Operational Flexibility in Complex Enterprises: Case Studies from Recent Military Operations

by

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For Lisa,
Quent and Dorothy

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Abstract

An emerging requirement for 21st century enterprises is operational flexibility, a requirement particularly important for the U. S. Department of Defense (DoD). To achieve flexibility, most practice and research emphasizes process improvement, robust collaboration and “flattened” or “networked” organizations. Lateral alignment has also been proposed as a means to enable flexibility. Missing from these approaches is an appreciation and understanding of the role of architecture and hierarchy as well how to apply these ideas at the enterprise level of organization.

The DoD has embraced information technology as one means to achieve flexibility via these methods. Within DoD the Air Force is a uniquely flexible combat arm, but it has proven particularly difficult to integrate air power at the level of inter-service (Joint) military operations in order to leverage this flexibility. Kometer (ESD Ph.D., 2005) used a complex, large-scale, interconnected, open, socio-technical (CLIOS) systems analysis to examine command and control of the Combat Air Operations System (CAOS), proposing new command and control concepts to gain flexibility.

This thesis extends Kometer’s research by using a qualitative architectural analysis to explore the twin ideas of hierarchy and laterality in enabling flexibility. We define lateral interactions as those within the same layer of an enterprise hierarchy. Lateral interactions enable formalized collaboration among peer entities, which can enable more operational alternatives and make these alternatives executable on more responsive timelines than possible with classic hierarchical structures. We identify previously unexamined trends in the operational architecture of combat air operations that are related to flexibility and examine the trade-offs between flexibility and other enterprise properties. We find a pattern of increasing enterprise laterality from beginning to end of the case studies and an association between upper- and lower-echelon laterality, overall system flexibility and strategic coherence. To enrich the analytical framework, an analogous example of flexibility in the New England Patriots football team is developed and presented.

We find that our architecture framework provides a rich addition to existing empirical research on combat air power and addresses difficult socio-technical analysis issues in a way that complements other approaches. We also find that traditional perspectives on flexibility, efficiency and effectiveness trade-offs are strongly dependent on hierarchical level of analysis. Our framework lays a foundation for rigorous holistic enterprise design efforts in the area of military operations and other socio-technical enterprises such as health care, disaster relief and large-scale defense acquisition.

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Chapter 1

Enterprise Flexibility as an Operational Requirement

1.0 Introduction and motivation: Why flexibility, why enterprises?

The end of the Cold War coincided with the commercialization of the Internet and World Wide Web to create new operational and technical challenges for the Department of Defense (DoD). Around the same time, there was an emerging awareness of historical periods of rapid change in military affairs driven by technological advance, called Revolutions in Military Affairs (RMA). Adjusting to this period of change is the central challenge of the Department of Defense in the early 21st century. Designing flexible strategies, systems and enterprises has been proposed as a means to make these adjustments and sustain competitive military advantage for the United States in today's environment.[1]

The inter-war period between World Wars I and II was the most recent prior period of revolutionary change in military technology and society. It was dominated by new, physically large, technical systems such as motorized vehicles, aircraft, and aircraft carriers.[2] These systems were by no means the complete determinants of 20th century military superiority or the sole drivers of social change, but they were the centerpieces; the animating forces for the activities and thinking that resulted in fundamental change.

The early part of the 21st century is different. This era of change is driven by information technology and information-based systems. In a prescient 1993 memo, Mr. Andrew Marshall of the Office of the Secretary of Defense wrote:

> "There may not be any new platforms (e.g., carriers) for innovators to rally round and commit themselves to…technologies (information, computational, communications) that seem central suffuse everything, the same way that small electric motors did several decades ago, changing everything but creating no new major system like the automobile or the airplane. New innovation strategies may be required." (Marshall 1993)

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[1] Rumsfeld Congressional testimony, May 2002; 2006 Quadrennial Defense Review.

[2] We do not ignore the significant contribution made by early information systems such as RADAR and radio, during the Inter-War period. These were *key* (possibly critical enabling) technologies as well, but were not physically or institutionally as central to change as the others.

Mr. Marshall hints at twin, intertwined, phenomena. In analogy to Say's Law, these technologies create their own demand for change and improvement.[3] Information systems themselves enable organizations to improve and change. But they also enable development of systems that are more sophisticated and the interoperable systems (of systems). The ability to use information technology to design new systems and to insert it into existing systems and organizations enables increased efficiency in design, production and other operational processes. It also enables the creation of new processes, new systems and new ways of delivering value by increasing and enhancing information exchange among systems and organizations. In military operations, the flexibility enabled by information technology produces beneficial effects as well as pathological ones. This factor makes it important to develop a clear understanding of the implications of information technology on system performance through its effect on key system properties such as flexibility.

The need for flexibility in the DoD is undeniable. Since the end of the Cold War, and particularly since Sept 11, 2001, the military services have been tasked to conduct a wider array of combat and non-combat operations than in the past and to adapt to the new threat of global terrorism. The DoD's overarching concept of "Network Centric Operations" captures a set of principles that have guided some efforts to achieve needed flexibility. The main idea of network-centric operations is that information technology enables increased collaboration within and among the combat force. The NCO concept says that increased collaboration can then be leveraged to enable highly decentralized and explicitly non-hierarchical command of operational combat forces. It is claimed that this style of operating will result in sustained advantage over adversaries.[4] Most efforts to

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[3] "It is worthwhile to remark that a product is no sooner created than it, from that instant, affords a market for other products to the full extent of its own value. When the producer has put the finishing hand to his product, he is most anxious to sell it immediately, lest its value should diminish in his hands. Nor is he less anxious to dispose of the money he may get for it; for the value of money is also perishable. But the only way of getting rid of money is in the purchase of some product or other. Thus the mere circumstance of creation of one product immediately opens a vent for other products." (J.B. Say, 1803: p.138-9) available on line at http://cepa.newschool.edu/het/profiles/say.htm.

[4] This mode of command has been called self-synchronization. The idea of self-synchronization comes from complex adaptive systems research, where it has been observed that large groups executing simple behavioral rules, usually only requiring local knowledge, can result in orderly patterns of large scale (system level) behavior. Self-synchronization captures the idea that many complex systems exhibit "emergent" behavior that is (a) not centrally coordinated or controlled and (b) not obvious from an

understand how network-centric concepts and technology provide competitive advantage have focused mainly on tactical level *behavior* and *processes*. Underemphasized is the naturally hierarchical character of military operations and the system-level architectural aspects as well as system level operational properties that may enable or constrain capabilities at different levels of the system.

1.1 The operational challenge defines the design challenge: enterprise architectures

In the 20th century, military advantage was a function of mass and numbers. With the advent of the information age, this type of advantage is reduced in value. Technology has leveled the playing field in many areas of warfare and conflict. As we end the first decade of the 21st century, it has been observed that capabilities of individual systems and organizations have improved to the point where advantage now derives from the ability to craft innovative combinations of systems and organizations—enterprise architectures.[5] Today competitive advantage accrues to those with the ability to adjust to changing circumstances quickly by having multiple alternatives available to accomplish a mission or to solve a problem.

Today, adversaries quickly adapt to technical advantages or they acquire systems that provide essential parity in capability.[6] The diffusion of information technology and the increased global mobility of people enable diffusion of advanced industrial processes, practices and technology through a global marketplace. This has leveled the playing field in physical systems and changed the main operational problem of military competition. Overwhelming force on the battlefield is no longer the dominant source of advantage.[7] In this environment, competitors must learn how to generate "overmatching power" against

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examination of the components of the system. Examples are swarming bees, market panics, riots, schools of fish and flocking birds.

[5] Watts, B., "US Combat Training, Operational Art, and Strategic Competence: Problems and Opportunities", briefing dated 21 Aug. 2008. The 9-11 attacks, the emergence of the Insurgency and the Improvised Explosive Device (IED) campaign in Iraq are examples of the diminishing power of overwhelming force and the increased effectiveness of innovative combinations of systems and organizations.

[6] We will see later that the Serbian army learned the lessons of Desert Storm: if you stand still, the US Air Force can hit you. Their response was to increase mobility of potential targets and to use decoys, deception and civilian shields to negate our advantage in sensing and precision targeting. A similar evolution can be seen in the recent conflicts between Israel and the terrorist groups Hamas and Hezbollah.

[7] Watts describes it as "moving up the food chain."

adversaries (Rumsfeld 2003).[8] But we have little in the way of concrete knowledge with which to support the design of architectures that can generate this needed overmatching power.

Flexibility is an enabler toward this goal. In the past flexibility in operations has often been "discovered" or developed *ad hoc*, usually driven by necessity and often in spite of existing organizational structures. In today's environment, flexibility must have a more prominent place in our thinking; our enterprise architectures must enable greater strategic, operational and tactical flexibility. We define flexibility as the ability to respond with relative ease to internal and external changes by having multiple alternatives with which to deliver value on operationally responsive timelines. In the 1990s Garlan and Shaw observed that future value in software development was going to come from architecture—that the critical development tasks were how software elements were put together (Garlan and Shaw 1993):

> As the size and complexity of software systems increases, the design problem goes beyond the algorithms and data structures of the computation: designing and specifying the overall system structure emerges as a new kind of problem. Structural issues include gross organization and global control structure; protocols for communication, synchronization, and data access; assignment of functionality to design elements; physical distribution; composition of design elements; scaling and performance; and selection among design alternatives.

We must think about military architectures and systems similarly. Today, the ability to put together teams of people and to develop complex systems, while difficult, represents only one component of a larger-scale design challenge. In systems design, a traditional approach is that the architecture is either given at the beginning (iterative design) or it "emerges" as the design process proceeds (clean sheet design) (Ulrich and

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[8] "Overmatching power" was described by SecDef Rumsfeld in July 9, 2003 Congressional testimony to contrast Iraq-II operations with classic massed force operations: "In the past, under the doctrine of overwhelming force, force tended to be measured in terms of mass—the number of troops that were committed to a particular conflict. In the 21st century, mass may no longer be the best measure of power in a conflict. After all, when Baghdad fell, there were just over 100,000 American forces on the ground. General Franks overwhelmed the enemy not with the typical three to one advantage in mass, but by overmatching the enemy with advanced capabilities, and using those capabilities in innovative and unexpected ways."(Rumsfeld 2003)

Eppinger 1995).[9] In military operations, we have historically relied on innovative people, judicious disregard of process and procedures as well as other ways of responding to uncertainty as a primary means to overcome inadequacies in our organization designs, processes and relationships.[10] In the past, task accomplishment was often confined to a single unit (aircraft, ground unit), missions were usually self-contained and there were a limited number of options for execution of them.[11] In our operations today, we connect organizations and systems across the globe to accomplish tasks and missions; system level function can be delivered in many different ways. This places a premium on attention to design of our operational architectures, rather than to the use of existing architectures or the undirected evolution of our operational architectures as the output (byproduct) of an existing process (Whitney 1990; Moses 2006a).[12]

Concurrent with the need to think about design of architectures and to increase emphasis on flexibility in them, there is an increasing trend toward operating with multiple organizations—enterprises (Agranoff and McGuire 1998; Stanke 2006). Even though multiple organizations have always interacted to achieve common goals, today's situation is different.[13] In the past, expertise inside an organization's boundaries ensured success—both for individuals and for the organization; inter- and intra-organizational relationships were usually highly formalized and were generally a secondary consideration in operations. In today's environment, this model is less relevant. As systems and operational problems become more complex—due to more intricate physical

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[9] Recent work in strategic engineering, real options analysis and multi-disciplinary system design optimization are examples of new approaches in technical systems, where architectures are considered, to some extent, *before* the system design process begins.
[10] This has also been noted in non-military organizations (Chisholm 1989)
[11] Analogous to the development of code modules and algorithms separately from the development of an overall software architecture as described by Garlan and Shaw.
[12] In Chapter 2, we will see that this is an indirect conclusion of Kometer's research (Kometer 2005, p. 188 and 243). He casts the challenge as the need to think clearly and ahead of time about command relationships with specific attention to the rules by which command authority in combat is delegated to lower command levels. Kometer's recommendations specify a design method; we aim to move toward the ability to define design goals (system level properties) at the enterprise level.
[13] For example, Boeing, Electric Boat, General Motors and other large system designers have always relied on supplier networks. However, today these networks require richer information interactions and closer relationships in order to sustain competitiveness. The attempt by Boeing in its 787 program to develop these types of relationships is an example of the need for explicit attention to enterprise architecture; its public failures are an example of our lack of understanding about how to design these enterprise architectures as well as to make them work.

system interdependencies, wider social concerns or more stakeholders—more organizations become involved in either design or operations. Whether in the execution of public governance, military operations or system development, intra- and inter-organizational relationships are becoming more dynamic at the same time as there is a rising demand for coherent action. This represents early evidence of the existence of enterprises (Agranoff and McGuire 1998; Allen et al. 2004; Stanke 2006a; Dodge 2008).

1.2 Flexibility in enterprises: Research Questions

The importance of architecture, the existence of enterprises, our poor understanding of them and the need to make them perform well in dynamic and uncertain situations generates our central research questions:

- *"How do we design flexible enterprises?"*
- *"What is the relationship between architecture and flexibility in complex enterprise systems?"*

Answering these questions requires inquiry at multiple levels. The construct of "enterprise" is new, and the application of architectural thinking to enterprises is also new; so, we have little in the way of theory to guide conceptualization and investigation. Our initial step will be to examine existing research literature and synthesize theory to guide our investigation—to connect architecture and flexibility and apply them to enterprises. This will guide development of a framework for analyzing and modeling enterprise architectures. Theory will also guide development of a simple model to investigate the relationship of architecture to flexibility and to other system properties. We will connect these two lines of investigation by extending the work of LCol Michael Kometer, USAF (ESD, Ph.D.) (Kometer 2005). His study, titled "Command in Air War: Centralized and Decentralized Control of Air Power," was a systems-level investigation of complex combat air operations. He examined how multiple organizations interacted in the process of transforming policy and strategy into combat actions, specifically, how those interactions gave rise to overall system performance (outcomes).

Kometer's research focused on process, using a CLIOS framework to develop his model.[14] Our goal is to enrich and complement his work with an architectural perspective and to connect it more closely to a theoretical framework that can support design of flexibility in enterprises and other large-scale systems. We propose to examine the proposition that lateral interactions at multiple hierarchical levels are related to the system level property of flexibility.

1.2.1 Case study background and boundaries

In Chapter 2 we will briefly discuss the origins of air power command and control doctrine that were the motivating force for Kometer's research. He was interested in addressing long standing tensions and perceived ambiguities in the doctrine of command and control of *air power*. As such, he focused *inside the air force* on how to resolve internal tensions created by a desire for control and efficiency with a recurring operational need for innovation and empowerment in combat. This investigation necessarily took him to look at air-ground operations, but the explicit structure of Army (ground forces) and Air Force relationships was not his focus. As we look at these cases architecturally, we will be naturally steered toward a more explicit focus on Army-Air Force interactions at multiple levels. This is both a slight expansion and a narrowing of Kometer's analytical lens. Also, Kometer focuses on empowering lower levels of hierarchy as a way of arguing for faster time responsiveness at the system level, while maintaining the accountability required in military operations. But as we will see, he does not bring the time issue to the forefront of his analysis because his system level model does not address the time dimension very well.

We will see in our case studies that many *ad hoc* modifications to enterprise structure created interactions that were closer to lateral (peer-to-peer, collaborative) than they were vertical (senior-to-subordinate, directive). Taking an architectural perspective opens the door for us to discuss these lateral interactions as a way to overcome extended feedback loops (which generally consume too much time) that arise when you have to go

[14] CLIOS: Complex, Large-scale, Integrated, Open Socio-technical system. CLIOS is an analytical framework developed by Dr. Joseph Sussman at MIT. Its aim is to aid researchers and policy makers in addressing the many complex interdependencies that exist in the development and operation of complex technical systems and their interaction with the many policy, organizational and institutional factors that influence their development (Sussman 2000; Mostashari and Sussman 2009).

up and down a hierarchy for both decisions and information access. However, we will see that some of the lateral connections at lower levels of hierarchy were in tension with concerns for accountability and coherence of the overall air campaign strategy. Chain of accountability and strategic coherence are central concerns in military operations and Kometer is meticulous in ensuring this issue remains clear in his concepts. From this perspective, there is *never* a lateral structure—somebody or some group is *always* 'above' or 'in charge' when decisions are made. There is always a tree hierarchy, which is true in virtually every decision-making context, something Kenneth Arrow showed us many years ago (Arrow 1950).[15]

1.3 Complex systems: An architectural approach

There are numerous ways to approach the study of complex systems. As we noted above, Kometer uses the CLIOS framework, using it to emphasize the dynamic behavior aspects of combat air operations. Others approaches are to look at the system from multiple perspectives, or views (Kruchten 1995; Nightingale and Rhodes 2004), Network-theoretic approaches have also been a source of many new insights. Our approach to the research is grounded in the computer science concept of architecture and the mathematical concept of abstraction. In computer science and mathematics, levels of abstraction are a central concept, enabling the simplification and solution of complex problems by ignoring certain details and allowing concentration on only a few (hopefully the most essential) details. Abstraction allows computer scientists to separate cleanly key system design and implementation considerations.[16] In operational situations, abstraction enables us to separate different degrees of problem complexity, treat them differently within different levels, and to control interactions across levels in ways that enables a balance between control and flexibility. Properly applied, the tool of abstraction can

[15] We know from Arrow's General Possibility Theorem that there is always a "dictator" or "decider" upon whom the ultimate decision depends, whether the situation is collaborative or directive (Arrow 1963). The potential consequences of this theorem for autonomous machines (software driven collaboration) has been explored as well (Meyer and Brown 1998). By accepting this phenomenon and viewing the problem from a layered hierarchical perspective, we open the door to another way of understanding the operation of complex systems. We don't consider the micro-scale dynamics of the situation, but only the overall flexibility in the system. Also, see the discussion of lateral connections in Chapter 3.
[16] This is similar to, but different than, modularity as a design concept and different than the more widely used concept of scale in complex systems.

enable us to design flexibility in to our enterprise architectures rather than rely on unstructured evolution and *ad hoc* interactions.

1.3.1 Hierarchy and laterality

The concept of abstraction leads us naturally to hierarchy. Hierarchy is a decomposition of a system into subsystems according to some criteria or scheme (each of which may also be further decomposed into smaller subsystems) (Simon 1962; Simon 1996; Allen 2006). In technical systems, hierarchy is usually viewed from the perspective of decomposition of a physical system into more specialized physical parts or sets of parts in order to manage complexity of development, assembly or understanding. More generally, a hierarchy is an asymmetrical ordering of the parts of a system into according to some chosen criteria where, at each stage (or level) of the ordering, the parts share some a common set of attributes. Also, following Simon, the meaning of hierarchy is generally assumed to be a tree-like structure, where interactions across branches of the decomposition are minimized as much as possible. We will take this meaning when we speak generally about "hierarchy," unless it is specifically noted otherwise with a modifier, such as "layered" or "lateral". Simon's seminal contribution on hierarchy generalizes the social system concept of hierarchy (organizations) to apply the idea to complex physical, biological and other systems (Simon 1996, p. 186). Simon assumes strong boundaries (minimal interaction) across branches of a social hierarchy (Simon 1996, p. 200-201).[17] Simon does not explicitly account for status or rank-based structure and the operational implications that it can have for the types of interactions that can be designed into an organization.

In organizations, hierarchies are sometimes contrasted with "networks", which are generally considered to be the antithesis of hierarchies and, hence, are assumed to be more flexible and "flat" (Powell 1990; Romanelli 1991).[18] A simple visual comparison of a hierarchy and a network is in Figure 1. In enterprises and organizations, the term

[17] This restriction on cross boundary interactions is an analytical tool to make problems tractable. Cross boundary interactions create increased complexity, both in quantitative analysis as well as in operation.
[18] Networks are also considered more complex and more difficult to control than hierarchies.

