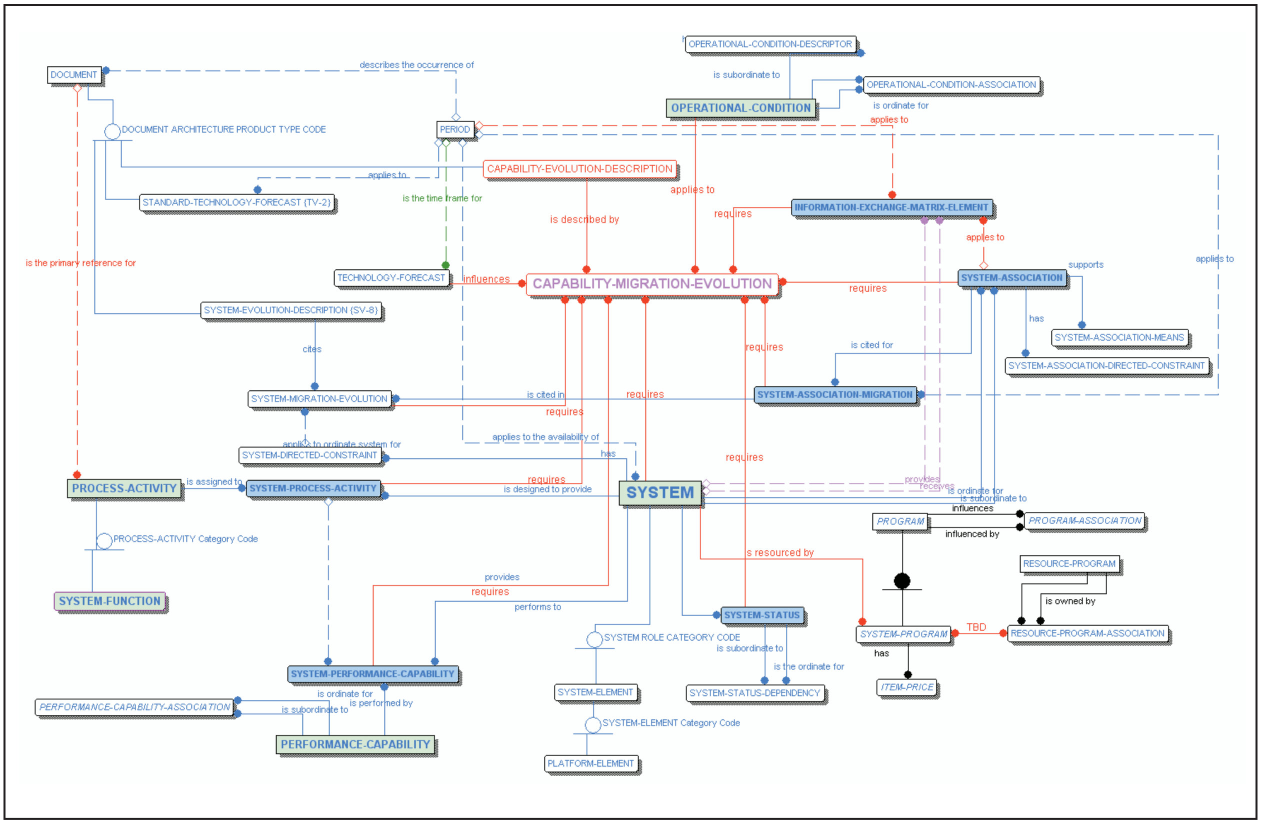

Figure 9-8. Proposed CADM Entity-Level Diagram for CED

ENDNOTES

[1] "Network Centric Warfare," *Department of Defense Report to Congress*, 27 July 2001, i.

[2] Ibid., A-1-A-2.

[3] Ibid., A-4 and A-5.

[4] Ibid., A-12.

[5] Ibid., A-9.

[6] C. Hall, Mitre, Private Communication (e-mail), 29 February 2000, 2-3.

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[8] Ibid., 90-91.

[9] Committee on Network-Centric Naval Forces, Naval Studies Board, *Network-Centric Naval Forces: A Strategy for Enhancing Operational Capabilities,* 2000, 25.