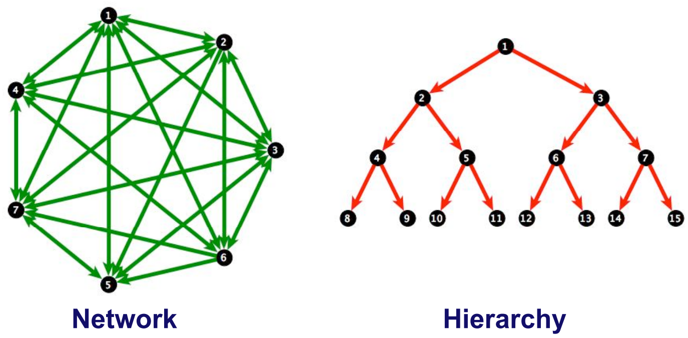

Figure 1: Simple representation of hierarchy and network

hierarchy represents a distinction in the level of problem complexity or difficulty (above the level of technical systems) that typically (but not always) corresponds with authority, rank, or status differences. Hierarchies can have several levels, depending on the size of the overall organization (Sloan 1972; Chandler 1990). In organizational contexts, then, we can also use the tree decomposition to identify hierarchical differences from top to bottom (usually with the highest level or authority at the top), as in Figure 2. Within hierarchical forms, Galbraith has proposed lateral interactions as a means to achieve

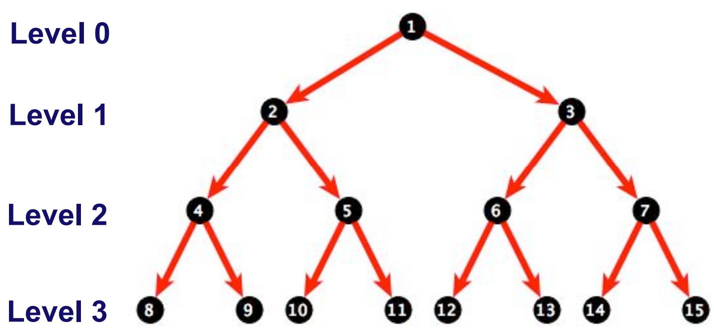

Figure 2: Hierarchy with four levels

flexibility (Galbraith 1993). Galbraith's model aims to create formal interactions across the hierarchically defined boundaries of an organization, ideally at the level where the best expertise for a given problem resides, as indicated by the green connections in Figure 3. Moses has offered still another type of framework, the layered architecture. In this structure, nodes at one layer can connect to more than just its immediately subordinate nodes at the next lower layer, as indicated by the blue connections in Figure 3 (in direct contrast to the classic tree hierarchy) (Moses 2006b). Though these types of cross layer and lateral connections happen all the time in real organizations, they are not generally recognized as part of a formal structure and are not usually considered important when developing formal designs or processes.[19] So, for us, architecture is more than "hierarchies vs. networks" or "markets vs. hierarchies." Lateral connections can be important to flexibility in organization systems; classic hierarchical systems (i.e., tree-structured hierarchies) help to manage complexity in problems that must be solved as well as to manage workload (information, cognitive load of people and groups). If we consider layered structures and lateral interactions *within layers*, we may be able to design, *ex ante,* hierarchical structures that enable greater flexibility while balancing the need to limit complexity as they act to deliver value in dynamic and uncertain operational environments.

1.3.2 Layers and laterality

As a system is decomposed and the hierarchy developed, each stage or level of decomposition is defined as a level. Connections can be made within levels of the decomposition and we define these as lateral interactions (Figure 3). Most organizations exhibit

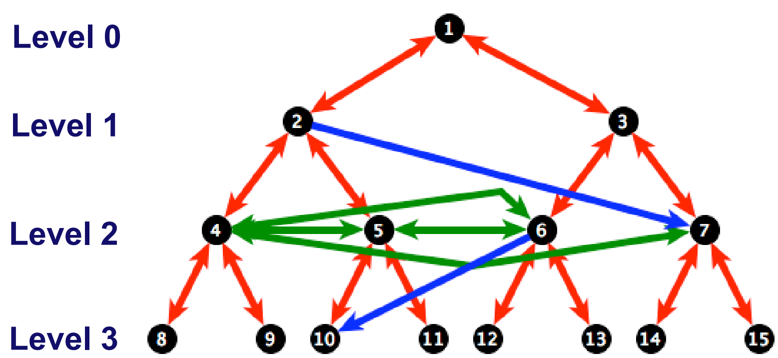

Figure 3: Lateral and layered connections in a hierarchy

[19] It is also very important to note that layered connections as defined by Moses are not part of a "Simonian" hierarchical construct, where these interactions are to be minimized. This also applies to many aspects of technical system design, especially matter-energy intensive systems, where these types of interactions can impact the ability to deliver required functions and/or performance. We amplify this point in Chapter 3. Dr. Kirk Bozdogan and Dr. Joel Moses have both pointed out the significance of this distinction and the need to make this point clearer in this thesis.

some form of hierarchical structure. We define hierarchy in an enterprise context as an ordering by rank, responsibility and abstractness, with higher ranks generally associated with levels that have greater responsibility and more complex and longer time horizon—more abstract—problems. It is widely accepted that hierarchies in organizations exist to manage the natural complexity of coordinating humans in collective work. It is also widely acknowledged that non-hierarchical (usually described as "informal" or non-authorized) connections also exist, developed to address problems that cannot be solved by the formal hierarchy (Chisholm 1989). We marry these ideas to the view of an organization as a problem-solving device, or an input-output information processing system (Thompson 1967; Tushman and Nadler 1978; Moldoveanu and Bauer 2004). This view enables us to combine levels of abstraction from computer science with lateral interactions at different levels of organization to examine architecture and flexibility. This is different from technical systems where, in general, we do not usually have lateral interactions, because we usually do not have many layers of abstraction, sometimes only one.

Military operations are usually divided into three levels of abstraction: strategic, operational and tactical (The Joint Staff 2001). These levels correspond to the overall complexity of problems handled and to the space and time horizon of those problems. Strategic level problems are the most abstract, most complex and have the longest time horizon, usually months to years. Operational level problems are less complex, less abstract, than strategic, with a shorter time horizon, usually days to weeks. Tactical level problems generally involve less uncertainty and fewer variables, so are relatively less complex than operational and strategic problems; they also occur on relatively short time scales, sometimes on the order of seconds and minutes. At each level the interactions, the qualitative nature of information and the complexity of issues are different. The ultimate architectural challenge is to design the interactions within each layer and across layers so that desirable outcomes are achieved. Our goal is to understand better the implications of architecture for system level properties.

1.3.3 Architecture and flexibility

In technical systems, design flexibility is generally a difficult and costly property to implement in terms of time, money, and performance. The increased application of multi-attribute trade-space and multi-dimensional optimization methods in the design of complex technical systems is evidence of an increasing need to examine carefully the many system trade-offs in light of increased uncertainty and dynamics in future requirements. As we noted in section 1.3.1, many organizational approaches to flexibility usually assume two main alternatives: a hierarchy or a network, formal or informal interactions and integration or differentiation in function. Often, these views do not address the deeper issue of hierarchy in enterprises very well and create at least two problems: (a) a lack of control when flexibility is necessary (informal, uncontrolled or unmonitored interactions can cause problems, whether in an organization or a technical system) and (b) a difficulty in responding to changes in requirements on appropriate time scales. Here we begin address these problems by taking an architectural view of enterprise operations that leverages the concepts of layers of abstraction and lateral connections to start working on how to design flexibility into the enterprise architecture up front.

1.3.4 Trade-off analysis

There are significant differences between mechanical physical systems and informational physical systems, differences that are significant from a design standpoint. The transfer of matter and/or energy dominates mechanical system characteristics, while information systems are dominated by low power interactions that transfer information (usually in the form of low voltage electrical signals). Since design is about balancing conflicting constraints while seeking a performance goal, the type of system under consideration dominates the nature of the trade-offs that must be considered. Specifically, efficiency-flexibility trade-offs are qualitatively different in information-intensive systems (organizations, enterprises, IT systems) compared to matter-energy intensive technical systems and particularly in organizational systems. It is well understood that designing alternatives into information systems is easier than in matter-energy intensive systems (Whitney 1996; Whitney 2004). This observation extends to making changes and/or designing flexibility into organizations. When we combine the relative ease of designing more alternatives into information-intensive systems with hierarchical levels of abstraction, we get a view of trade-offs among flexibility and efficiency that are different in character from those in physical systems. In an enterprise or an organization, each layer or each branch of a tree can be considered a discrete entity, often able to deliver function separately from the enterprise as a whole. This means each layer or branch can be evaluated in terms of flexibility, efficiency and effectiveness on its own, as well as a part of the enterprise.

Because the parts of an enterprise can deliver function and value on their own, separate from the enterprise, evaluation of the trade-off between efficiency and effectiveness becomes more complex. Recall that we can increase flexibility by adding connections across layers of the enterprise and by adding lateral connections within layers (Figure 3). Adding these connections increases the complexity of the structure—there are more interactions to be managed or monitored, more considerations in design. In enterprises, we find a fundamental question is not the trade-off between flexibility and efficiency but between flexibility and the degree of increased complexity necessary to achieve it in the context of the performance demands of the operational problem (environment). At this level of discussion, we find that traditional distinctions between efficiency and flexibility, which can often be examined (traded) on the basis of a commensurate quantity such as cost, become highly dependent upon the overall strategy and other constraints on the system (such as specific outcome requirements or external political and regulatory constraints).

1.3.5 Summary

Leveraging the computer science concept of architecture and the mathematical concept of abstraction offers a way to begin examining large-scale enterprise systems in a new way. Multiple levels of abstraction naturally extend to a hierarchical organizational approach, where higher levels deal with more general problems than lower levels and where levels generally correspond both to rank and responsibility differences. There are various forms of hierarchical structures, such as pure tree structures and layered structures. Other forms, such as lateral and networked architectures have been observed, but have not been placed in an integrated hierarchical frame of reference.

In organizational contexts, we can use decomposition to identify hierarchical differences between top and bottom (usually with the highest level or authority at the top) and where levels of hierarchy represent distinctions in problem complexity or difficulty.

From this perspective, enterprises usually have several levels, depending on the scale, scope and complexity of operations. Within hierarchical forms, lateral interactions at the most appropriate level of organization have been proposed as a means to achieve flexibility (Galbraith 1993). In layered hierarchies, flexibility can be gained by allowing certain subsystems at one level connect to more than one subsystem at a lower level (in contrast to classic tree structures) (Moses 2006b). Though these types of connections (outside of formal tree structures) happen all the time in real organizations, they are not generally recognized as part of a formal structure and are not usually considered when developing formal designs or processes. Lateral connections in organizations can be important to flexibility in solving problems, processing information and accomplishing tasks in changing or uncertain environments. While classic tree-structured hierarchies help to manage complexity in problem solving and in workload (information processing and cognitive load of people and groups), considering layered hierarchical structures and lateral interactions within layers may enable us to design-in flexibility while balancing the increased cost and complexity of these added interactions.

Key considerations in designing flexibility into enterprises are the tradeoffs that must be made to achieve it. Because of the multi-layer and multi-organizational aspects of enterprises, these tradeoffs are often difficult to assess and can be highly dependent on the level at which the trade-off is considered.

1.4 Research approach and method

While the term enterprise is an old one, it is increasingly used in new and varied ways to describe new forms of organization and new types of organizational relationships (Castells 2000; Murman 2002; Allen et al. 2004; Rouse 2005; Stanke 2006a). For some, enterprises represent a new level of organization analysis, for some it is a way of thinking about organizational relationships and still others use it to describe the need to integrate multiple organizations and their stakeholders in the development of complex products or services. Here, we treat enterprises as new organizational forms. In general, the idea of enterprises comes to us with little in the way of concrete theory or analytical frameworks to guide our desire to design their architectures to have specific properties—to behave as goal-directed, managed, entities. Complex systems research is a natural place to search for applicable tools, but many of these research approaches address only certain aspects of the emerging nature of enterprises. For example, network-theoretic approaches have provided many interesting insights into the structure and dynamics of complex systems; operations research methods have enabled managers and process designers to optimize a wide variety of systems. But each tool leaves important parts of needed understanding of complex systems unaddressed. In order to start filling this gap, we must use a combination of approaches. As discussed in the previous section, our approach will be architectural. We have introduced our architectural concepts, drawing on from computer science and mathematics. Later we will continue our development, leveraging these concepts to use organization and complex systems theory to develop a literature-based framework for analysis and theory of enterprise architecture flexibility.

In Chapter 4, our literature review develops the ideas of hierarchy, laterality and flexibility discussed briefly in the last section. Using this foundation, we take a case study approach to begin examining our ideas (Eisenhardt 1989; Yin 2003). Our cases are drawn from previous analysis of combat air operations conducted by LCol. Michael Kometer, USAF (ESD Ph.D., 2005). Kometer's analysis looked at each case from five different perspectives, as shown in Figure 4. We will review his approach in more detail in Chapter 3. His analysis provided new insights about command and control of air power, focusing mainly on processes and behaviors in the system.

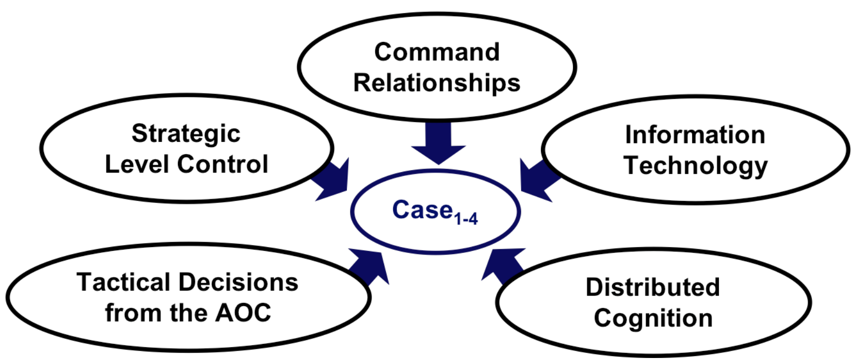

Figure 4: Kometer's approach

To extend his research, we conduct a meta-analysis, integrating Kometer's five lenses by conducting an architectural analysis of each of his cases, focusing specifically on flexibility. We treat the relationships among various entities and organizations in the cases as a systemic whole, without distinguishing interactions as technical or organizational. This allows us to examine the enterprise holistically, as a complete socio-technical system. A depiction of our framework is in Figure 5. In contrast to examining different aspects of several cases of combat air operations to develop a better understanding of command and control techniques, we aim to understand the overall enterprise architecture and how it relates to the system level property of flexibility. Our analytical goal is two fold:

1. To provide a complementary interpretation of Kometer's presentation of air power and combat operations command and control;
2. To test new theoretical propositions about the relationship between architecture and flexibility in complex socio-technical systems—specifically focusing on the role of multi-level interactions in enabling enterprise level flexibility.

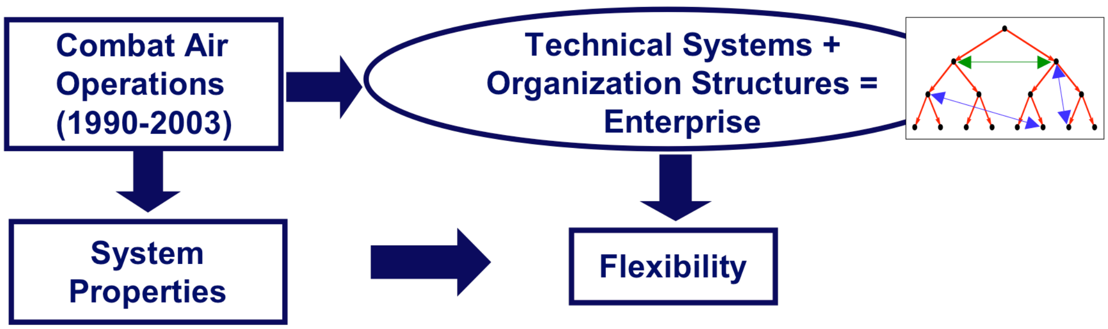

Figure 5: Approach of this thesis

The research design is a multiple case study meta-analysis, interpreting previous historical research and analyses through the lens of a hierarchical architecture framework to expose aspects of the existing case research that have not been clearly addressed up to now (Eisenhardt 1989; Yin 2003). Most examples of multiple case study research aim to generalize a theoretical proposition. Our goal is exploratory in this regard. We propose to examine the theoretical proposition that lateral interactions within multiple hierarchical layers are related to the system level property of flexibility. Our analysis is descriptive and qualitative and we use a wide variety of research reports, theses, analysis and data sources with the aim of capturing a diverse analytical perspective on the subject matter and passing this data through our architectural filter. We choose the case study method because military operations are non-repeatable natural experiments that cannot be re-created in a laboratory setting. They are subject to high uncertainty that results from dense interdependencies both within the military enterprise and between the military enterprise and its environment (to include the enemy).[20] Every military operation is a separate natural experiment, each one unique, but also driven by a common set of fundamental forces and mechanisms. By examining multiple cases and multiple analyses, we reduce the possibility of getting a skewed perspective of the campaigns. To further understand the generalizability of the framework and the analysis, we apply the architecture perspective to a case from an unrelated field, the New England Patriots football team. An architectural analysis of the Patriots further explores the role of flexibility via the use of multi-skilled players, the interactions during game play that are enabled by them and the overall team and game-play architecture (analogous to enterprise architecture). In this context, hierarchical relationships are spatial (on the field—the depth of the defense) and at different competitive levels of the game that correspond to military contexts: strategy (season), operations (game) and tactics (plays).

Our framework, , highlights hierarchical relationships and their connection to flexibility and is shown in Figure 5. This approach has the virtue of bringing a new perspective to enterprise architecture. Unlike other methods that emphasize multiple and more detailed views, and that often separate technical from organizational issues, our single, integrated, view aims to get the "big picture" right, so that more detailed analysis efforts can be placed in an enterprise-level context.

1.5 Findings and contributions

Our analysis reveals several interesting findings about enterprises:

1. Enterprise architectures with lateral interactions at multiple levels of hierarchy are more flexible than strict tree structured hierarchies.
    a. *ad hoc* lateral interactions at tactical (low) levels of organization enable flexibility but can contribute to loss of coherence;
    b. Interactions (usually commands) from higher levels that skip intermediate levels can result in unintended outcomes.

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[20] This idea is captured in two famous quotes from military practitioners: "The plan is nothing, *to plan* is everything" (Eisenhower) and "No plan survives first contact with the enemy" (von Moltke the Elder).

2. Lateral interactions <u>*at higher levels of the enterprise are important*</u> to maintaining strategic coherence

    a. Where lateral interactions at high levels failed, did not exist, or were by-passed, either operational problems developed or tactical and/or operational level flexibility was inhibited.

3. Lateral interactions *at lower hierarchical levels are required* to gain flexibility in uncertain and fast-moving operations.

4. Our architectural framework enables system level comparative analysis of flexibility across the variety of enterprise architectures, some of which were briefly discussed in section 1.3.

5. Layered hierarchical approaches to enterprises may prove to be a powerful design tool for operational architecture design and represent a potentially rich source of insight to many challenging enterprise problems.

We also find that an architectural approach is complementary to approaches that emphasize processes and feedback loops in systems. It provides us with a rich and general understanding of complex socio-technical systems without separating of social and technical aspects of the systems. Architecture analysis enables examination of high-level properties that are relevant to senior level decision makers (enterprise architects) without becoming overly burdened with extraneous details.

1.6 Chapter summary

Military operations in the 21st century are marked by a demand for flexibility in order to remain effective in an uncertain and dynamic global environment. Past military operations and long-term military competitions hinged on mass and efficient logistics. The advent of global information networks and ability to make many physical systems[21] interoperable requires us to focus on architectures, which we define as the holistic articulation of the relationships among organizations and the technical system they operate which create a set of capabilities. This research leverages computer science and

[21] By this, we mean both physical information systems as well as individual platforms, such as aircraft, tanks, ships and even individual weapons and the people that use them.

mathematical concepts of architecture and abstraction to bring a multi-level hierarchical perspective to enterprise architecture. We examine Kometer's research of command and control of combat air power through this architectural lens. We aim to complement his process-oriented research and highlight the impact of multiple levels of interaction on enterprise level properties.

1.7 Outline of the thesis

Chapter 2 presents a *very brief* overview of the evolution of air power command and control. It emphasizes fundamental physical differences between air and ground combat that give rise to differences in priority regarding use of air power and is one of the root causes of the need to address the enterprise architecture of command and control. Chapter 3 provides a review of Kometer's thesis, *"Command in Air War",* and the origins of the main architectural issue regarding inter-service organizational structures. It establishes the orientation of his work and highlights how it can be extended with an architectural perspective. Chapter 4 reviews the literature and develops the architectural framework that supports analytical interpretation and extension in Chapter 5. Chapter 5 presents an architectural analysis of Kometer's air power cases. Chapter 6 contains a trade-off analysis, where we examine the classic efficiency-flexibility-effectiveness trade-off perspective and highlight how the traditional paradigm is altered in cases of information-intensive systems such as enterprises. Chapter 7 is a flexibility analysis of the New England Patriots football team that applies the concepts developed in Chapters 5 and 6. Chapter 8 provides a discussion of the strengths and limitations of this work, future work necessary to enhance the framework, to further develop the initial theoretical extensions presented here. It also discusses applications to other problems such as disaster relief operations, health care operations and acquisition program management.

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Chapter 2

Air Force Concepts of Flexibility:
The Roots of Centralized Control, Decentralized Execution[22]

2.0 Introduction

The roots of difficulty in attaining the U.S. Defense Department's goal of operational flexibility by capturing synergies across the military services run deep and span combat, peacekeeping and humanitarian assistance operations as well as business and acquisition operations. The case of command and control of air operations provides a useful example with which to begin examining how an architectural approach may help address this challenge. A perennial debate among professional military personnel (and many civilians) is how best to command and control military forces. Especially since the advent of combat aircraft during WW-I, there has been a running debate over how best to employ and command the combat power that *aircraft* bring to military operations. This debate generally centers on how to leverage the natural flexibility of airborne technology to achieve political goals via combat operations. These debates usually evolve to differences of opinion about priorities among different missions. Since there are differences of opinion about how best to use aircraft, there are also differences of opinion on how to command them (allocation to missions, control of mission changes and execution of missions).

The development and evolution of air power command and control is described in many historical accounts of the Air Force as a service and of the use of air power in combat during and since World War II. A detailed analysis of these events and their causal forces is beyond the scope of this study. To meet our needs, we will provide a brief overview and general discussion of air power in operations to set the stage for analysis. Current enterprise level challenges in command and control of air power can be traced to early air power theory and theorists. Original thinking on air power, found in the writings of early theorists and advocates such as Giulio Douhet and BGen. Billy Mitchell claimed that future wars would be won by air power alone, obviating the need for a repetition of the carnage of trench warfare of World War I. This strongly

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[22] My thanks go to Dr. Dan Whitney for pointing out the need for this discussion as a way to establish the context and emphasize the importance of our chosen problem and the utility of our approach.

deterministic view is in contrast to the observed indeterminacy of war (Watts 2004; Mattis 2008). The tension between the Air Force view and observed realities of war and combat has generated a cyclic debate within the Air Force and resulted in a cyclic degree of cooperation between the Air Force and the Army over time. Our objective is to expose the tensions that generate operational problems and doctrinal ambiguities regarding command of air power that an architectural perspective can help clarify.

In his research, Kometer examined control of air operations across the strategic, operational and tactical levels of war. He specifically highlighted air-ground operations (close air support and air interdiction, the coordination necessary between ground and air operations in parts of the battlefield where air and ground forces operate in close proximity) as well interfaces across multiple organizations. He concluded that the core doctrine of the air force, "centralized control and decentralized execution" was valid, but vaguely articulated. Kometer then discussed how centralized and decentralized command and control of *air power* can be brought into balance by a systemic approach, but he addressed architectural issues only indirectly. Our architectural examination will take a closer look at hierarchical aspects of inter-organizational interactions that involve control of air power, mainly those between Army and Air Force and mainly in the context of air-ground operations.

We will provide a brief review of the origins and evolution of the air power theory of war. Then we will move to a discussion of how this theory differs from the theory of war held by ground forces. This background will provide valuable insight on the issues of enterprise flexibility in military operations—why it is a challenge to develop the ability for different military services to collaborate in the application of military force.

2.1 Air Power Theory and Command and Control—History

In Douhet's *Command of the Air*, he claims that air power is a necessary and sufficient condition for adequate national defense, that it can achieve quick and certain victory, and that air forces should be resourced in preference to both naval and ground forces (Wylie 1989; Douhet and Ferrari 1998). Mitchell, considered by some the grandfather of the Air Force, was a follower of Douhet and an ardent advocate of a separate air combat arm in the 1920s.[23] Following the thinking of Douhet, air power theorists and practitioners through the 1920s and 1930s came to view strategic bombing—bombing enemy populations, leadership and industrial centers so that political leaders would capitulate—as the sole viable war winning approach to armed conflicts of the future.

The co-equal ideas of establishing air superiority and of airmen alone having adequate knowledge and skill required for effective employment of aircraft in war animated the efforts of airmen seeking to apply air power theory in operations. The organizational and doctrinal solutions derived from these two premises were:

1. there should be only one air commander, an airman, controlling all air resources;
2. this airman should work for the overall theater commander.

This arrangement would enable the full power and flexibility inherent in the technology of aircraft to be leveraged toward the strategic aims of the war and avoid unnecessary diversion and dilution of air power to less important tasks, such as attacking the enemy's army.[24] The fundamental view of air power theorists is that the most important dimension of flexibility in air power is spatial—the ability to range across the depth and breath of a theater of war, massing aerial fire power at the time and place of the commander's choosing. The corollary to this is, as we stated at the beginning of this paragraph, that the most effective use of air power is against enemy strategic targets; all other missions are of lesser importance. The other prominent dimension of flexibility, the ability to operate across the levels of war from strategic to operational to tactical, is of secondary importance. Though this position has been moderated over time, it remains a pervasive and strong preference in current doctrine (U. S. Air Force 2000; U. S. Air Force 2003).[25]

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[23] He was court-martialed in 1925 for insubordination over this issue.
[24] The explicit presumptions are that (a) wars can be won without massive bloodshed if targets are properly chosen and (b) that air power is the only combat arm capable of addressing this class of target.
[25] The historical roots of this priority are found in Douhet. The evolution of thinking and technological development through the 1920s and 30s can be found in other works such as (Greer 1985; Futrell 1989; Murray and Millet 1996; Biddle 2002)

Uses of air power below the strategic level, while viewed as legitimate, were and remain of secondary importance.[26] These missions are interdiction of enemy army's support structure (opposing airfields and aircraft, supply lines, etc.), direct interdiction of enemy army elements that are beyond the range of organic army artillery fires and close air support of elements of our army in close contact with the enemy.[27]

2.2 Ground Force Theory—RADM. J. C. Wylie's analysis

RADM J. C. Wylie's *Military strategy: A General Theory of Power Control* is a seminal but underappreciated synthesis of different theories of war (Wylie 1989). Wylie's early writing on Maritime Strategy and influences on the thinking of naval officers was published in the *Proceedings of the Naval Institute* in the 1950s. He expanded his thinking in the 1960s and published *Military Strategy* in 1967. We will lean heavily on his work, specifically Chapter 5, in this section. In Chapter 5, Wylie discusses four specific theories of military strategy: maritime, air, continental and guerrilla. We will maintain our focus to the "continental" or ground theory in the discussion that follows.[28]

The first issue is that the physical environment combined with technology drives the fundamental outlook of each branch of service. Ground forces (soldiers) are primarily concerned with geography and terrain by virtue of the nature of ground combat. Airmen do not consider geography except to fly over and across wide expanses of it. As Wylie notes, for soldiers terrain "is everything." Because of this physical limitation, soldiers are constrained in their view of operations. They think of operations in terms of a limited geographic area, with directly observable and tangible outcomes of engagements. Wylie points out a second difference between airmen and soldiers: the nature of their combat. Soldiers aim to engage the enemy, maintain that engagement until the enemy is defeated, and then hold and occupy his territory. Airmen (and sailors as well) aim to engage the enemy in a series of separate encounters, moving more freely

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[26] The current Air Force leadership is attempting to change this view, based on statements and strategic intentions of the new Chief of Staff of the Air Force, Gen. Norton Schwartz (Dudney 2009).
[27] This preference order of missions runs through several current Air Force doctrine publications and is mentioned again in Chapter 5.
[28] As fascinating as a detailed discussion of the four strategies and their architectural implications would be, including the guerrilla strategy, we will not dive into this subject here.

around the battlespace looking to find weak points that, when attacked, will cause the enemy to quit suddenly. Wylie's third point, derived from the first two, is that soldiers hold as their objective destruction of the enemy's armed forces as a means to victory.

Wylie goes on to explain that these three factors drive the soldier's view that naval and air forces exist to support him in his quest, to "transport [him] to the scene of action and support him after he gets there." It logically follows that the soldier should want to control those forces that support him. We have already seen that this is markedly different than the airman's view, which explicitly seeks to avoid engagement with the enemy army, instead seeking to influence the political leadership of enemy through strategic attack and, as a secondary function, to isolate the enemy army from its support structures.[29]

2.3 Lingering disagreements create chronic problems

Armies and air forces approach armed conflict with different technical systems, which, in combination with their operational medium, provide them different physical perspectives of conflict. As we have seen, they reach different conclusions about priorities for force employment and methods of command and control. For the U.S. Army and the U.S. Air Force, these priorities are particularly contentious and long-standing (Schlight 2003).

Armies seek to support achievement of political objectives by defeating opposing armies, seizing and holding territory. In World War-II, this meant using aircraft's superior position and mobility to enhance their own mobility, provide reconnaissance of enemy positions and movements and to complement or supplement artillery with airborne offensive firepower. This desire conflicted with a strong community of airmen in WW-II who thought that strategic bombardment of enemy industrial centers was the path to victory, bypassing any need to engage an enemy army. These tensions were not sufficient to cause serious operational difficulties during the war—the Army Air Force was young and there were still a wide variety of opinions about the "best" use of air power.

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[29] This view is also consistent with Clausewitz's *On War* and the idea of a center of gravity that, if disrupted or attacked can have a significant effect on the enemy's collective will to fight.

Before and during WW-II, there were two competing views of the value of air power, the strategic bombing view and the support of ground forces view. Immediately following WW-II, the Air Force became independent of the Army, and the strategic bombing coalition won bureaucratic control of the new service. The story of Air Force support of Army needs in battle over the next thirty years is complex but can be boiled down to a simple statement: the Air Force's primary concerns were strategic nuclear warfare and preservation of its status as an independent service.[30, 31] Virtually all other considerations were secondary. In the late 1970s and early 80s, strategic nuclear warfare was displaced by a focus on deep interdiction and support of the Army in Central Europe (Winton 1996). In the late 80s and since, the strategic focus saw a resurgence, with an emphasis on non-nuclear strikes on critical infrastructures and leadership targets of an enemy (Warden 1988; Warden III 1995).

In Korea, close air support and interdiction were particularly difficult and contentious. During Vietnam, though there were recurring issues with command and control of air power, at the tactical level close air support methods were worked out that enabled particularly effective support (ref). Because of the persistent low priority of close air support and interdiction during the post-war period, over time the Army addressed its concerns regarding longer-range battlefield challenges with it's own solutions. It acquired it's own observation aircraft, attack helicopters and eventually long-range precision missiles.

The post-Vietnam recovery of the Army saw an intense focus on Europe and the Soviet Army with a dedicated program to address Army doctrinal deficiencies identified by Vietnam. The Army realized that deep interdiction was going to be necessary that it would require the Air Force's help, and made it a priority to establish a partnership (Winton 1996). This led to the AirLand Battle doctrine of the late 1970s and early 80s.

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[30] A comprehensive demographic history of Air Force leadership since WW-II can be found in (Worden 1998), good histories of close air support are (Schlight 2003) and (Cooling 1990).

[31] The story of the institutional evolution of air forces (not just in the US) is one that deserves careful study that cannot be addressed here. The UK had a similar tension in the proper use and employment of aircraft, tested during the Battle of Britain. It is notable that the commander of the Battle of Britain (Dowding) was effectively ousted, along with his closest and most effective squadron commander (Park), while the worst performing squadron commander (Leigh-Mallory) was promoted.

This effort gave rise to numerous joint Army-Air Force programs, exercises and common doctrine for air interdiction and command and control. The partnership on AirLand Battle doctrine endured into the 1980s and coincided with the rise of "The Fighter Generals" to leadership of the Air Force (Worden 1998).

The partnership lasted through the late 1980s, about the time that then LCol. John Warden published *The Air Campaign: Planning for Combat* (Warden 1988). This work represented a return to strategic attack theories of air power, advocating the primacy of air power alone in achieving war aims. The Army-Air Force partnership began to wane at this point, as the Air Force began to emphasize once again, strategic attack in preference to support of ground forces. This preference found tangible expression in 1990 as Saddam Hussein invaded Kuwait and the U.S. and its allies responded with Operations Desert Shield and Desert Storm. The air campaign developed for Desert Storm was architected by Col. Warden and his strategy and concepts staff in the Pentagon, named "Checkmate". This emphasis on an air-dominated campaign coupled with the disintegrated partnership of the AirLand Battle, combined to create tension and distrust among the ground forces of the Air Force.

Whatever the reasons for the difficulty of cooperation between the Army and the Air Force, and there are many on both sides of the institutional boundary, the fundamental facts are (Schlight 2003):

1. The Army does not think the Air Force places a high enough priority on support of its operations, despite Air Force protestations to the contrary;
2. The Air Force has been institutionally unwilling to relinquish any degree of control over air assets in battle, has actively sought and, until very recently, succeeded in gaining control over all service air assets in a theater;[32]
3. as a result, the Army invested in technologies that have given it the ability to influence the battlespace at increasing distances from the front lines, creating coordination issues with the Air Force that need to be addressed;

[32] The employment of unmanned air vehicles in post Major Combat Operations Iraq has not been centrally managed (Odierno et al. 2008).

4. Air Force doctrinal priorities regarding missions have not fundamentally changed since at least 1943 (Futrell 1989).

A careful review of Army and Air Force relations regarding air support might show a cyclic pattern, where there are periods of partnership, such as World War II and the late 1970s-early 1980s, and periods of tension, such as post-World War II and from Operation Desert Storm to the present. As we stated earlier, the fundamental issue is that different theories of war and physical realities of combat create differing priorities for missions and the need for different control methods. The Air Force, in its doctrine, specifically deemphasizes the need to coordinate with other services over the allocation of resources, and to allocate assets in support of missions that are not strategically focused. The relationship between the air component and other forces regarding prioritization of missions is shown in Figure 6. As we will see in Chapter 2, Kometer seeks a means to be able to leverage the full range of flexibility in air power—to capture simultaneously its geographic and mission flexibility as a way to address these operational tensions.

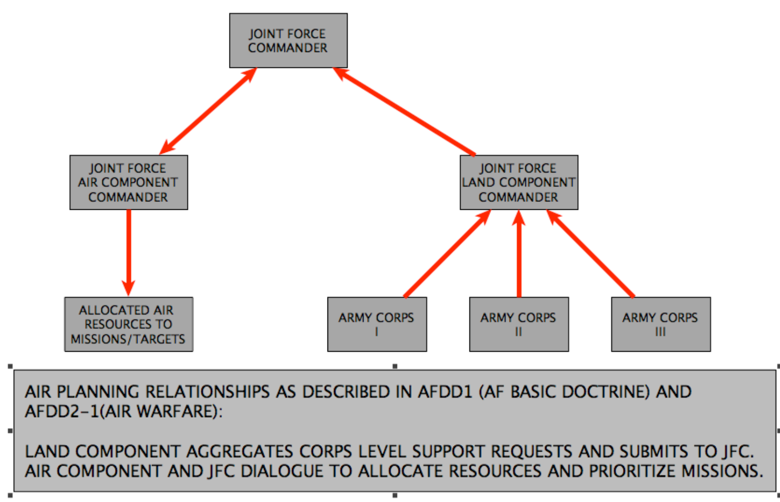

Figure 6: Architectural representation of air-ground command relationships

2.4 General Battlefield geometry and geography

Armies are labor and capital-intensive organizations. They are difficult to move from place to place and require long logistics trains to ensure sustenance. With respect to offense, this means that long-range weapons such as aircraft could be used to attack enemy army’s supply lines and other support structures. These types of missions are classified as interdiction.

Since armies win based on their ability to control physical territory, an army commander naturally wants to control as much territory as possible. This gives him maneuvering room as well as control. So, an army commander, or the army as an institution, is going to seek means to control large areas of land. This means long-range weapons. But also, the army is limited by the amount of weapons it can carry. So it is likely to be unable to attack all of the targets it wants to attack. This is what requires closer support than interdiction, what has sometimes been called battlefield air interdiction. The battlefield air interdiction mission is not as long range as interdiction and not so close to friendly forces that very high coordination is required. But some coordination is required. This generated the need for a "fire support coordination line". At distances short of this line, Army and Air Force must coordinate so that the fires are synergized and don't conflict with each other (Figure 7). Close air support is the mission requiring closest coordination between air and ground forces and is required when in direct contact with the enemy.

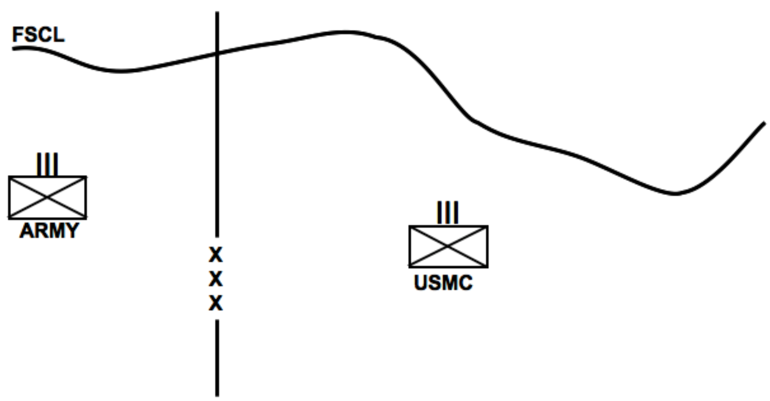

Figure 7: Fire support coordination line

2.5 Army and Air Force Today

Throughout the inter-war period, the Army Air Corps held that the most effective use of air power was to bomb strategically important targets of the enemy, causing him to give up without ever having to engage with the opposing army or navy. The primacy of this view attained full force following World War II with the Cold War and strategic deterrence as centerpieces of national strategy. Following the end of the Cold War, this view remains embedded in Air Force doctrine, though without nuclear weapons as the means to exert strategic coercion.[33] Ground forces see the need to directly engage the enemy, and see air power as a key tool in aiding their effectiveness toward that goal. Ground forces also seek to control and influence as much territory as possible as they seek to defeat the enemy.

The empirical reality of conflicts since World War-II provide strong evidence that the theoretical ideal of strategic bombing as a bloodless way to win wars may never come to pass (Pape 1996; Cooper 2001). In the post-Vietnam era, strategic attack was replaced by deep interdiction as the stand-off with the Soviet Union became the centerpiece of national strategy (Winton 1996). In this period, air-ground coordination became more important in doctrine, practice and procurement. However, it fell in importance with the resurgence of strategic air theory in the late 1980s, aided by the serendipitous invasion of Iraq by Saddam Hussein. The air campaign strategy employed by Gen. Schwarzkopf and LGen. Horner was drawn from a modern treatise on air power theory by Col John Warden (Warden 1988). In any case, today's technology is eliminating many of the impediments to close air-ground coordination that have served as arguments for a "status quo" approach to command and control of air power (Stein and Fjellstedt 2006). These changes, as we will note in later chapters, are blurring the distinction between classically delineated air missions of strategic attack, deep interdiction and close air support.

The emergence of precision weapons, global positioning, two-way air-ground voiced-video and data links, all conspire to make any application of weapons from the air identical in process. Technology has changed the performance discriminator in air-ground operations from "hitting the right spot" to "getting the weapon to the right spot fast enough", no matter where that spot might be.

Aircraft can range the depth and breadth of the battlespace and conduct *any mission* with little difference in cost or difficulty. The key is developing a command structure that can make aircraft available on appropriate timelines. Kometer provided a start at this examination. He placed air power in context of larger strategic issues, not just the "operational level of war" and not limited to the somewhat narrow air power

[33] We discuss elsewhere that Air Force doctrine specifically articulates command relationships that ensure it holds the last word on how air power is allocated to various missions.

strategic view, which is often implicitly and improperly extrapolated to a general view of strategy.

2.6 Summary

While the Air Force claims flexibility as a core capability, a perennial complaint of ground forces is the lack of flexibility in the use of air power to support ground operations. This tension is aggravated by the increasing ubiquity and capability of information technology that enables ground and air forces to collaborate much more easily (especially at the tactical level) and that has improved the operational depth to which the Army can influence the battlefield (Daily 2006). In addition, improved technical capability has begun to blur the lines between traditional air power missions of strategic attack, air interdiction and close air support (Kometer 2005; Pirnie 2005).

In practice, operational military organizations are rarely designed *ex ante*. Though the military is a rare institution in that it documents its organization in doctrine, these structures are usually codified battle experience—documentation of "what worked"—as well as reflective of legal, regulatory, fiscal and cultural differences of the military services. Most military practioners focus on organic modification of existing organizations in response to emergent needs, usually without considering systemic impact or potential unintended consequences (Mandeles et al. 1996). Though organizational structure has always had strategic implications, as information connectivity across technical and social systems increases and improves, organizational architecture has emerged as a fundamental source of competitive advantage (Hax and Majulf 1981; Hammond 1995; Moses 2004a; Mandeles 2005). Architecture has become a key enabler (or inhibitor) of success and failure. Architecture defines the space of operational alternatives in processing information from the environment and the range of possible coordinated actions by determining the number of possible alternative sequences (paths) through the system to respond to changing circumstances.

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Chapter 3

Review and Architectural Interpretation of "Command in Air War"

3.0 Introduction

This chapter reviews the analysis and findings of Kometer's study of air power command and control, titled "Command in Air War." We interpret his process and behavior-focused analysis using an architectural model and identify research extensions that enrich and amplify his conclusions. Understanding the nature of enterprises so that we might be better able to operate and design them is methodologically challenging. We must find a level of abstraction that provides accurate understanding of the principal characteristics of the enterprise as a holistic system while at the same time avoiding detail that can obscure architectural features and properties. Many modeling tools and approaches in use today assume or require a great deal of detail. In addition, many approaches aim at predicting specific outcomes with the (sometimes implied) objective of controlling them. Achieving these goals has proven elusive.

For these reasons, early analyses of enterprise level phenomena have been approached by extending models and frameworks aimed at other problems and by using grounded theory and historical case studies (Kometer 2005; McKenna 2006; Stanke 2006a). Where modeling is attempted at the enterprise level, it is often supported by approaches analogous to models of physical systems, where micro-scale activities within the enterprise are modeled with the intent of precision prediction of events and outcomes. There have been some attempts at multi-level and hybrid modeling, creating a system level model by coupling detailed models built at different scales (Mathieu et al. 2007). Again, the implied or explicit objective of this modeling approach is to increase prediction precision and ultimately precise control of the system.