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[11] David S. Alberts, John J. Gartska, and Frederick P. Stein, *Network Centric Warfare: Developing and Leveraging Information Superiority*, (Washington, D.C.: C4ISR Cooperative Research Program, August, 1999), 32-33.

[12] Ibid., page 188.

[13] Institute of Electrical and Electronics Engineers (IEEE), *IEEE Standard 610.12,* adapted by the DoD Architecture Framework, Version 2.0, 18 December 1997.

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[15] Command Joint Chiefs of Staff (CJCS), *CJCS Instruction (CJCSI) 3137.01B*, 15 April 2002.

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[22] Ibid., p. 3.

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[27] Keithley, H., *Multi-INT Fusion Performance,* Joint C4ISR Decision Support Center, OASD(C3I), Washington, D.C., 2001 (http://www.dsc.osd.mil/DSC.cgi?c=/studies/index00-2.htm;http://www.dsc.osd.mil/Studies/downloads/(U)_DSC00-2_readme.PDF; http://www.dsc.osd.mil/Studies/downloads/(U)_DSC00-2_Exec_Sum.PDF).

LIST OF ACRONYMS

ACTD	Advanced Concept Technology Demonstration
AFATDS	Army Field Artillery Tactical Data System
ALAM	Advanced Land Attack Missile
AO	Area of Operations
ASAS	All Source Analysis System
ASD	Assistant Secretary of Defense
ASN	Assistant Secretary for the Navy
ASW	Anti-Submarine Warfare
AT&L	Acquisition, Technology, and Logistics
ATACMS	Advanced Tactical Missile System
ATO	Air Tasking Order
BFA	Battle Functional Area
BMDS	Ballistic Missile Defense System
C2	Command and Control
C4I	Command, Control, Communications, Computers, and Intelligence
C4ISP	Command, Control, Communications, Computers, and Intelligence Support Plan
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CADM	Core Architecture Data Model
CDL	Common Data Link
CEC	Cooperative Engagement Capability
CED	Capability Evolution Description

CFO	Communicate Force Orders
CGP	Common Ground Picture
CHENG	Chief Engineer
CIAP	Coalition Integrated Air Picture
CISA	Command Information Superiority Architectures
CJTF	Commander, Joint Task Force
CNO	Chief of Naval Operations
CO	Communicate Order
COA	Course of Action
CONOPS	Concept of Operations
COTS	Commercial Off-The-Shelf
CRD	Capstone Requirements Document
CS	Communicate Status
CSD	Communicate Sense Data
CV	Capability View
CV-6	Capability Evolution Description
DARS	Department of Defense (DoD) Architecture Repository
DIAD	Department of the Navy Integrated Architecture Database
DII COE	Defense Information Infrastructure Common Operating Environment
DoD	Department of Defense
DODAF	DoD Architecture Framework
DON	Department of the Navy

DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities
DSC	Decision Support Center
ECM	Electromagnetic Countermeasures
EE	Engagement Execution
EMI	Electromagnetic Interference
ERGM	Extended Range Guided Munition
FBE-I	Fleet Battle Experiment - India
FP	Force Positioning
FoS	Family of Systems
GCCS	Global Command and Control System
GIG	Global Information Grid
GOTS	Government Off-The-Shelf
GSM	Ground Station Module
HA/DR	Humanitarian Assistance/Disaster Relief
ICOMs	Inputs, Controls, Outputs, and Mechanisms
IE	Information Element
IEEE	Institute of Electrical and Electronics Engineers
IER	Information Exchange Requirement
IKA	Information and Knowledge Advantage
IMINT	Imagery Intelligence
IPT	Integrated Program Team
IR	Infrared
ISPP	Integrated Sponsor Planned Program