Many approaches to design of organizations or enterprises aim at the goal of finding an "optimal" design that will lead to predictable outputs and micro-scale controllability that minimize uncertainty. Here we are taking a different approach. The goal of our enterprise-level analysis is to gain an understanding of enterprise architecture that can help design flexible enterprises. We are interested in flexibility at the enterprise level because, as noted in Chapters 1 and 2, the operational environment in the early 21st

Century demands it. In the area of combat air operations, the challenge is particularly acute. The evolution of operations in Iraq has been toward missions that the Air Force has traditionally (since WW-II) deemphasized: close air support. In addition, these support missions have been increasingly located in or near urban environments. These missions and environments are characterized by higher rates of change and higher degrees of uncertainty than the traditional interdiction or deep attack missions that are more central in Air Force doctrine.

Our approach to enterprise modeling and analysis aims at supporting the creation of structures that enable flexibility, so that *effective outcomes* are achieved in a changing environment, rather than attempting to predict or control behavior precisely with the aim of delivering well-known (and precise) *outputs*. To do this we need to connect architecture to flexibility.

To accomplish this task, we take an existing set of case studies performed in a systems-level framework and interpret them through an architectural-structural framework. Our starting point is "Command in Air War", Kometer's analysis of command and control of air power (Kometer 2005).[34] To guide interpretation and modeling of this analysis, we will concentrate on system level properties relevant to design and management of flexibility. Specific focus is on interactions among the hierarchy of organizations and systems discussed in "Command in Air War".[35]

This chapter summarizes Kometer's research, focusing on hierarchical structures and how these relate to or enable flexibility. Our approach is in line with his basic premise, which posits that an emerging source of competitive advantage in the 21st century is the management and design of relationships among systems and organizations (p. 19).[36]

3.1 Overview of Kometer's thesis and recommendations

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[34] Where page numbers are used as citations in this chapter, they refer to Kometer's Ph.D. thesis.

[35] Our focus on the structure of interactions, with less emphasis on explicit properties of individual nodes, is consistent with Kometer's emphasis on command relationships—the interactions among different organizations along the command hierarchy.

[36] Page number citations in this chapter refer to Kometer's thesis.

Kometer's thesis, "Command in Air War: Centralized vs. Decentralized Control of Combat Air Power" is a system-level analysis of an enterprise. His analysis is conducted at multiple levels of command hierarchy and across multiple dimensions of operational performance. He examines events from multiple perspectives across a variety of conflicts and distills them to develop an overall assessment of causal relationships that drive enterprise level behavior.[37]

Kometer focuses on a key aspect of the air power enterprise that we claim is the source of advantage to any enterprise in the information age: relationships among people, organizations and systems. Based on his causal analysis of four air campaigns from 1990-2003, he synthesizes two recommendations for addressing the tension that has challenged commanders of air power through history: control vs. empowerment. Indirectly, he also focuses on a key attribute of enterprise architecture that we are interested in: flexibility.

His first recommendation is what he calls the "general formula for command and control." In the general formula, Kometer recommends that commanders at each level of organizational hierarchy delegate responsibility for the plan to the next lower level and then conduct a robust debate of the operational plan (cross-layer interactions) as it is developed. As part of this debate, the commander should ensure that, where coordination among subordinates is necessary, it is provided (lateral interactions). His second recommendation is that, as part of implementing the general formula, commanders should strive to achieve "depth of command." Depth of command is his term to describe the ability to shift decision-making to lower levels of command hierarchy in response to shifting external conditions. Depth is achieved by focusing on establishing relationships between elements of the organization that will need to interact in the course of the planned military campaign. Provision for depth should be made because of the process of implementing the general formula (p. 240).

[37] Kometer's main interest is in behavior: how system interactions give rise to either good or bad behavior when viewed in the context of constraints and desired outcomes. Behavior is not performance, nor is it a system property. We are interested in a specific system property: flexibility. Performance is a subjective matter, highly contingent on the evaluator's perspective and perception of what constitutes "good."

Kometer's attention is not specifically on flexibility, but on developing (in our framework, designing) a capability to respond effectively to the dynamics and uncertainties of combat while maintaining a level of control that manages risk and achieves favorable outcomes. His aim is to provide a means to balance control—detailed management of systems, people and events—with empowerment—the need to innovate at critical times when the environment does not respond as predicted. The process of planning and of command that Kometer recommends is clearly aimed at building (designing the architecture of) a flexible enterprise. Analysis later in this review will make this connection clearer. For now, we say that balancing control and empowerment is enabled by flexibility; the structural effect of implementing depth of command as a principle of enterprise architecture is to create the ability (in real time) to change the configuration of the Combat Air Operations System (CAOS) in response to changing requirements of the environment.

3.2 Intersection of this research with Kometer

Kometer focuses on causal relationships that drive command and control of air power and, ultimately, its effectiveness in battle. We intend to focus on architectures of the enterprises that conduct command and control. His two recommendations, the general formula for command and control and depth of command, aim to at balance the contradictory demands of effective operations in risky and uncertain operations: management of the risk of bad outcomes and the need to respond quickly to unforeseen circumstances. These are methods to achieve flexibility by building different enterprise architectures. For example, Kometer discusses using depth of command to empower low-level entities to allocate resources, define, assign and direct tasks to accomplish a mission—changing the structure of operational decision-making, increasing the number of possible force combinations and making them available on operationally relevant time scales. From an architectural perspective, the net effect of implementing his general formula and achieving depth of command is to change the structure of the enterprise.

Our thesis aims at two complementary goals: (1) developing knowledge to support architecture design in complex enterprises such as military operations and (2) a model to help understand trade-offs between different possible enterprise architectures that could be implemented.

While Kometer focuses on patterns of interactions and behaviors, we are interested in architectures for operational command and control.[38] We aim to provide diagnostic tools that can help commanders employing Kometer's recommendations understand how to match better their enterprise architecture to policy constraints and operational situations as well as to show them whether they are achieving or moving toward their desired architectural goals.

We aim to understand the structures defined by the patterns of interaction that Kometer describes and to understand and model how these structures inhibit or enable flexible response to dynamic and uncertain environments.

3.3 Summary review of Kometer's research and recommendations

Kometer's thesis investigates how political strategy and policy is transformed into combat air power. He begins with an examination of historical foundations for current doctrines and practices governing command and control of air power. This historical analysis identifies patterns and trends in the employment and control of air power and the influence of technology on these trends and patterns. Following his historical review, he conducts a CLIOS analysis to obtain a system level perspective.[39] CLIOS diagrams visualize causal relationships and feedback loops between policy and combat organizations, activities and systems. Done well, a CLIOS analysis should enable prediction of system-level behaviors.

Kometer's CLIOS diagrams identify significant interactions that drive system level performance. The main body of the thesis is an examination of these interactions in through four historical case studies of combat air power employment over the 1990s:

- Desert Shield/Desert Storm (1990)
- Operation Allied Force against Slobodan Milosevic in Kosovo (1999)

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[38] The term "command and control" has become synonymous with technical systems such as communications networks and, more recently, other information systems that ***support*** operation and command of military forces. We use the term much more inclusively, encompassing doctrines, methods, organization structures and relationships—all of which are bound together by information systems.

[39] CLIOS: Complex, Large-scale, Integrated, Open System. CLIOS is an analytical framework developed by Prof. Joseph Sussman to support analysis of how policy impacts complex collections of physical systems.

- Operation Enduring Freedom in Afghanistan (2001-2002)
- Operation Iraqi Freedom (major combat operations through May 2003)

He examines each case from six different perspectives as shown in Figure 8, using these

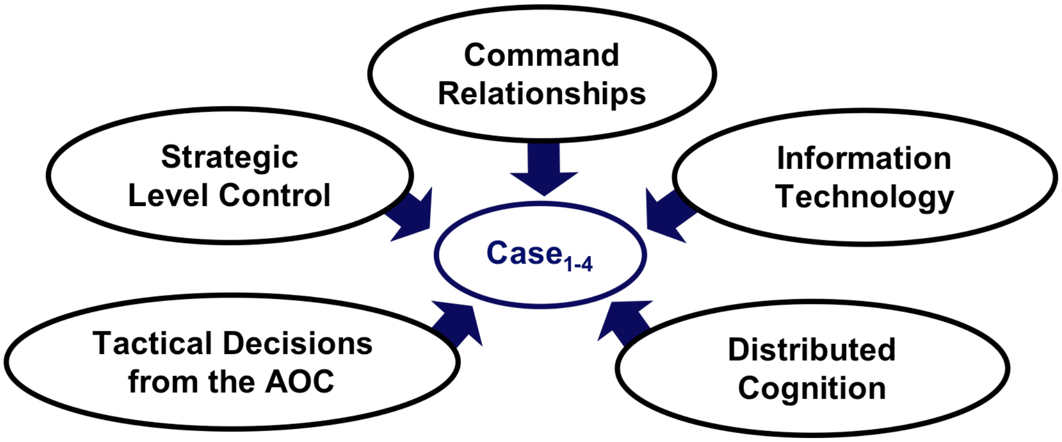

Figure 8: Kometer's analytical lenses

views to identify common features and causal relationships in the system. Using these insights he develops the two core recommendations to improve command of combat air power: (1) a general formula for command and control and (2) a design concept called depth of command. As a pair, these concepts aim at providing senior civilian and military decision-makers the ability to balance risk management in combat operations with the imperative to enable innovation in the battlespace. These recommendations represent two unique contributions:

1. An extension of classic civil-military command relationship thinking to all levels of the air combat enterprise;
2. A more explicit connection between command and control approaches and the ability to respond effectively to a wide array of operational demands and risk profiles.

3.4 Connecting Kometer's recommendations to enterprise architecture flexibility concepts and framework

Kometer's recommendations aim to address long-standing tensions between control and empowerment in command of air power. These tensions result from a strong institutional desire to validate air power theory, recurring disagreements with policy makers and other services over proper use and employment of air power in military operations and the need to have different control modes for different air combat missions (Kometer 2005) (p. 26 and 34). His case analysis is conducted over a period of rapid technological change, so the analysis also addresses impact of technology on trends in control and on the changing preferences of policy makers regarding employment and control of air power. This approach makes his recommendations generally applicable to almost all cases where air power might be employed

First, Kometer's general formula says that commanders should establish a thorough debate up and down the chain of command during the planning process—that the plan should be communicated across multiple levels of command and discussed in a "back and forth" mode. This requires flexibility at the enterprise level, by having multi-level interaction (information flow) paths through the organizations that make up the enterprise. Every planning process unearths coordination problems, unforeseen information needs, and new perspectives on the overall approach to the organization's objective. As new information and knowledge is gained through the planning process, the general formula tells commanders to ensure their enterprise is able to establish new interactions to ensure coordination, to ensure that uncertainties are exposed and resolved as best possible and that disagreements over the plan are resolved.[40] At the organization level, member organizations of the enterprise must have flexibility, which can be as simple as having the ability to have shift priorities among missions or resource allocations or as complex as having multiple alternatives for processing information.

Second, depth of command is the capability of the enterprise to shift command locations up and down the depth of the enterprise hierarchy during operations. Depth of command enables flexibility within a tree-like (pure) hierarchical architecture, the ability to have alternative decision flow paths through the organization in response to changing external requirements and internal risk management profiles.

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[40] Kometer's general formula is about much more than information flow. It is implicitly about generating and sharing knowledge, reducing uncertainty, minimizing chances of error and developing a team. It is also about creating depth of command and effective responses to uncertainty as it unfolds. But at the risk of reading the general formula too closely and semantically, it is mostly about coordination, planning and direction; there is very little explicit or even implied collaboration in the concept (a word count of Kometer's thesis reveals 8 uses of collaborate/collaboration and 186 uses of coordinate/coordination).

Kometer's two recommendations for command and control represent architecture design rules. They represent tools that commanders can use to implement high-level guidance by mapping organizations and technical systems to implemented configurations. Further, as we noted Kometer strives for flexibility inside a tree hierarchy by creating depth of command as an enterprise capability. This thesis extends that concept by examining the role of lateral connections at multiple layers of hierarchy, connections which we view as necessary to enabling flexibility while simultaneously balancing the need for control and accountability that depth of command aims to retain.

3.5 Detailed summary of Kometer with an architectural interpretation

This section presents a chapter-by-chapter summary of Kometer's thesis.

3.5.1 Scholarship and historical foundations

The significant growth of the Internet coincided with the end of the Cold War to create an imperative to develop new operational concepts, new organization structures and new technical systems. In fact, the imperative was for more than this. With post Cold War fiscal constraints, it became important to capture synergies among the different branches of military service. With this came the requirement to make each service's systems interoperable, not just within service boundaries but also across them. The institutional embodiment of these forces came in the concept of Network Centric Warfare (NCW). Kometer briefly reviews the NCW concept and its argument for decentralized control. He also highlights the confusion that has developed because of recent empirical evidence indicating a tendency toward centralization of control in practice, both within the military as well as at the political level.

To establish a clearer perspective on military command, Kometer reviews seminal works on command of military forces by Samuel P. Huntington (*The Soldier and the State*), Eliot Cohen (*Supreme Command: Soldiers, Statesmen, and Leadership in Wartime*) and Martin van Creveld (*Command in War*). Huntington and Cohen address the relationship between political leaders and the military, van Creveld deals with command on the military side only. Kometer creates the motivational force for his research by noting that Huntington and Cohen separately are incomplete but together provide a useful framework for command—robust debate of ways, means and ends, with political leaders exercising control over the military. He takes van Creveld's approach to military command, which advocates that the commander gather information from the battlespace to inform his decisions, but craft an organization that can operate without detailed direction and under conditions of uncertainty. Kometer combines these two approaches and extends them to the total military enterprise: the Huntington-Cohen command-debate method should be extended to lower military echelons and van Creveld's military command approach should be extended to the political level (oversee, but don't micromanage; create organizations that can operate without detailed direction). He also notes that these works do not directly address the unique technology and operational capability of air power, van Creveld's in particular.[41]

To lay the foundation for his analysis, Kometer reviews the history of command of air power since World War II. He reviews:

1. The various ways that political and military commanders have managed, controlled and employed air power;
2. Tensions between air and ground commanders over the balance between giving priority to strategic attack of enemy political leadership and civil-military infrastructure or to more direct support of ground operations against an enemy's military force;
3. The impact of centralized vs. decentralized control methods on effectiveness of air power;
4. The influence of technology on command and control;

Kometer observes that the engagement of policy makers in the command of air power over the years varies with the situation and political forces driving the specific conflict. The main factors that have combined to influence the overall trends of this political engagement are:

1. Increased media feedback loops that can bring tactical level events to strategic and political level importance (e.g., collateral damage);

[41] Kometer notes that Cohen addressed some situations that included air power (p. 24).

2. Increasing precision in weaponry the promises the ability to exert precise control or influence over adversaries (though the promise remains unfulfilled).

Consequently, politicians have sometimes placed tight constraints on the use and employment of air power and have sometimes "micromanaged" it.

Looking inside the military organization, he finds the Air Force has never wavered from its World War II lesson learned of centralized control of air power.[42] In Korea and Vietnam achieving central control was elusive. However, although the services were never able to agree on this point at the beginning, by the end of each conflict it was clear that a single manager for air power was a necessary ingredient for success. This is where Kometer begins to identify command relationships as a core issue. In each conflict, differences of opinion between ground and air commanders (and sometimes between air commanders) generated friction that more often than not precluded single point control of air power. Even more fundamental in control of air power than command relationships are mission priorities and who gets to establish and enforce them. The Air Force, because of the capability at its disposal, provides high-level command with longer and wider combat reach than land forces. But land force effectiveness can be improved tremendously with air support and it seems reasonable that ground commanders want to have some measure of control over air assets aimed at supporting their objectives. Kometer addresses command relationships as a driver of combat outcomes; command relationships are also a key driver of the ability to adjust mission priorities, to achieve flexibility in adjusting air power mission priorities[43]

At the tactical level, the Air Force has had to repeatedly re-learn and reinvent procedures for supporting ground forces. Air power theory holds as a central belief that air power can dramatically affect the will of an enemy to continue in battle in such a way as to make air power the sole determinant of a war's outcome (Mitchell 1925, 1988; Warden 1988; Douhet and Ferrari 1998). Though this belief has been challenged on both

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[42] The codification of a single commander for air power was a result of lessons learned from the Battle of Kasserine Pass, the first major engagement of U.S. Forces in the European theater in World War II.
[43] A deeper discussion of these differences can be found in RADM. J. C. Wylie's *Military Strategy: A General Theory of Power Control* (Wylie 1989)

empirical and theoretical grounds, it holds tremendous influence over the Air Force as an institution (Wylie 1989; Pape 1996; Watts 1997). Kometer points out that for a combat arm that can deliver multiple capabilities to high levels of command, different modes of control are appropriate for each type of mission (p. 55).

In summary, there are four main insights developed from Kometer's review of air power history, some internalized by the Air Force, some not. First, history shows that in every conflict since WW-II, without a single commander to coordinate air power, the air efforts of different branches of military service were fragmented and often uncoordinated. The claim of air proponents is that this prevented full utilization of the potential of air power and a loss of strategic focus in these campaigns.[44] Therefore, there must be a single commander for all air assets to ensure optimal employment. Second, the Air Force had to re-learn in each conflict since WW-II that control modes effective for deep strike and air interdiction missions are not effective for ground support missions. Therefore, because of the diversity of mission capabilities brought by air power, multiple modes of control are necessary. Third, political leaders have learned to pay close attention to the employment of air power, since connection between tactical level events and strategic level considerations has increased as real-time media connectivity diffuses globally. This trend has paralleled the tendency for political leaders to use air power more frequently and for non-vital national interests, motivated in part by the increasing ability of the Air Force to engage targets with precision weaponry, which offers the promise of low risk manipulation of enemy political behavior. Lastly, the Air Force continually invests in technology that improves the ability of headquarters organizations to gather and process information about the battlespace as well as to more precisely engage targets and to predict the impact of targets on the overall behavior of the enemy from a systems perspective.[45]

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[44] The general claim of air power advocates that air power was "suboptimized" is debatable. A case has been made that air power in every case was employed as the national leadership wished (Cooper 2001). Regardless of this evaluation, what the record does show is that lack of a unified command structure for air resources resulted in *ad hoc* mission assignments, confused relationships and many distractions for the theater commander, starting with the Battle of Normandy. A succinct summary can be found in Appendix 2 of Volume 1, Part 2 of the Gulf War Air Power Survey (Cohen 1993).
[45] For a discussion of viewing the enemy as a system, see (Warden 1995; Warden 1997).

3.5.2 CLIOS analysis.

To get a handle on these factors and how they influence each other, Kometer conducts a CLIOS analysis. CLIOS is a two level analytical framework for exposing feedback effects among policy and complex technical systems. The goal of a CLIOS analysis is to improve overall system understanding regarding the impact of policy actions on technical systems. Kometer's CLIOS analysis of the Combat Air Operation System (CAOS) identified the following key dynamics (p. 83-84):

1. Command relationships: High-level policy constraints cascade to lower levels and how the nature of these constraints affects outcomes. When high-level military command is constrained by political considerations, control tends to become centralized. This can limit the ability of the CAOS to respond to uncertainty.

2. Longer term interaction of policy constraints and technical capabilities: Technical capabilities change the "art of the possible" in terms of combat air power. Politicians modify their employment based on these changes. In turn, the Air Force, with its desire to conform to its doctrine, chooses to invest in new technologies that both further the doctrine as well as address shortcomings in exposed through operations. These dynamics create changing relationships between combat situations and the methods of control necessary to achieve desired outcomes.

3. The impact of political constraints on how command relationships in the CAOS are formed and the nature of those relationships.

4. The ability of the Air Operations Center (AOC) (and other decision making organizations) to gather information, generate accurate representations of the world in order to make decisions about how to command air power and, when necessary, control it. The AOC has been continuously improving its ability to gather and process information. It has attained the ability to directly sense and direct tactical level actions from afar. But it has had recurring difficulty in gathering information

the enables adequate (accurate) battle damage assessment from those tactical actions.

5. The need for and ability of the AOC to balance precision in employment (achieve specific outcomes) with the need for increased speed of response. Specific outcomes generally imply a central direction and control mode, which can take longer than locally directed action. Locally directed action generally runs the risk of an error (at least from the perspective of higher headquarters with a different information picture and different risk management priorities).[46]

These key dynamics are the foundation for the analytic focal points of Kometer's thesis.

3.5.3 Strategic level and evolution of air power control

Kometer begins his case analyses at the strategic level. In this section, he reviews how policy makers either did or did not constrain the use of air power over the four cases. Kometer's examination illustrates how differing levels of constraints as well as different levels of attention to political-military differences over goals and objectives shape the employment and effectiveness of air power. He exposes the long-term impact of the use of constraints by politicians on evolution of command and control systems and processes implemented by the Air Force. He also highlights that the short-term impact of constraints is on the nature of command relationships (depth) that are developed within the CAOS during a specific campaign.

In general, the increasing use of air power for limited scale conflicts creates motivation for politicians to tightly constrain its employment. This has driven the Air Force to invest in technology and systems that enable central direction and the processing of ever more detailed information about battlespace operations. As a result, the AOC has become a hub of information and control activity—an integrator of intelligence, surveillance and reconnaissance information. This integration has led the AOC toward

[46] This is a complex trade-off, which is highly dependent on the specific situation. There are cases where control from the top can be both precise and fast as well as cases where local control can lead to inaccurate and slow response.

real-time direction of combat aircraft, an activity consciously avoided in the first conflict in the study, Desert Storm (Mandeles et al.).

Kometer also identifies in his cases the fact that as constraints increase, the ability to innovate at lower levels decreases. While in tightly controlled and politically sensitive situations this style of command is appropriate, he discovered that it is difficult to shift to an innovative mode of control when it becomes necessary to loosen constraints. This phenomenon is one factor driving his depth of command concept.

3.5.4 System level command relationships

Next, Kometer examines command relationships in the context of constraints, empowerment and technology, an effort that yields several insights. First, when politicians tightly constrain the use of force, military commanders generally do not empower their subordinates. This leads to a tendency to control from the top and inability of the operational level headquarters (AOC) to adjust effectively to dynamic battlespace conditions. Conversely, when politicians impose fewer constraints, empowerment "trickles down" to lower levels, enabling rapid response to demands for shifting control modes. However, in some cases, technical limitations can constrain the ability to fully empower down to tactical level forces.

A second factor Kometer identified in this chapter was evolution in the employment of air power and the types of missions for which it is employed. The emergence of Time Sensitive Targeting (TST) as a mission (both driven and enabled by the advance of precision targeting and information processing technology) blurs the lines between traditional air force missions of strike, interdiction and close air support (p. 139). Traditional control modes, roles and relationships that rely on visual cues, extensive voice coordination and rigid rules regarding weapons release authority between ground and air forces, as well as relationships between aircrews and headquarters (AOC) personnel are increasingly inappropriate or suboptimal as these mission lines blur. Command, especially in a TST mission, must be based on good information, so the location of the command function within the hierarchy is constrained by where the best situational awareness can be provided. Kometer ends this chapter by stating that shifting control from ground to air forces in specific tactical situations requires “a command presence with total situational awareness” (p.140).

The architectural perspective on this chapter is that top down control creates fewer potential interactions that can be leveraged when it becomes necessary. Tight constraints in the overall architecture create fewer alternatives (options). Concurrent with this observation is an evolution in employment of air power that demands development of new control modes. Evolving missions do not fit existing control architectures very well. Kometer implies that only technical issues (information processing and access) limit the development of more appropriate control modes. This conclusion may be overly conservative—there may be other ways to adjust enterprise architecture than purely technical ones.

3.5.5 Information processing in the CAOS

This chapter reviews the use of information technology to bring battlespace information to headquarters organizations and to share information among organizations. Kometer finds dramatic improvement across the 1990s in the ability to share information digitally within and among organizations. In Desert Storm it was unusual for the air headquarters to have a complete air picture of the battlespace (Cohen 1993, p. 74). By the time of Operation Enduring Freedom in Afghanistan, a consistent, real time picture of the battlespace was the norm (p.153).

Kometer identifies a common fallacy of many advanced military operational concepts: the “common operational picture”. His analysis showed that, even with good information, it is still difficult to assess precisely and in totality conditions in the battlespace and progress toward political goals. He points out that data and information aggregation and interpretation is still largely an individual process and that people differ in perceptual capabilities.[47] This fact makes attaining a common strategic assessment of ongoing progress in a campaign difficult.

The bottom line of this chapter is a tension. First, lower levels of command are still “information poor”, creating an impetus to make decisions in a central headquarters

[47] Different people can reach different conclusions when presented with the same information.

that could (or should) be decentralized. But on the other hand, even if lower levels could have (will have) better information that could enable decentralized decision-making, errors of judgment and perception will still be committed. He identifies the nascent indication of potential decentralization: the routine establishment of a "time critical targeting" (TCT) cell in the AOC. In every campaign, a new organizational team (cell) had to be created to deal with time-sensitive tasking. In Desert Storm, it was the ATO Change Cell; in Kosovo, it was a loosely coupled team of three different cells. By the time of Afghanistan, it was a formally established TCT Cell (p.153). Over the course of the four campaigns, this functional decentralization (even though physically located in the AOC headquarters) had become necessary in order to shorten the response time for TSTs and to leverage the inherent flexibility of the air arm.[48]

3.5.6 Time-sensitive targeting (TST)—AOC decision making

Next, Kometer examines the evolution of the AOC's insertion into real-time targeting decisions. He notes that in Desert Storm processes were developed to push real time target decision making to lower echelon control nodes, including pilots, through techniques called "Push CAS" and "Killbox Interdiction". These techniques were aimed at placing decision-making where the best information existed as well as to make the CAOS more responsive to real time developments in the ground campaign. These procedures were driven by a mixture of the inability of the AOC to gather the requisite information to direct real time targeting and by the command philosophy of the air commander, LGen. Horner.

However, in Kosovo there was no ground force to help guide the aircraft toward targets and target areas. Couple this with increased political risk and the AOC was forced to inject itself into the targeting process. To accomplish this task it created a set of separate cells (teams) to gather, process and pass information to aircrews over Kosovo. This organization and process was only moderately successful and stimulated technical

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[48] It is also possible for currently decentralized decisions to move up the command hierarchy as well. With improved access to imagery databases, close air support (CAS) that previously had to be conducted by Forward Air Controllers (FACs) can be conducted by higher echelon units, as related by Capt Harold Qualkinbush in a U.S. Marine Corps Oral history interview dated April 5, 2003 (Lowrey 2005).

investments and process changes that increased information gathering and processing capabilities for the AOC.

Architecturally speaking, the TCT cell is what we term a 'lateral organization'. It connects peer organizations in gathering, processing and commanding air assets in the prosecution of time critical targets.[49] Its reason for existence is to enable (leverage) the inherent flexibility of air power. Kometer notes, however, that flexibility can be hampered if the headquarters is too involved in real time decisions because the subordinate levels lack empowerment (real and perceived), hence tend not to leverage all of their capabilities. He also observes (as he did in the previous chapter) that it is still not possible (may not ever be possible) to pass enough information to lower levels for effective decision-making in all possible cases.

A key observation related to the architectural focus of my research is the second to last paragraph of this chapter (p. 188).

> "Prophets of Network Centric Warfare envision a time when all in the system will have the ability to access the same information. If this occurs, there will then be a necessity to make conscious decisions about who should make decisions. Gen. Franks made a move in this direction when he established the matrix for TSTs in Iraqi Freedom. This will have to be done in a way that affirms and emphasizes the command relationships…"

The overall insight from this observation and this chapter is that, as information access diffuses across the enterprise, competitive advantage shifts toward *architecture and architecture design*. "Decisions about who should make decisions" is an architecture design issue.

Some circumstances drive the AOC and other higher headquarters to become involved in real time decisions in the battlespace. There are also conditions where it is

[49]Note that the term "time critical target" and the term "time sensitive target" are almost synonymous and that both are unclear. As recently as Operation Enduring Freedom, the term "time sensitive target" had two meanings depending on the level of command and the interests of the commander. For General Franks, these were time ***sensitive*** targets; for the AOC they were ***time*** sensitive targets. This created friction in the prosecution of many strategically sensitive and fleeting targets (LaVella 2003). The confusion of terminology highlights the evolving nature of classic divisions among target types.

necessary to ensure lower levels have decision-making authority. As information access diffuses to lower and lower levels of organization, enterprise architecture design decisions need to be made such that response to the environment is dynamically optimized. The dimensions of decision on control vs. empowerment hinge upon the following factors: risk (manifested as political constraints on operations), operational philosophy, information needs and information gathering capability.

3.5.7 "Distributed Cognition": Fragmentation and dispersion of function chains

The last part of Chapter 7 opens the door to enterprise architecture analysis, alludes to the subject of Chapter 8 and is directly related to the issue of enterprise flexibility. Chapter 8 deals with the impact of distributed information and dispersed decision-making on enterprise performance. It chronicles the transition of the CAOS to a true enterprise—multiple organizations with intersecting (but not always aligned) interests working toward a common goal. What Kometer describes as distributed cognition is the physical distribution of functions in the kill chain to a set of globally dispersed organizations. This distribution and dispersion creates complexity and alters traditional roles of these organizations. Kometer argues that this change places a premium on understanding and paying attention to command relationships. We take this one step further and argue that we must have a deeper understanding of architectures on system level properties, specifically the impact of hierarchy and multiple layers of abstraction.

For enterprises to be effective (for distributed cognition to work), they must have the ability to shift control dynamically among units of the enterprise. This need for dynamic control requires that aircrews and other participants acquire new skills as well as limiting employment or use of other skills, something Kometer defines as "latent excess capability" (p. 227). Latent capability is equivalent to an embedded but not always exercised option to execute a function or establish an interaction among members of the enterprise when it becomes necessary. This latent potential increases flexibility but also increases risk that organizations (specifically aircrews) acting autonomously will inadvertently cause accidents. Kometer addresses this issue in Chapter 9.

From an architectural perspective, this latent capability is represented by structural interactions designed into a network graph. These interactions represent potential alternatives that can be used when necessary. Observations of patterns of interaction while the enterprise is operating can tell us actual flexibility or the nature of control in use at any point in time. They represent Kometer's depth of command and the interactions necessary to implement the general formula.

3.5.8 Failure issues in distributed operations of complex organizations

Chapter 9 focuses on system accidents, a feature of complex systems where, despite the best efforts to prevent them, failures occur. Bombing incorrect targets, friendly fire incidents or casualties to non-combatants are the focus of this chapter. When 'kill chain' tasks are distributed through many organizations, both an increase in responsiveness as well as increased potential for mistakes is enabled. Flexibility in the form of latent beneficial connections among systems, people and organizations can enable pathological sequences as well.

Kometer addresses this issue by reviewing cases of overly tight and restrictive procedures that eventually came to be ignored because they did not match the risk profile or efficiency demands of day-to-day operations, resulting in a loose set of relationships among the parts of the air operations system. In these situations, problems arise when the restrictive procedures that have come to be ignored, must be invoked because of changed requirements. Kometer describes these as shifts from loosely coupled situations to tightly coupled ones. Once a situation becomes tightly coupled, accidents are more likely because operators cannot shift from their evolved mode of loose control quickly enough, or the need to shift modes is not perceived until an accident occurs (p. 221).

In the context of architecture design, Chapter 9 presents a discussion of a cost of what might be called "*ad hoc flexibility*": increased chance of unintended consequences (cascading failures and pathological event sequences) as well as the cost of measures intended to minimize chances of these types of failures. Kometer's general formula and depth of command concept are intended to mitigate (but not eliminate) this pathological feature of complex systems.

3.5.9 Conclusions: General formula and depth of command.

Kometer's final chapter ties together the observations from his four case studies through five different analytical lenses. Though stated and reinforced throughout the thesis, his recommendations for a general formula for command and control and the 'depth of command' concept are discussed in detail here.

The general formula for command and control is synthesized from the three seminal studies of military command reviewed in Chapter 2 as supported by the case analysis. My architectural interpretation of the general formula is that the commanders at *each layer of hierarchy* should engage in a vigorous, *two-way vertical dialog* with subordinates. Where *subordinates within a layer need to collaborate, the commander should ensure that this collaboration occurs* (two-way *lateral connections* at a given layer in the hierarchy). Viewed this way, Kometer's "general formula" becomes a recommendation to create (design) a layered hierarchical organization so that the 'nearly decomposable' problem of air power command and control can be 'solved' as much as possible prior to 'run time' (Simon 1996; Clark et al. 2005). Kometer's general formula is about information processing: the commander (political leader) injects tasking at the top of the organization, information flows among the component parts, and then back to the commander. The commander decides when the process has provided an adequate solution to the tasking. This is much like an iterative product development process, where work is processed among project teams, where feedback causes re-work (iteration) and, when certain criteria are met, an output from the process is generated (Arrow 1974; Yassine et al. 2003; Huberman and Wilkinson 2005). We are not as interested in this as we are in the ability to have multiple alternatives for information to flow among different parts of the enterprise, as it is discovered and as it becomes necessary in the process of solving the problem. This objective is separate from the issue of ensuring the likelihood of a "good" decision. Organizations (especially military ones) make large investments in ensuring that its members are able to make "good" decisions, often under pressure and uncertainty. But often, there are heavy structural barriers to implementation of these decisions.

Depth of command aims to achieve the ability to shift command authority up and down the hierarchy in response to changing operational needs for centralized or decentralized control. Through the course of implementing the general formula—engaging in a vigorous debate over the strategy and operational plan and the development of detailed missions (tactical implementation of the plan)—commanders should be able to identify where and under what circumstances different components must interact and where local decision-making will likely need to occur. By pre-defining these situations and providing information access at the locations where they are likely to arise, commanders can "design-in" flexibility to the enterprise.[50]

3.6 Extending Kometer's research: Motivation and a modeling approach

My motivation for extending Kometer's research is two fold. First, military operations are the typical complex system. There are few areas where technology and organization are so densely intertwined and applied to a problem as dynamic and uncertain as combat operations. In peacetime, different services are essentially autonomous organizations, nearly decomposable in the Simon sense. But when combat operations commence, they come together with a common and compelling interest, conforming to the definition of an enterprise, requiring initiative and flexibility within the multiple levels of organization and stronger interactions among the decomposed parts than Simon implied in his work (Simon 1996).[51] This implies that a hierarchical view of structure might yield insight to the properties of complex military operations that are not accessible otherwise.

Second, Kometer approaches his analysis from the perspective of the emerging key source of advantage in the information age: interactions and relationships among distinct, often stand-alone systems and organizations.

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[50] There are many methods involved in gaining this knowledge, such as a formal iterative planning process, training exercises, wargames and test and evaluation of new technical systems. Each of these is appropriate to different aspects of developing depth of command.

[51] Note that peacetime exercises are increasingly frequently conducted with multi-service participation. This trend began in earnest in the late 1990s, with the first truly multi-service (Joint) exercise/experiment conducted in 2000 (Millennium Challenge-00) by the United States Joint Forces Command. These exercises are aimed at improving inter-service coordination and cooperation, as well as testing new equipment and procedures against (hopefully) likely future operational scenarios. This trend may be an implicit recognition of the loss of an extensive "learning period" in future conflicts. Though a learning curve in combat and military operations will always exists, the U.S. has been actively seeking ways to minimize this phenomenon.

Kometer specifies a system for creating architectures and structures.[52] The recent explosion of network theoretic research shows us that structural analysis can reveal important characteristics of a complex system not accessible via other methods (Braha and Bar-Yam 2007). My claim here is that structural analysis and a model built upon Kometer's concepts can help move toward better insights to the properties of complex military operational enterprise systems.

Kometer specifies how to do things: how to develop a plan more effectively and how to achieve a balance between risk and innovation. His work is silent on how to know whether what is created corresponds to a commanders' intent. Indeed, Kometer provides no way to concretely assess whether the structure created by his method (or that evolves over time as operations are executed) matches well the intended operational context. Knowledge of properties of different structures is necessary in order to understand how to match them to operational problems and contexts. This is a problem of design. We also need to know if the structures we are creating are the ones intended. This is the management problem.

A model of structure that illuminates the system property of flexibility is our starting point. Kometer addresses behavior and cause-effect. I intend to address structure and certain properties of structures—this is a more abstract and general view, which should be applicable outside the air combat problem.[53] Complementing the challenge of structural analysis, we also need to understand how architecture maps to structure: how do the high-level design rules create complex enterprise structures?

To restate, our core modeling hypotheses are:

1. Architecture drives the creation and evolution of relationships in an enterprise—its structure.

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[52] As discussed earlier, I make a conceptual distinction between architecture and structure. Many use the terms interchangeably. Structure is a narrow term used to describe the specific hierarchical (or non-hierarchical) relationships between (arrangements of) parts of a system. Architecture is a more abstract term that includes discussion of overall system goals, properties and general rules that govern interactions.
[53] Specifically, I am interested in how this can be applied to institutional transformation and system acquisition and architecture.

2. Lateral structures and layered hierarchies are more flexible than strictly tree-like hierarchical structures and are more controllable than fully connected (flat) networks.

Therefore, our modeling focus is on the structural representation of interactions and relationships in an enterprise—the edges along which information, coordination, collaboration and control occur. It is these patterns of interactions that constitute the structure in which we are interested. As with many organizations, hierarchy is a critical feature. Kometer *describes* the intersection of control and hierarchy, and the implications of violations of hierarchy (for example, what we call level skipping) for system behavior and outcomes. It is obvious that different levels of war correspond to different levels of organization and on the nature of functions performed at each, which is one reason for the unintended or suboptimal outcomes he describes in the cases of tightly constrained campaigns. Hierarchical differences between levels also make interaction across levels difficult, yet another reason for concentrating our focus on interactions—especially ones that cross layers of hierarchy

Kometer's analysis highlights these hierarchical differences among levels. A central point of his research is that, in all but a very few cases, detailed (top-down) specification of the actions of and relationships among people and organizations can often lead to "incorrect answers" to the problem (Landau 1969; Chisholm 1989; Simon 1996; Bar-Yam 2002).[54] From a complex system perspective we say that there are differences in the way problems are efficiently presented and handled at different levels of hierarchy, usually described as a difference in scale (Meyer 2000; Bar-Yam 2003). Because of the difficulty of specifying ahead of time both decisions to be made and the appropriate level where decisions should be made, Kometer developed the depth of command concept. Depth of command is aimed at providing the ability to locate (or enable) decision-making to the most appropriate level in the enterprise when the sequence and timing of events is unpredictable. The goal of creating depth is to increase effectiveness by locating decisions at the lowest level possible, contingent on the

[54] An extreme example of top-down specification of actions and relationships is the command and control structure for strategic nuclear weapons. Very precise and well-understood control mechanisms must exist for these massively destructive weapons that are reserved for use in the most extreme circumstances.

commander's risk level. Exceptions can be made to this idea of avoiding top-down (level-skipping) decisions when issues of risk or time definiteness are more critical than the problems (potential confusion or ineffectiveness) generated by skipping layers. A useful model of enterprise architecture can help decision makers and enterprise architects understand better when and how these situations can be effectively mapped to structures.

From a modeling perspective, the main recommendation of Kometer's research is to concentrate on specifying relationships among nodes, not specifying the detailed characteristics of nodes nor specifying detailed, specific arrangements of nodes for every possible situation. His thinking is that, by paying attention to relationships (edges between nodes) and their character, the operating rules of the nodes can be defined so that the interactions (edges) can be activated when demanded by operational requirements.[55] This is *similar* to the approach of "programming" decision alternatives discussed in

3.7 Modeling approach and philosophy

A theme that is repeated throughout Kometer's research is the difficulty that arises when commanders and operators attempt to reach across layers of hierarchy to attempt precise control over lower level events, especially when they stretch beyond adjacent levels of (i.e., when they try to skip an intermediate level (or commander) and go directly to the (a) point of action). The nature of war and combat creates the chronic inability to achieve the precise outcomes sometimes desired by political and military leaders and that drives the desire to skip levels of hierarchy in operations (Watts 2004).[56] The difficulty of attaining precision when dealing with complex systems drives the approach taken by many complex systems architects and designers of specifying less and less precisely the details of the system. Instead, architects prefer to craft a minimal specification of the system, usually discussing only the types of entities that can make up the system and the specifications of how they interact. We will discuss this approach in more detail in Chapter 4. A key in this approach to designing, modeling or analyzing complex systems and processes is to uncover these essential aspects of the system while

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[55] Of course, Kometer's Chapter 9 is devoted to the issue of nodal characteristics and the implications of developing these characteristics and then embedding these nodes in a system that may or may not make full use of them.
[56] Related to this is the enduring goal of some theorists to achieve precise manipulation of the enemy system to achieve political ends.

avoiding unnecessary details. This is similar to Einstein's "as simple as possible but no simpler" principle for scientific theories. In my experience, many issues surrounding complex military operations suffer from either willful or passive ignorance of this principle, so a quick review/overview of an effective approach is in order.[57]

In the classic *Methods of Operations Research*, Morse and Kimball tell us to "ruthlessly strip away details" in order to identify the "broad approximate constants" of the operation.[58] By examining the relationships among these constants to each other and to theoretical optimums, it may be possible to identify areas for operational improvement. We are interested in a slightly different version of this type of problem: we are interested in architecture trade-offs.

Many complex system modelers strip away much detail in their models. This has enabled statistical physics approaches to yield bountiful insights into certain fundamental properties of these systems. However, some claims of universality of these properties (e.g. power law behavior) have been shown to be incomplete (Li et al. 2004a). As a result, others have called for more rigorous and detailed approaches to these types of models (Mitzenmacher 2005). These researchers argue that the addition of detail (usually in the form of domain specific information) is needed in order to move toward more effective engineering and design capability for these systems (Li et al. 2004b) (Carlson and Doyle 2002).