ISR	Intelligence, Surveillance, and Reconnaissance
JCC(X)	Joint Maritime Command and Control Capability (Experimental)
JCMOTFC	Joint Civil Military Operations Task Force Commander
JCS	Joint Chiefs of Staff
JFACC	Joint Force Air Component Commander
JFC	Joint Force Commander
JFLCC	Joint Force Land Component Commander
JFMCC	Joint Force Marine Component Commander
JFSOCC	Joint Force Special Operations Component Commander
JITC	Joint Interoperability Test Command
JMA	Joint Mission Area
JMAAT	Joint Mission Area Analysis Tool
JMETL	Joint Mission Essential Task List
JPOTFC	Joint Psychological Operations Task Force Commander
JRCOA	Joint Task Force Representative C4ISR Operational Architecture
JROC	Joint Requirements Oversight Council
JTA	Joint Technical Architecture
JTF	Joint Task Force
JWAR	Joint Warfare Architecture
KIP	Key Interface Point
KPP	Key Performance Parameter
LSAM	Land Attack Standard Missile
LPTF	Littoral Penetration Task Force

M&S	Modeling and Simulation
MCP	Mission Capability Package
MNS	Mission Needs Statement
MOE	Measure of Effectiveness
MOP	Measure of Performance
MS	Multi Sensor
MTW	Major Theatre War
NAVSEA	Naval Sea Systems Command
NCEE	Naval Collaborative Engineering Environment
NCO	Network Centric Operations
NCTSI	Naval Command for Testing System Interoperability
NCW	Network Centric Warfare
NETWARS	Network Warfare Simulation
NGO	Non-Government Organization
NII	Network Integration and Interoperability
NMCI	Navy and Marine Corps Intranet
NRO TPED	National Reconnaissance Office Targeting, Processing, Exploitation, and Dissemination
NTM	National Technical Means
NTOA	Naval Targeting Operational Architecture
NWDC	Naval Warfare Development Center
OGO	Other Government Organization
ORD	Operational Requirements Document

OSD	Office of the Secretary of Defense
OASD	Office of the Assistant Secretary of Defense
OODA	Observe, Orient, Decide, Act
OSI	Open System Interface
OUSD	Office of the Undersecretary of Defense
OV	Operational View
OV-1	High-Level Operational Concept Graphic
OV-2	Operational Node Connectivity Description
OV-3	Operational Information Exchange Matrix
OV-4	Organizational Relationships Chart
OV-5	Operational Activity Model
OV-6c	Operational Event/Trace Description
PACOM	Pacific Command
PGM	Precision Guided Munitions
PNT	Precision Navigation and Timing
POM	Program Objective Memorandum
P-Spec	Preliminary Specification
PVO	Private Volunteer Organization
RDA	Research, Development, and Acquisition
RF	Radio Frequency
SA	Situational Assessment
SAM	Strategic Air Missile
SATCOM	Satellite Communication

SIAP	Single Integrated Air Picture
SIGINT	Signals Intelligence
SOF	Special Operations Forces
SoS	System of Systems
SPAWAR	Space and Naval Warfare Systems Command
SS	Single Sensor
SV	System View
SV-3	Systems-to-Systems Matrix
SV-3a	Systems to Systems Functions
SV-3b	Operational Activities to Systems Traceabilty Matrix
SV-3c	Systems^2 Matrix
SV-4	Systems Functionality Description
SV-4a	High-Level Systems Functions List
SV-4b	Systems Functional View
SV-4c	Logical Interface View
SV-5	Operational Activity to Systems Function Traceability Matrix
SV-6	System Data Exchange Matrix
SV-8	System Evolution Description
SV-9	System Technology Forecast
TA	Technical Architecture
TACAIR	Tactical Air
TAMD	Theater Air Missile Defense
TBM	Theater Ballistic Missile

TCPED	Tasking, Collection, Processing, Exploitation, and Dissemination
TP-4	Technical Panel Four
TRIXS	Tactical Reconnaissance Intelligence Exchange System
TST	Time Sensitive Targeting
TTCP	The Technical Cooperation Program
TTLAM	Tactical Tomahawk Land Attack Missile
TTPs	Tactics, Techniques, and Procedures
TV	Technical View
TV-1	Technical Standards Profile
TV-2	Standards Technology Forecast
UAV	Unmanned Air Vehicle
UJTL	Universal Joint Task List
USJFCOM	U.S. Joint Forces Command
USMTF	U.S. Message Text Format
WTP	Weapon Target Pairing

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