There are other points of view toward modeling complex systems, similar and consistent with those just cited. Again, the key is to identify the basic features and mechanisms that describe the most important aspects of the system. Once the fundamental dynamics or features of the system are understood, additional detail can be added to address contextually specific issues (Lloyd and Pagels 1988) (Wolfram 2002). Also with complex systems, it is important to operate and analyze at the appropriate

[57] A similar observation has been made by Dr. Barry Watts regarding the pervasiveness of friction in war. His observation is that many thinkers on future war through the 1990s tended to discount the effects of friction, assuming that technology would remove it from combat operations.(Watts 2009)
[58] A version of this approach was recently highlighted in an MIT news story about Prof. Richard Larson, where he calls this approach "simplify, simplify, simplify". This is something that has taken this researcher an inordinately long time to learn and do.

scale, to identify and attempt to control and design attributes that can be measured and managed (Meyer and Brown 1998) (Bar-Yam 1997).

Kometer's CAOS is a complex system. Our modeling approach is aimed at avoiding the problem of too much detail; to theorize, conceptualize, analyze and model at a scale that captures essential aspects of the system while avoiding details that can confuse and obscure fundamental insights. Kometer's CLIOS analysis and qualitative case studies of air power command and control takes a step in this direction. Our goal is to bring greater precision to his description through architecture analysis.

3.8 Modeling interpretation of Kometer's concepts

Kometer's thesis is a system level, process oriented, view of an enterprise. I am interested in architecture. I want to develop a model that captures the relationship between architecture and flexibility. Though flexibility is not a term used frequently in his research, I argue that the main performance attribute Kometer seeks is flexibility and the method he implicitly advocates to achieve it is by layered hierarchical structures.

In this section, I will make explicit connections between the central concepts of this research and the systems analysis presented by Kometer. This mapping will allow a clearer and more general discussion of Kometer and will hopefully help us to develop a layered hierarchical model of complex military operations.

Here are our terms and concepts presented with their analog in Kometer's research:

a. Enterprise system: multiple independent organizations working together toward a common goal, sometimes with diverging interests. This is a more formal and general term for the Combat Air Operations System (CAOS), Kometer's holistic conceptualization of the technical systems and organizations that comprise and employ air power. CAOS is considered an enterprise.

b. Focus on structure over process. Kometer focused on process, specifically on how processes as well as strategic or policy intent influence system interactions that create behaviors, which generate outcomes. Our focus is on structure—the paths on which processes "ride" as they are executed or enacted by people and organizations of the enterprise.

c. Architecture: a minimal statement of the enterprise purpose and goals, its members, their relationships with each other and the environment. Guidance for establishment, disestablishment and modification of relationships as well as additions to or deletion of members are part of an architectural statement.

   i. Kometer does not discuss architecture. The closest thing to an architecture discussion he provides is inclusion of policy constraints and the degree of "management of details" and how these impact performance outcomes.

   ii. The definition provided here is an addition to his discussion of the CAOS. It provides conceptual support and grounding for understanding the impact of policy constraints and risk management processes in the CAOS.

   iii. A central point of Kometer's thesis is that detailed specifications of arrangements among systems and organizations can lead to "incorrect answers" to the problem. More specifically, if details are too tightly specified or controlled, they create an inability to adjust effectively when the environment changes. This points to the need for more general guidance and descriptions of enterprise relationships, which is closer to our definition of architecture. Our concept of architecture, with its relationship to specific implementations (structures) provides a theoretical foundation for his analysis and may help connect his research to other complex systems analysis.

   iv. Kometer's normative recommendation is that commanders concentrate on specifying relationships between nodes, not specifying the detailed arrangement of or the detailed nature of the relationships between nodes in all situations, for the reason cited in (iii). Again, this is clearly an architectural philosophy statement consistent with our definition of architecture.

   v. Kometer does not address node characteristics in more than a general way. He addresses node characteristics changing over time, by referring to Air Force investments in making the AOC a hub of information processing and dissemination. He also addresses the fact that, as kill chain functions are distributed and dispersed among various elements inside and outside the CAOS, that certain node capabilities will be used to varying degrees over time. This, he points out, can lead to system accidents.

d. Hierarchy: complex systems (including organizations) can be decomposed from large parts to interrelated subsystems of parts that are themselves composed of more finely divided subsets of parts (Simon 1962); efficient modeling of complex systems requires models matched to the appropriate level of hierarchy (Meyer 2000). Hierarchy is also defined as a set of authority relations or conceptual abstractions, and is the meaning usually taken in operational contexts—a set of superior-subordinate relationships. Figure 9 shows an example hierarchical representation of a military operational structure. This representation carries the multiple meanings of hierarchy as just defined. It represents the system according to level of focus (strategic, operational, tactical), which generally corresponds to time scale of interest, degree of information aggregation and complexity of operational activities. This hierarchy also represents senior-subordinate relationships, as the person in charge of strategy is senior to those who carry it out

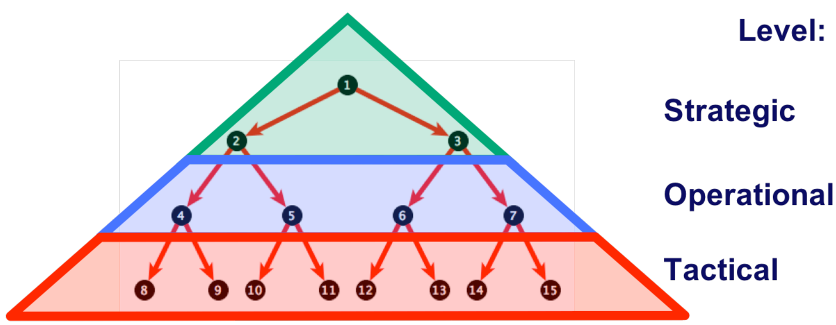

Figure 9: Multi-level tree hierarchy

at the operational and tactical levels. It also represents a decomposition of the system into subsets of systems that can be further subdivided. A major focus of Kometer's analysis is the impact of hierarchical (senior-subordinate/level of abstraction) interactions on system behavior and outcomes. The major focus of our work is on the impact of interactions within and across layers of hierarchy. We define a layer within a hierarchy as the level of decomposition where all nodes or entities share the same general properties or attributes (this is discussed in more detail in Chapter 4).

i. A multi-level tree hierarchy minimizes connections between nodes at different layers of the system, usually by restricting a node to having only one parent node, as shown in Figure 9.

ii. In a more complex hierarchy, allowing nodes to connect across levels to more than one subordinate node creates more flexible layered structures as shown in Figure 10 (Moses 2006a). In these cases, organizational interactions across layers may be more difficult or less efficient than interactions within layers. This problem develops because what is important or clearly understood at one level is often less important and/or less clearly understood at another level, whether we are looking up or down the hierarchy. It is also possible that lateral interactions (interactions within layers) can be more difficult to implement than cross-layer interactions. For example, a lateral interaction

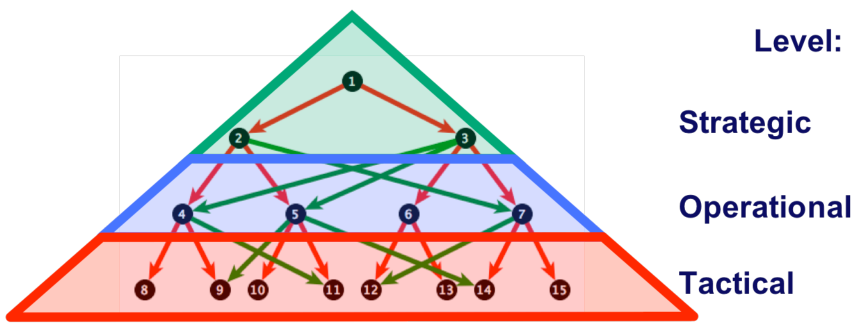

Figure 10: Layered structure

between nodes 2 and 3 might be more difficult to implement than a cross-layer interaction between nodes 4 and 11. Nodes 2 and 3 define two separate branches of the tree (e.g., Air Force and Army in a military structure). If node 2 is an Air Force node and node 3 is an Army node, each with strongly held priorities, or a lack of understanding of the practical issues surrounding each other's tasks, establishing this connection can be hard. By contrast, nodes 4 and 11 fall within the same branch of the hierarchical tree. In an organizational setting, it is more likely that these two nodes will share a common framework or set of concepts about relevant problems and solutions, making interaction easier, even in the face of hierarchical differences.

iii. Hierarchy is described throughout the Kometer's thesis as a feature of the CAOS, but it is usually addressed from a behavioral perspective, not a structural one. A key hierarchical issue he highlights is that it is sometimes better for decision nodes to be at intermediate or low levels of hierarchy. This is because information at different layers can be interpreted differently—noise or other factors can distort information as it travels up and down a hierarchy. Despite the increasing ubiquity of information, there may still be information asymmetry across levels—better information may be available locally than is available either higher up or lower down the hierarchy. Also, higher information update rates may be available at lower levels than higher.[59] A third (and possibly important) consideration is that information may be interpreted differently at different levels based on different priorities or preferences. While these problems can also exist within layers (across branches of a hierarchical tree structure), because nodes at the same level are operating at a consistent level of abstraction, resolution of differences is likely to be easier, in principle. In practice, establishing these types of lateral interactions can be difficult. We will discuss this issue in more detail in Chapter 5.

iv. Kometer explicitly highlights hierarchical effects within the confines framework of an existing tree-like hierarchical architecture, he does not conceptualize the problem from the perspective of alternative structures and their potential impact on system properties. His example notes confusion is generated because the AOC today operates at two different levels (p.187-188):

"It can be confusing that the AOC plays two different roles in the CAOS.
It is simultaneously the air component's portion of the Plans subsystem

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[59] This statement about information update rates is very general and is meant to capture the observation that strategic level information update rates are by nature slower than more tactical information as well as the general nature of strategic information sources (sensors) which have historically had slower update (or revisit) rates than tactical sensors. There are exceptions to these general observations.

> and the lead agent in the Adjustment subsystem. In the last three conflicts, its Plans role was to allocate resources and give guidance to the Adjustment subsystem [specifying] fewer and fewer of the details prior to the missions. The TCT Cell and others in Combat Operations then used those resources…to prosecute the war as it occurred—with a shorter OODA (Observe-Orient-Decide-Act) Loop than the full ATO (Air Tasking Order) cycle.[60] The reason this confuses many observers is that…it is not currently possible to delegate the role of information gathering and distribution much lower than the AOC…the TCT Cell can be looked at as an entity that could be moved an echelon down from the AOC if it were possible to either distribute the information…or gather the information somewhere else…This would be a big step towards the kind of depth of command relationships for which we are searching."

v. Kometer's general formula for command and control describes two-way, hierarchical problem decomposition and aggregation (composition) when developing a plan. This aims at two things:

   1. Building relationships for use during operations
   2. Reducing uncertainties as much as possible

The general formula can be seen as a means to create latent structure—interactions that can be used in the future when needed to respond to unforeseen circumstances.

e. Flexibility is the ability to have alternatives, or options, that can be chosen or exercised with relative ease in response to certain types of changes in operational demands.[61] These alternatives can be in the form of changed relationships among systems and organizations, altered system configurations, or other means of changing function delivered by the system short of redesign. I think this is both a more precise and more general term for what is necessary at the system level in military operations than Kometer's (and others') more narrow discussion of innovation and empowerment. Depth of command is Kometer's means to achieve

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[60] OODA: Observe-Orient-Decide-Act. The OODA loop is a concept developed by Col John Boyd, USAF to help understand air-to-air combat and how good pilots achieve success. It has been applied widely as a metaphor and concept at other levels of analysis and to other operational situations, such as commercial business.

[61] We have kept our discussion of the types of changes that can be accommodated by an architecture very general. Flexibility is dependent on the architecture—it is a design choice, so for different purposes and different contexts, the types of changes that are relatively easy to make will most likely be different.

innovation via situational empowerment—what we term flexibility. For Kometer, innovation is the ability to coordinate and direct different system functions (represented by operational systems and organizations) on short notice—to have alternative means to achieve military objectives or accomplish tasks in response to changes, whether internal or external. Empowerment is the delegation of command authority (decision location) to lower levels of hierarchy. Both involve changing the pattern (or path) of interactions within (through) the enterprise.

i. Architecturally speaking, for Kometer flexibility is a system attribute created by implementing the depth of command concept: the ability to have alternative control modes when coupling changes from loose to tight or vice versa. By paying attention to relationships (the edges between nodes), the character of the edges and the operating rules of the nodes can be managed and structured so that alternative relationships are available when external circumstances change.

ii. A diagram depicting added flexibility is in Figure 11. In this example, the system can be thought of as an input-output system with input coming in near the top (not necessarily the root node) and moving through a sequence of

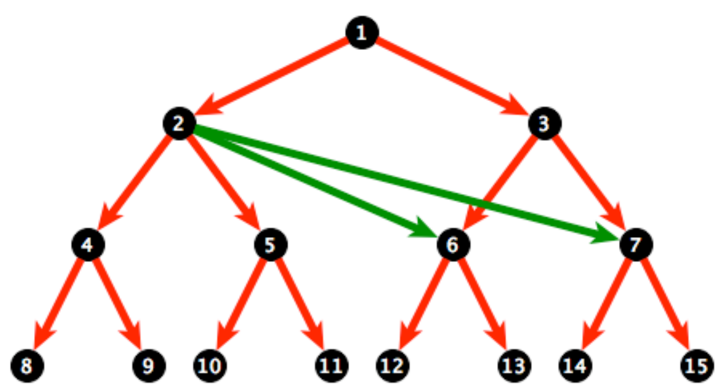

Figure 11: Interactions across layers of a tree structure

choices or steps leading to an output at the bottom. If we refer back to Figure 9 (the base tree hierarchy), we can see that there are only four alternatives from node 2 to any output at the bottom of the hierarchy—those through the children of node 2. If we look at Figure 11 we can see that two additional connections have been added (colored green), allowing access to the alternatives that flow from nodes 6 and 7. Additionally, the added links from nodes 4 and 5 provide even more alternatives, starting from node 2.

iii. We illustrate how input can start at node 2 (colored white) can flow along any one of eight possible paths to an output at the bottom of the structure in Figure 12.

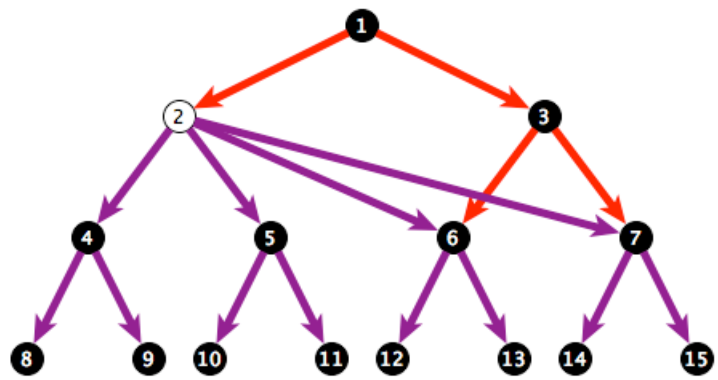

Figure 12: Paths from node 2 in a layered structure

f. Lateral interactions: Lateral interactions in a hierarchical structure are interactions between nodes at the same level of decomposition in the system as

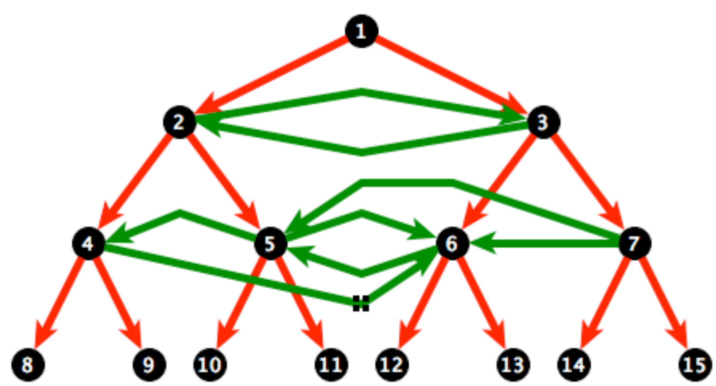

Figure 13: Lateral interactions

represented in Figure 13. Organization theory tells us that lateral interactions enable flexibility (Galbraith 1993; Joyce et al. 1997). Peer interactions, trust, information asymmetry across levels of hierarchy as well as other factors can make lateral interactions easier to manage than vertical ones, though there is some possibility of disagreement and confusion in these interactions.[62]

i. Though Kometer does not address laterality explicitly, his case studies describe situations where lateral collaboration:[63]

   1. reduced time to gather, process and transmit information
   2. created ability to respond effectively to changes in internal or external circumstances

ii. He also describes circumstances where poor lateral interactions (lack of radio communications), in combination with other factors, were the cause of system accidents.

iii. The depth of command concept ensures that there is <u>*always*</u> a clear hierarchical relationship in terms of control and accountability for action. Viewed from a

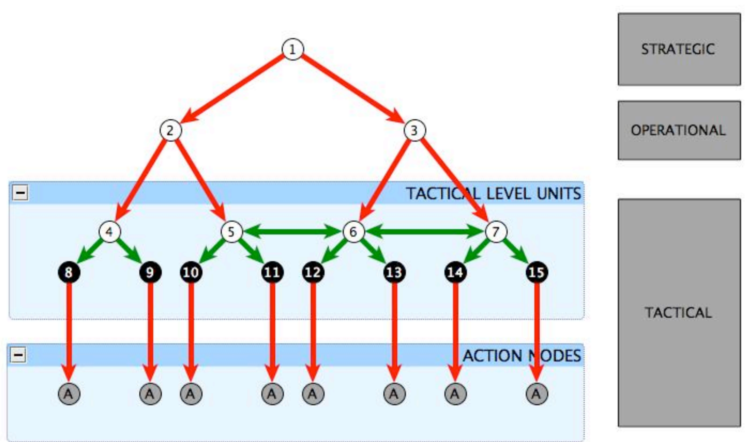

Figure 14: Architectural representation of depth of command

higher level of analysis, depth of command allows movement of decision authority to lower levels of the command structure, to a level of organization

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[62] In practice, the development of trust, experience, training and other factors usually outweigh the potential negative effect of lateral interactions. We do not mean to imply that these interactions or the required trust levels are easy to develop, only that the potential benefits in an uncertain operational environment warrant serious consideration when developing an enterprise architecture.

[63] There are examples from other sources as well.

most appropriate to the situation. It enables lateral interactions. Figure 14 shows both depth and laterality by indicating white colored nodes as command/decision nodes and black colored nodes as taking direction. Nodes 4-15 are at the same level (tactical), so we say that interactions among them are lateral (green) when observed at the system level. If we were to consider only the interactions at the tactical level, however. Some of the lateral interactions are classified as vertical (red) as shown in Figure 15.

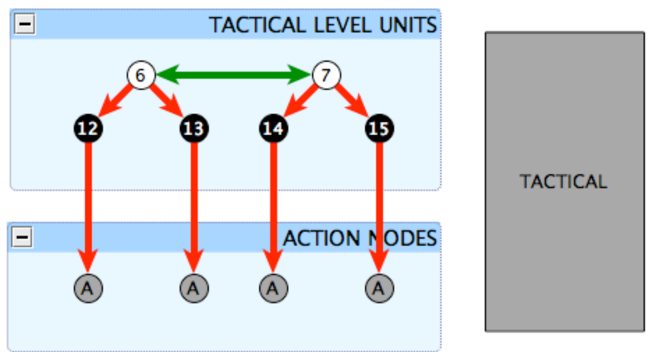

Figure 15: Lateral and vertical interactions at the tactical level

iv. The general formula for command and control *implicitly* calls for lateral information exchange in addition to hierarchical debate as discussed in section 3.5.9 by specifying the following (Kometer, p.240):

1. ensuring coordination among components where necessary;
2. collaboration at multiple levels of hierarchy in order to generate the foundation for depth of command.

g. Architecture design: Architecture design takes the perspective of developing abstract statements of the fundamental aspects of a system. A motivation[64] for Kometer's research is to make the case that in the information age commanders need to focus attention on "decisions about who can make decisions" (p. 188, 253). Since one of the explicit observations in his research is that it is difficult (impossible) to completely specify how strategic level considerations and constraints map to tactical situations, Kometer advocates commanders provide

[64] Perhaps it is an insight he gained in the course of his research.

guidance and identify relationships that need to be developed "just in case." These are operational design decisions. A military plan in execution, where relationships are established and disestablished as demanded by the environment, represents the operation of the system—the system *in use*—exercising the built-in options of the enterprise architecture.

3.9 Research Extensions

Kometer's research, like most research in military operations, is solidly empirical and necessarily case-based (Eisenhardt 1989). From an engineering systems perspective, two things can enhance its utility and lead to a useful model:

1. Connecting it to a theory-based architecture design framework
2. Interpreting Kometer's research and conclusions through an architectural lens, emphasizing hierarchy to understand better the relationship between structure and system level properties, with a special focus on flexibility.

For example, Kometer's description of the need to have, at different times and places both a centralized and a decentralized operational mode is similar to Lawrence and Lorsch's integration and differentiation contingency-theoretic model of organization (Lawrence and Lorsch 1967). His discussion of the creation of time-sensitive targeting cells and the development of the depth of command concept both aim to move decision making lower in hierarchy as well as to connect all relevant expertise at the level in organization where it resides as in Galbraith's "flexible lateral organization" (Galbraith 1993). In addition, the insights gained from both Galbraith and Lawrence and Lorsch can be enhanced by a more explicit examination of the role of hierarchy in enabling flexibility.

From our perspective, Kometer's analysis is fundamentally architectural. He analyzes interactions among entities that compose the system as well as the schemas that drive their interactions.[65] Where Kometer emphasizes behavior and process, we intend to

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[65] However, he spends little time focusing directly on schemas; most of his attention is on the consequences of them.

concentrate on structure and system properties, specifically on hierarchical and lateral structures. By applying *enterprise level theory* to enrich and extend Kometer's analysis, I hope to be able to (a) support a more generalizable theoretical perspective on enterprises and (b) develop a model of flexibility at the enterprise level that can provide decision support, evaluation and diagnosis of enterprise transformation and change efforts. I hope that this effort will enhance theory and practice of enterprise architecting by providing a foundation that allows an engineering approach.

As we will discuss in Chapter 4, layered structures, hierarchy and network concepts provide a theoretical foundation for architectural analysis of Kometer's research. By examining the role of lateral connections and hierarchical layers as enablers of flexibility, I hope to be able to develop a simple model that can move us toward the larger goal of designing flexible military enterprises.

3.10 Summary

Kometer's systems analysis of the Combat Air Operations System (CAOS) provides us with an objective look at the fundamental tension in employment and command of air power since 1943: centralized vs. decentralized control. In this chapter, we reviewed his presentation of air power command and control, highlighting the differences between a process-based and an architecture-based approach. We also noted that there is a richer theoretical basis for Kometer's prescriptive recommendations about air power, which we well review in more detail in Chapter 4. We highlighted the importance of hierarchy, a factor that Kometer addresses in passing, as he emphasizes the behavior and performance aspects of hierarchical interactions in the system.

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Chapter 4

Enterprise Architecture Definitions, Framework and Structural Model

"The Beginning of wisdom is the definition of terms"—Socrates

4.0 Introduction

This chapter defines our terms in more detail than in Chapters 1 and 3. We use these terms to build a framework and structural model of flexibility in enterprises.

As we discussed in Chapter 2, while the Air Force claims flexibility as a core capability, a perennial complaint of ground forces is the lack of flexibility in the use of air power to support ground operations. This tension is aggravated by the increasing ubiquity and capability of information technology that enables ground and air forces to collaborate much more easily (especially at the tactical level) and that has improved the operational depth to which the Army can influence the battlefield (Winton 1996; Daily 2006). In addition, improved technical capability has begun to blur the lines between traditional air power missions of strategic attack, air interdiction and close air support (Kometer 2005; Pirnie 2005). Kometer's concepts of depth of command and a general formula for command and control offer a way to reconcile these tensions. As we saw in Chapter 3 he seeks to use depth of command as a method to achieve a balance between system-level flexibility and appropriate degrees of control—the ability to alter quickly the arrangements of forces against an enemy while limiting chances of accidents and maintaining coherence across levels of command.

The fundamental purpose of any military operational organization is to translate political goals into positive outcomes by gathering and processing information from the environment and from its constituent parts (both human and technical), then translating this information into actions that exert control over the enemy. Control is usually attained by being able to process information effectively and by being able to arrange force combinations in time and space such that the enemy is unable to operate (often because of physical destruction).

To develop an architectural perspective on enterprise flexibility this chapter defines terms, concepts and levels of analysis. We will briefly review current views on flexibility as a system property and follow with a review of architecture concepts, connecting them to the literature on organization design. This discussion lays a foundation for the development of a model of flexibility in enterprise architectures. The model will be applied to the specific case of military combat operations and will be used in Chapter 5 on Kometer's cases.

4.1 Flexibility

There are two main aspects of flexibility: design and operation. Moses has addressed both aspects: flexibility as "the ability of a system to be modified relatively easily in certain classes of situations" (design) as well as the ability to have multiple alternatives in response to changing operational requirements (operation) (Moses 2003). As a definition of a system property, these capture the essence of what most practitioners would accept as an adequate definition.

The economic implications of manufacturing flexibility were pointed out in the mid-20th century (Stigler 1939). There are two issues here. First, until the 1980s efficiency considerations dominated economic decisions in manufacturing. Flexibility only gained momentum as companies responded to lean production systems in Japan, and to the fragmentation and globalization of markets (Piore and Sabel 1984). The emphasis on lean production in the 1990s prompted increased attention to efficiency *and* flexibility on the shop floor (Womack et al. 1991; Adler et al. 1999). Second, most attention to flexibility surrounded relatively slow-to-change situations, where uncertainties were low and trade-offs between high capital costs and economic returns to flexibility were amenable to detailed analysis. Today, uncertainties are higher. This has generated interest in strategic perspectives on flexibility. Recent efforts in strategic engineering have gained attention as a way to cope with design of complex, high cost, hard-to-change and long-lived product systems where uncertainty about future requirements clashes with near-term engineering and economic concerns (de Weck et al. 2004; Silver and de Weck 2006; Ross et al. 2008).

Understanding flexibility becomes more challenging when we move to organizations that operate in higher rate of change situations. Until shortly after World War II, hierarchical bureaucracies aimed at maximizing efficiency were the dominant paradigm (March and Simon 1958). Studies conducted in the immediate post World War II years led to contingency theory—the view that the structure of an organization should match its environment (Burns and Stalker 1961; Lawrence and Lorsch 1967). But since the environment changes, a new tension developed: how to balance the efficiency required to survive in the existing environment with the flexibility (change, innovation) necessary to maintain an adequate “fit” with the environment. This tension was captured by frameworks that attempted to buffer a stable core from the external environment or that identified either integrated or differentiated substructures that could be used to match structure to different environmental demands (Lawrence and Lorsch 1967; Thompson 1967). More recently, evolutionary concepts have been applied to address this tension (Volberda and Lewin 2003). But overall, addressing the challenge of organizational flexibility has been difficult, both in practice and in theory.

The result is that flexibility as an overall system property lacks a unifying framework, theory or models. An overview of the literature shows us that the conceptualization of flexibility is fragmented, with multi-dimensional and multi-scale definitions and measures (Sethi and Sethi 1990b; Suárez et al. 1991; Gerwin 1993; Volberda 1998; Koste and Malhotra 1999; Moses 2003; Whitney et al. 2004; Brusoni and Prencipe 2006). Most research views flexibility as expensive to implement and therefore sees its value as being highly contingent on the system, the expected operational environment and level of analysis. In addition, although operations researchers have been effective at optimizing flexibility at the shop floor level (machines and processes), it has been difficult to optimize processes when uncertainty rises and becomes pervasive at ever-shorter time scales, such as those experienced in military operations. This problem becomes especially acute, as operations are characterized by ever higher rates of change (Cebrowski and Garstka 1998; Kometer 2005). As a complementary development, diffusion of information systems is lowering the cost of flexibility, thus making it even more important to understand how flexibility can be designed as an architectural property of organizations and enterprises.

In general, the approach to flexibility in systems[66] ranges from *ex ante* design of a limited amount of flexibility into products or manufacturing systems, to assuming the emergence of *ad hoc* flexibility in operational organizations or enterprises. Considering the various ways in which flexibility is conceived and implemented across various types of systems, it can be posited that flexibility is a multi-dimensional, multi-level concept *without a clear overarching framework or model* to guide design efforts for large-scale system architectures.

4.2 Architecture

One way to move toward a more general understanding of flexibility is to examine a feature common to many systems: architecture. With origins in building architecture and civil construction, the concept of architecture has increased in importance in the engineering domain, and is especially important in computer science. Architecture is receiving increased attention in many engineering disciplines and is capturing attention in organization studies (Nadler and Tushman 1999; Jacobides 2006; Magee et al. 2006; de Weck 2007). Like flexibility, architecture definitions vary with discipline. But, in contrast to flexibility, most definitions of architecture share a common conceptual foundation. In this section, we will review and synthesize a definition of architecture to help us capture the richness of flexibility in an enterprise context.

Architecture is often used as a synonym for structure, which becomes confusing as systems become more complex. As we work through the various definitions of architecture, we will see that a large part of architecture is about structure and arrangements within systems. As noted in Chapter 3 and section 4.1, flexibility means having many alternatives available for the system or enterprise to deliver value in the face of change. As we continue our review and analysis, we will find that, if we represent the system as an input-output system, we can define a path as a sequence of nodes through the system that, at its output, delivers value. Using this construct, the number of alternative ways (or paths) to generate a relevant output that exist in a system can be used

[66] We intend a very general meaning for the term systems here, focusing on man-made systems from product systems as discussed in Ulrich and Eppinger, to complex space systems as analyzed by de Weck and his collaborators, to computer systems (software, networks), to systems of systems, organizations and enterprises.

as a general measure of flexibility. This establishes a theoretical connection between architecture and flexibility.

We will start our investigation of architecture with product systems, which are mainly matter-energy intensive systems.[67] We then move quickly to information systems and discuss the concept of architecture here, highlighting differences with matter-energy systems. We will briefly address systems of systems, highlighting their similarity with information systems and how they can serve as a bridge to enterprises.

4.2.1 Engineering Systems

4.2.1.1 Systems

Since we are interested in the architecture of large scale technically oriented and enabled enterprises, we need to say something about how we view them as systems. The core system that we are examining, the military combat operations enterprise, from the operational level of war down to the tactical level, is fundamentally an information processing system.[68] It takes in information from the environment, processes that information, makes decisions on what to do (action to take), then executes that action. It then repeats the process, attempting to understand how it is effecting the environment (which almost always includes an enemy or competitive adversary). This overall process involves many different sub-processes, which include information processing, decision making, information passing and many others.

The entities involved in these operational processes include individuals, teams, groups and organizations as well as technical systems operated by individuals, teams, and groups, which are themselves sometimes directed by other organizations. The combined action of these diverse and interacting systems and organizations acts on the environment. We will discuss later the concept of organizations as information

[67] Information-intensive systems such as software, computers certainly qualify as product systems, but the general use of the architecture definition for product systems is for matter-energy (mechanically oriented) systems (Ulrich and Eppinger 1995).
[68] Kometer's focus was the CAOS. By necessity, he discussed interfaces with ground forces where issues of control were relevant. Though we intend to extend his perspective by looking at structure, we are also looking at multi-level issues that are relevant to flexibility. This brings into focus for us the need to address air-ground interactions at multiple levels of command hierarchy, a slight extension of the analytical boundary beyond the CAOS.

processors and of the emerging concept of "system of systems" as an information processor. The need for these systems to be responsive to uncertainty and external change gives rise to the demand for flexibility. It is the ability to process information in different ways, recombine or re-sequence processes composed of both technical systems and organizations that enable flexibility.

4.2.1.2 Product Systems

A practice-based definition of product system architecture is Ulrich and Eppinger's: "the scheme by which the functional elements of the product are arranged into physical chunks and by which the chunks interact" (Ulrich and Eppinger 1995). It provides a description of architecture, but no guidance on how to craft one to have specific properties. This definition becomes limiting when factors such as life cycle cost, acquisition cost and long-term uncertainties in requirements become design considerations. When these types of considerations become important, we need to understand the implications of the original "scheme" and the limitations it places on the flexibility of the system by form-function mapping and physical arrangements of the design. These issues point out a fundamental difference from mechanical systems, where there is a close correspondence between form and function, generally tight and sometimes difficult to learn (expose) interdependencies between physical parts. We will see later that, as information intensiveness in a system increases, these issues become less constraining.[69]

Product platforming has emerged as a way to address some of these difficult issues in mechanical systems. Platforming uses different subsystems on a common infrastructure to produce variants of a product at lower overall cost to add design flexibility (Meyer and Lehnerd 1997; de Weck et al. 2003). A product platform serves as a layer upon which different alternatives can be designed. Product platforms increase the number of combinations (product alternatives) as well as the number and type of design considerations. This economizes on design effort, manufacturing

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[69] As Dr. Whitney points out "this relaxation doesn't make the system any easier to understand or design." It may actually be quite the opposite, design of information intensive systems may be more difficult in certain ways because of this relaxation and the many more degrees of freedom that are possible (Brooks 1987a).

systems investment and production process complexity. It also manages product complexity by standardizing certain interfaces and placing complex interactions in well-bounded areas. Platforming represents a use of hierarchy in architecture as a means to manage complexity and to enable flexibility. This practice (platforming) and the increasing complexity of system architectures have begun to change the language of system architectures. More frequently, system architectures are discussed as abstractions of physical relationships in the system rather than detailed function-form mappings (Chao and Ishii ; Rebentisch et al. 2005).

Choosing the "right" platform architecture has significant long-term consequences for the effectiveness of the systems being built on the platform and, consequently, for the enterprise that develops it (Ulrich 1995; Silver and de Weck 2006). Physical (hardware) systems, are usually designed with a limited number of configurations, and changes to the system are generally difficult unless careful decisions are made early in the development of the system. This makes development of product platform architectures to achieve flexibility a tough design challenge. Information-intensive systems are physically able to accommodate more flexibility in design than matter-energy systems. Even so, information-intensive systems, too, can be hard to change if the change is *not* in a class of which the system was designed to handle. But in general, flexibility in information systems is much higher than in matter-energy systems, especially if the design of its architecture is well chosen (Moses 2004b; Whitney 2004). In general, the long term impact of architectures on system viability make architecture decisions important and, as Moses has pointed out, developing a good architecture is challenging (Moses 2004b).

4.2.1.3 Information systems

Abstraction is a key principle in software engineering (Fielding 2000). For computer scientists, architecture is the overall concept that drives the choice of system parts, the specification of interfaces between parts and the constraints on performance of parts and the system. This approach enables easier adjustment of a design as technology improves or as performance requirements change (Gifford and Spector 1987b; Perry and Wolf 1992).

Software architecture has been defined as the organization of the overall system, represented by a graph, where nodes are software modules and edges are function calls and other relevant interactions between nodes (Garlan and Shaw 1993). Kruchten describes architecture as "the design and implementation of the high-level structure of the software" (Kruchten 1995). For Perry and Wolff, "software architecture deals with abstraction, with decomposition and composition, with style and esthetics." (Perry and Wolf 1992). The common theme among these concepts is a higher degree of freedom in creating specific system implementations. This freedom is enabled by the relative ease of rearranging elements of a software or information system and is a key differentiator between information-intensive systems and matter-energy intensive systems (Whitney 1996). In practice, the ability to create layers of abstraction in information systems increases this design freedom even more (Moses 2006a).

Computer network designers describe architecture as the overarching description of purpose, the set of abstract principles that define how a system is decomposed into parts and the interface specifications among the parts (Braden et al. 2000; Clark et al. 2004). Others have amplified the idea of interface definition, adding that interface specifications impose "both constraint and freedom" (Clark et al. 2004). This additional idea opens the concept of architecture to more explicit recognition of the inability to foresee all possible issues that might arise once a system is fielded; people act to alter the system as needs change and the nature of information systems allows a larger degree of freedom for changes after the system is fielded than is possible with matter-energy systems.[70] This is a key observation about computer network architectures: the architecture defines the terms of evolution and the long-lived system properties—structure changes over time but is constrained by the architecture. "There is no 'final outcome' of these interactions, no stable point, and no acquiescence to a static architectural model" (Clark et al. 2005). But there are certain

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[70] These statements are true of any system, and any organization. The important point to note is that computer system architecture concepts recognize this issue more explicitly and the technology of information systems enables designers to craft architectures that can better account for their effects. That we should be able to achieve similar capabilities for enterprises is a motivating force for this research.

properties that can be assumed to remain valid over longer time scales and an overall high-level structure that can be observed.

Computer science provides us with more abstract concepts of architecture, focusing on relationships, their effect on system level function and on evolution in the face of external or internal changes. Though more abstract and dynamic than product system concepts, information system concepts of architecture are still more limiting than what we observe in organizations and enterprises. They are practice-based definitions with little that helps us map architecture to desired system properties. Technical issues are dominant constraints, as evidenced by efforts to craft a new set of architectural principles for the next generation internet (Clark et al. 2004).

4.2.1.4 Systems of Systems

Individual product systems are now being connected together into systems of systems (SoS). Architecture concepts for this class of system are immature and most approaches emphasize traditional tree-like decomposition. Maier has proposed a more computer science-like view, defining architecture for these systems as "a framework for systems that can evolve and adapt through a distributed process of individual decisions…defined as much by standards and regulations as by technical components" (Maier 1997). In a further development of this idea, he states that "design and engineering should shift…to higher layer standards…much greater attention must be paid to how components develop and maintain collaborative relationships." (Maier 1998). Maier's perspective echoes internet-based ideas cited above, where the system continually evolves based on the interface standards as they are implemented into specific systems and as standards are altered over time.

4.2.1.5 Summary

As we consider technical system architecture concepts for application to enterprise architectures, patterns emerge that can help us extend them to more complex systems and enterprises. First, almost all discussion of technical system flexibility is from the perspective of system design—ease of changing physical and functional aspects of systems. Second, for product systems, flexibility is usually a difficult property to implement and, when implemented, is usually limited in scope.[71] The practice of product platforming increases flexibility by making certain changes to a system design easier to implement. Innovative methodologies have enhanced the ability to create flexible product systems, often by taking a strategic approach to system design by examining a wider array of system designs, usually during the conceptual design phase of development (de Neufville 2003; de Weck and Jones 2004). However, these efforts focus on design of systems, not on architectures that govern how individual systems are designed. They also concentrate on knowing performance requirements with a certain degree of fidelity ahead of time, something that is difficult in a combat environment (as well as almost any operationally oriented environment).

Architecture concepts can become more abstract as systems become more information intensive, include stand-alone systems as part of a larger functioning system and as the focus moves from design of an artifact to design of operations conducted by and with multiple artifacts and organizations. Structures are more easily altered and architecture discussions hinge on the multiple potential ways to achieve a desired outcome or deliver a required function. Structure becomes a dynamic concept, based on patterns of interaction among the member entities. Correspondingly, definitions of architecture move away from concrete specification of arrangements to statements of interface requirements, interaction patterns and desired outcomes. In computer network engineering, architecture discussions are almost completely about system level properties (Maier 1998; Clark 2004; Clark et al. 2004).

As we move up in scale from individual product systems through information systems to systems of systems, organizations and ensembles of organizations, our concept of flexibility shifts in focus. The "system" is no longer a static object of design, something that is delivered then operated. It becomes animated, operating within and on an external environment with some purpose or goal; the number of alternatives that can be designed into the system increases dramatically. So, for enterprises, our focus shifts away from design of individual systems and single organizations to the design of an

[71] I am mainly thinking about matter-energy intensive systems, but the same situation applies to information intensive systems, only with different trade-offs. A good example is provided in (Ross 2006) and another example, using word processing software, is discussed in Chapter 6.

architecture within which systems and organizations can be re-arranged during operation in response to internal and external changes (Garlan and Shaw 1993). Flexibility in this context takes on a different character and requires a corresponding new approach toward architecture. In these systems, a high degree of flexibility can be achieved *if the architecture is properly designed—if there are alternative ways to deliver value or to accomplish tasks—alternative paths from input stimulus to output function of the overall system*.

Using this logic, an architecture concept appropriate for enterprises means we are dealing with information-intensive systems, which require abstraction to manage complexity. They must operate at multiple levels. But we still lack a theoretical foundation that can help us design a complex architecture to deliver desired properties—flexibility in our case. We still have no clear understanding of how arrangements can deliver system level properties, so do not know what arrangements we should want.

4.2.2 Enterprises and architecture

4.2.2.1 Organizations and design

Organizations are complex artificial systems (Simon 1996). They are made up of individual parts (individuals, groups, teams, committees, etc.) that, together, exhibit aggregate properties that are different from the properties of the individual components of the system as viewed separately (people, teams and technical systems bound together with information technology). People craft organizations to achieve specific goals. Once crafted (analogous to fielding of a technical system) organizations become subject to natural and man-made influences, both internal and external. Untangling the implications of these interactions for organizational performance has been the subject of decades of organizational, sociological and economics research. (Katz and Kahn 1966; Arrow 1974; Ranson et al. 1980).

Organizations have been considered objects of design activity for some time now. Recently organization theory and organization design research have migrated toward concepts of architecture and architecting as a way to address the challenges of keeping organizations viable in ever-changing environments (Nadler and Tushman 1997) (Sanchez and Mahoney 1996) (Schilling and Steensma 2001).

4.2.2.2 Sociology, Organization Design, Structure and Change

Research in organization design continues a trend toward abstraction where computer science leaves off. Following the work of Burns and Stalker, early work by Thompson, Lawrence and Lorsch, Katz and Kahn, and others aimed to help management understand how interactions both within an organization and between the organization and its environment impacted overall organizational performance. The abstraction of organizations as resource or information processors—systems that interact internally and with the environment externally is well known and connects to our goal of applying technical architecture concepts to enterprises (Galbraith 1969; Arrow 1974; Tushman and Nadler 1978; Moldoveanu and Bauer 2004). In an examination of the sociological aspects of organizations Ranson, et al., described the interplay of multiple factors in both enabling and inhibiting change. They specifically address the impact of human agency, self-interest and coalitions on the overall patterns of interaction (which they define as structure) and its ability to remain viable in a changing environment (Ranson et al. 1980). This view of organizations is architecturally analogous to the Internet architecture:

> "[It]…is shaped by controlled tussle, regulated not just by technical mechanism but by mechanisms such as laws, judges, societal opinion, shared values…There is no "final outcome" of these interactions, no stable point, and no acquiescence to a static architectural model. Today, the Internet is more and more defined by these tussles." (Clark et al. 2005)

Ranson et al. developed a rich synthesis of sociological theories of organizational structure, behavior and change dynamics. They provide a logical explanation of structure and dynamics in organizations, grounded in institutional theory (Ranson et al. 1980). Using the perspective of Ranson, et al., organization structure can be defined as the pattern of interactions produced as a continually evolving outcome of group and individual interactions, interdependencies and cognitive processes as mediated by environmental constraints and power coalitions. Moving from structure to architecture, Nadler and Tushman also recognize organization architecture as intangible and subject to group dynamics and human behavior. For them organization architecture is a term that describes "the variety of ways in which the enterprise structures, coordinates, and manages the work of its people in pursuit of strategic objectives." Adding detail, they define architecture as "…the grouping boundaries and linking processes, the patterns of personal and cultural relationships that get work done in certain ways, the interaction of the social with the technical sides of the organization." (Nadler and Tushman 1999). Organization architecture has also been described as "how different types of capabilities fit together, to shape firm-level and aggregate technological and strategic advances" (Jacobides 2006).

Lawrence and Lorsch identified integrated and differentiated structures within organizations contending with changing and uncertain external environments (Lawrence and Lorsch 1967). Galbraith developed the concept of the organization as an information processor, where uncertainty drives information processing requirements and where different structures are able to deal with differing degrees of uncertainty (Galbraith 1969). Tushman and Nadler, following Galbraith, developed an information-processing model to aid in making choices among competing organizational designs (Tushman and Nadler 1978). More recently, Moldoveanu and Bauer have taken an explicitly computational design approach to organizations, aiming to match computational requirements to processing structure of the organization (Moldoveanu and Bauer 2004).

Combining these concepts from contingency theory and information processing with the concept of hierarchy allows us to move toward a multi-level understanding enterprise architecture (Lawrence and Lorsch 1967; Tushman and Nadler 1978; Moldoveanu and Bauer 2004). In this view, nodes near the bottom of a hierarchy have better information about local conditions and the likely effectiveness and efficiency of decisions on operations at that level. Nodes higher in the organization generally have less local knowledge and better global knowledge about operational effectiveness and efficiency in relation to system level goals. We define allowing nodes within a level to coordinate, control, and share resources among themselves according to criteria developed at higher levels as laterality or lateral interactions (Galbraith 1993; Kometer 2005). Laterality enables nodes within the same layer of organization to share information and coordinate action.

Since higher levels handle more abstract problems, engage in interactions that are more complex, and usually specify constraints and provide direction to lower levels, lateral connections at higher levels can enable better local level interactions by lowering confusion about priorities and by clearly and formally delegating some decision authority to lower levels. Interaction patterns in an enterprise are the result of innumerable decisions based on multiple criteria at all levels. As we will see later (in Chapter 5), the interactions (or lack of them) among higher-level nodes (commanders and staffs) can inhibit the creation of connections at lower levels. While the structure of the enterprise is a reflection of the many individuals acting to accomplish their individual and collective missions, at the highest level, it is a physical manifestation of the overall intent of the senior leadership (the commander in a military context).

4.2.2.3 Enterprises

The term enterprise has emerged as a general and intuitively applied description for large, complex organizational endeavors of almost any scale. Black's Law Dictionary defines an enterprise as "one or more persons or organizations that have related activities, unified operation or common control, and a common business purpose". This definition applies to a two-person joint activity as well as to activities on the scale of societies and is too broad for our purposes of design and engineering enterprise architectures. The Lean Aerospace Initiative, in their book, *Lean Enterprise Value* (LEV) has offered the following definition of enterprise: "It is significant when a leader in aerospace or any industry asserts that a given set of activities—regardless of scale—*must* be viewed as an interconnected whole. That interconnected whole is an *enterprise*." (Murman 2002). LEV further identifies program enterprises and industrial-scale enterprises as a way to focus on larger-scale, multi-organizational activities that must be integrated in order to deliver complex technical systems with minimal waste and with the goal of reducing overall system cost (Murman 2002). A significant feature of enterprises as conceived by LAI is the need to collaborate across organizational boundaries and across multiple organizations with the goal of satisfying many requirements driven by multiple stakeholders. The definition provided in LEV leaves many open questions regarding design, operation and management of enterprises.

Nightingale and Rhodes have defined enterprises: "Enterprises are complex, highly integrated systems comprised of processes, organizations, information and supporting technologies, with multifaceted interdependencies and interrelationships across their boundaries" (Nightingale and Rhodes 2004). They further define enterprises as moving "…from simple organization to a complex networked organization (an extended enterprise). Though never explicitly stated, this makes enterprises conceptually similar to multi-organizational systems, a subject of public administration research (Agranoff and McGuire 1998; Mandeles 1998). But there are differences between these two types of organization. In multi-organizational systems, member organizations are not usually connected directly to enterprise outputs and generally pursue their own interests, with little consideration for a larger system-wide goal, even though achieving a system level goal may be the motivation for their participation in the system. Thus, multi-organizational systems are less cohesive and less clearly managed than enterprises.[72] Also, multi-organizational system research as well as the growing body of research on new organizational forms leave out issues of explicit control, guidance and design, all of which are important in enterprises (Chisholm 1989; Romanelli 1991; Agranoff and McGuire 1998; Castells 2000; White et al. 2004).

4.2.2.4 Enterprise defined

As a first step in addressing these gaps, we define an enterprise as an *ensemble of organizations* working cooperatively toward a defined and collectively accepted goal, with an explicit leadership and/or governance structure. Enterprises are characterized by:

1. More permeable organizational boundaries compared to individual organizations;
2. Higher reciprocity in interactions compared to organizations;
3. More variable interactions over time but with clearly recurring patterns;
4. Interactions at multiple hierarchical levels;
5. Simultaneous intersection and separation of member interests that change over time;

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[72] The term "manage" implies tight controls. As observed by multi-organizational systems researchers, these types of systems do not have very much central control, if any. Enterprises are controlled, but less tightly than traditional organizations and more tightly than multi-organizational public administration systems.

6. More decentralized action than in a traditional organization;
7. Difficulty in causal relationships between individual members' activities and enterprise outcomes.

This definition moves Galbraith's longstanding conceptualization of organizations as information processors to a larger scale—they gather information from the environment, process it in numerous ways and then act on the environment. Members of enterprises are, in general, more autonomous than members of organizations. Higher information flows and more reciprocity in interactions enable (but do not ensure) more alternative ways to process information and to take action based on that information. Whereas organizations are usually focused on clear and specific goals, enterprises must accommodate goals of individual organizations as well as those of the enterprise.

A major issue in enterprises is using cooperation, collaboration, and coordination to gather and process information in order to achieve goal directed behavior by acting on a continuously changing environment. We need to understand what types of structures can do this. We are specifically interested in enterprise level flexibility, the ability to change interactions within the enterprise in response to internal and external uncertainty and change. One of the main problems facing enterprises in this regard is balancing efficiency and effectiveness. We discuss this trade-off in detail in Chapter 6.

4.2.2.5 Enterprise Architecture

We define *enterprise architecture* as the overarching scheme, the high-level statement of purpose and principles, that guides generation of patterns of interaction among enterprise members, that governs decisions about how to interact with the environment and that specifies the overall properties of the enterprise or the value to be delivered. An enterprise architecture statement includes:

1. Initial members of the system;
2. A description of the structural pattern of interactions among members (tree, layer, lattice, network, etc.);
3. Interactions: relationships among the members and at what level of enterprise they operate;
4. Constraints on interactions, member behavior and system level behavior;

5. Rules on entry/exit and addition/deletion of members from the system;
6. A clear statement of where freedom is allowed when unspecified conditions arise.

A strategic goal of the architecture statement should be to define and shape the evolutionary trajectory of the enterprise as it shapes and is shaped by the environment.

4.2.3 Summary

The approaches of organization design research and their definitions share similarities with information system architecture: defining general rules, standard interfaces, ongoing evolution and change in response to internal and external demands. Early organization design research focused on understanding contingent forms (Lawrence and Lorsch 1967), and on how to build a structure that could deal effectively with external changes and the need for internal stability (Thompson 1967). Recent work has aimed at understanding how to craft organizations that can operate under conditions of high external change and turbulence, both in the short and long term (Volberda 1998; Volberda and Lewin 2003). In general, researchers claim that this is achievable by intelligent choice of product architecture and organization structures (Ulrich 1995; Sanchez and Mahoney 1996; Augier and Teece 2006).

But there are nagging inadequacies. First, the challenge of keeping an organization viable and competitive in a changing environment is a daunting task (Hannan and Freeman 1989; Christensen 1997; Kaplan and Henderson 2005). Second, knowledge of organization architecture and design lags our experience and observation. Complexities of product development coupled with economic and other constraints require a larger array of and differently structured organizations to develop systems (Clark and Fujimoto 1991; Cusumano and Nobeoka 1998; Robertson and Ulrich 1998; Murman 2002). Similarly, in military operations, changing threats, fiscal constraints, political risk tolerance and a trend toward use of military forces for a wider array of contingencies and operations drive operational force organizations in a similar direction.

4.3 Enterprise Architecture constructs and relationships

4.3.1 Hierarchy and complex systems

A missing idea from many definitions of architecture reviewed so far is the notion of hierarchy. Many engineering systems operate at multiple levels of abstraction, as do organizations and enterprises. Anderson's seminal article on complexity offered an early discussion of the implications of scale (size) on the understanding of complex systems (Anderson 1972). From a more practical perspective, Simon articulated the need for hierarchical decomposition and minimization of cross boundary interactions in order to manage both cognitive and physical complexity (Simon 1962). Bar-Yam has proposed multi-scale representations as a framework for understanding complex systems (Bar-Yam 1997). More technically, the computational efficiency of models has been proposed as a means to identify different levels of abstraction. If a model becomes cumbersome (computationally inefficient) as the system increases in size, the system can (should) be formulated as a new, more abstract, model, one that disregards certain details but captures the essential properties of interest in the system (Morse and Kimball 1998; Meyer 2000). This view is especially helpful in separating analytical approaches based on different performance or design concerns as well as for simplifying discussion and analysis of complex systems.

But if we are to undertake design activities, we need to connect structure to system properties. Connecting the ideas of decomposition and multiple levels of abstraction in analysis provides this connection. Moses and the ESD Architecture committee have proposed a view of architecture that accounts for this connection (Moses 2003; Whitney et al. 2004). Simon's hierarchies emphasize a tree-like decomposition, specifically limiting cross-tree branch interactions in order to minimize complexity. But from a practical perspective, this approach lacks richness and reaches computational limits rather quickly.[73] Also, in real systems, especially organizations, interactions across branches of a tree happen frequently (Chisholm 1989; Mandeles et al. 1996). Systems designed for one purpose are often applied to a previously unknown or not considered task. For example, F-111 bombers were designed to strike strategic targets deep in enemy territory. In Operation Desert Storm, they were used to hit Iraqi tanks after it was discovered that their infrared sensors could discriminate warm tanks against the cold

[73] A hierarchical tree with a constant branching ratio, represented as a network structure, grows exponentially in size (number of nodes) with branching ratio and number of levels: size = $\sum_{l=0}^{L} b^l$; where b = branching ratio and l = level of decomposition and L = total number of levels.

desert sand at night. Moses' idea is that creating alternatives in a system (paths through it) adds both flexibility and complexity, but that the increase in complexity can be managed (limited) with a judicious choice of architecture, specifically of the abstraction around which the architecture is crafted. He claims that attention to architecture can achieve a balance between increased complexity and improved performance through flexibility while also reducing design cost over the lifetime of the system (Moses 2003).[74]

4.3.2 Hierarchy and layers

We say that hierarchies are vertical structures, where levels (layers) exist "above" and "below" each other. We will consider two main types of hierarchy, "classic" trees and layered structures. Trees are a specific type of hierarchy where there is a single root node, branching at succeeding levels of decomposition, with few interactions among nodes at each level (recall that in a strict tree structure there are no interactions among nodes at a given level, each node has only one parent and a limited number of children at

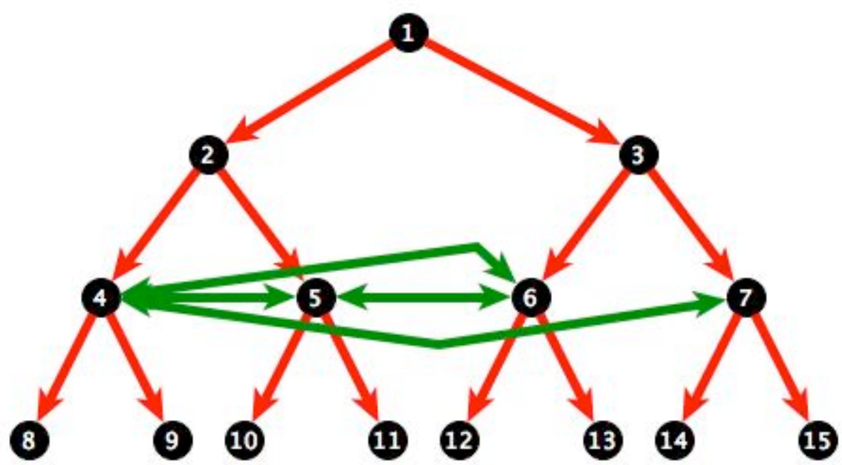

Figure 16: Tree with lateral interactions

the next level down). A level is a set of decomposed elements of the system that have similar attributes or characteristics; they exist at a similar level of abstraction. If we use hierarchy as an organizing concept, layers are defined as horizontal substructures in the architecture, where each hierarchical level represents a different abstraction (Moses

[74] The logic is that if flexibility is enabled up front (before fielding the system) by a properly designed architecture, then there will be fewer system changes necessary after it is fielded and those that are necessary may cost less in both design and implementation.

2003). We define lateral connections as interactions within a layer of abstraction (green arrows in Figure 16). A simple example is the rank structure of the military services, where Generals and Admirals are above Lieutenants who are above Sergeants and Petty Officers. In a formal hierarchy, command or direction usually flows from the higher levels to lower ones, so relationships are asymmetrical (Simon 1962; Allen 2006). Figure 16 depicts a simple representation of this type of hierarchy, where nodes represent entities at different levels, red arrows indicate directive interactions (commands) and green arrows indicate collaboration among peers.

Since relationships between levels are asymmetrical by definition, entities in different levels have different interaction characteristics and can be described or modeled differently (Anderson 1972; Meyer 2000). For example, in an organization a higher-level individual interacts differently, possibly using a different grammar, with a subordinate than with a peer; a higher-level committee deals with more complex and multi-dimensional problems than a work group on the shop floor (March and Simon 1958; Tushman and Nadler 1978; Galbraith 1993). In social systems formal rank, social status or other dimensions can be used to define hierarchical levels.[75] In technical systems, types of interactions, or a specific grammar (data class, data format, program language, information exchange protocol, etc.) can be used to define layers. In general, skipping layers in either a social or a technical context can create complexities that make certain aspects of system management difficult or can generate unintended operational consequences (Swain 1994; Moses 2003).

4.3.3 Hierarchies and flexibility

Thompson proposed the resource-based view of the firm, the firm as a consumer and processor of physical, information and knowledge resources (Thompson 1967). Lawrence and Lorsch developed the integration-differentiation model of contingent organizational forms, where different structures were needed in different locations in the organization in order to deal with different external conditions or different task integration requirements (Lawrence and Lorsch 1967). Later, Galbraith highlighted

[75] These types of levels are also used for analytical purposes, as well as everyday social interaction purposes(Watts et al. 2002).

laterality as an organizational form that enables flexibility, beginning with information processing as a way to understand how contingent organizational structures cope with uncertainty in the environment (Galbraith 1969; Galbraith 1993).

All of these versions of contingency theory address the connection between internal structures, the external environment and the potential for success or survival of a firm. In short, organizational structure (the ability to process information and handle uncertainty) must match the problem. But Thompson and Lawrence and Lorsch do not address how to keep the form matched to a changing environment, nor do they address hierarchical issues of organization. Galbraith addresses the issue of matching to the environment by proposing lateral interactions—replication of the formal large-scale structure of the firm at the appropriate level hierarchy. Analogous to Kometer's depth of command, this method achieves flexibility by moving decisions down the hierarchy and enables the integration of knowledge at the level where it best matches the problem (Galbraith 1993). This is one way to achieve flexibility: lateral interactions at lower levels of hierarchy.

4.4 Designing Flexible Enterprise Architectures

4.4.1 Architecture model

4.4.1.1 Theory, modeling, complex systems and operations research

A key goal of modeling a complex system is to abstract and represent the property or characteristic of interest while retaining only essential detail (Morse and Kimball 1998; Boccara 2004). Military systems are highly complex, and many issues surrounding their behavior or choices about operating them can be traced to different models of war used by different military services (Wylie 1989). This makes modeling military operations and communicating the results or implications of a model challenging. Our goal here is a simple model, supported by a descriptive architectural analysis of military combat operations.

We need to be clear about the bounds of this analysis. The availability and application of computer power makes is easy to move prematurely toward simulation and detailed design or modeling (Koopman 1999).[76] But we must be careful, models running *in silico* can lead to difficulties, usually in the form of mismatches between reality and the mechanics of the model (Nordhaus 1973; Koopman 1999).[77] Our intent is not to build a simulation or a design tool (yet). Perhaps some day we can do this. For now we seek to lay a foundation for designing enterprise architectures by developing a model grounded in "fundamental constants" that help us understand enterprise flexibility (Morse and Kimball 1998).

As we have noted, complex systems—enterprises—operate at multiple levels of abstraction. In a major corporation (like General Motors), there are both functional and product divisions (branches of a tree) that must work together at multiple hierarchical levels to generate products valued by markets that change over time. In military operations, various organizations operate together at different levels, strategic, operational and tactical, to achieve the purpose of a commander, sometimes in the face of a deadly adversary. In these examples (and many others we could present) the fundamental issues of information processing, resource allocation and alignment require a balance between top-down direction, bottom-up action, aggregation (abstraction) of information, coordination and myriad other dimensions of performance.

We are interested in a model that allows us to understand structures that enable flexibility. Based on our discussion so far, we expect these structures to be lateral as well as vertical. Our earlier discussion showed us that complex systems are multi-scaled and sometimes hierarchical, where efficient description, modeling or qualitative analysis of activities identifies the levels of abstraction (or analysis). We expect that interactions within levels of an enterprise are going to be less prone to misunderstanding, friction, filtering, loss or miscommunication than they would be if (or when) they cross layer boundaries.

Key to our model is the definition of an interaction path within the system. In simple terms: what does a line on a diagram mean? Is it information flow? Is it

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[76] In fact, a good deal of effort has been expended in the course of this research on investigating the utility and potential validity of a computational model.
[77] Anecdotal evidence suggests that current financial industry troubles can be traced to the continued use of quantitative models after the real market had outpaced their ability to accurately value certain aspects of it.

functional dependency in a sequential (grammatical) sense? Can we simply discuss interactions abstractly and say that function alternatives are what the edges point toward? How general or abstract can our model be and still portray the system with appropriate fidelity? The next sections will address these issues.

4.4.1.2 Articulating a model

Representing a complex system as a set of nodes and edges is a useful way to model a complex system. This has been done for social networks, infrastructures, metabolic networks and product development organizations (Watts 1999) (Ravasz and Barabási 2003; Braha and Bar-Yam 2007). In this type of enterprise model, a node is an organization, system or person, with an edge between them if there is an interaction relevant to the system property of interest. For many systems, especially enterprises, we can classify nodes into a hierarchy by using abstractions. A set of nodes can be contracted to a higher-level abstraction when input-output relations are identical between the single node and the set of individual nodes that are contained within it. We can also identify a higher-level node if it is possible to make a short description that captures all the essential features of the nodes contained within it (Moses 2004b). This form of hierarchy has been called “closed” or “nested” (Allen 2006). We know we have a consistent abstraction when all nodes at a given level of the system hierarchy share similar attributes or interact with each other and levels above and below them in similar ways (Moses 2003; Allen 2006). For example, an Air Operations Center (AOC) is a node that aggregates all nodes inside it into a single entity—nesting as noted above. The external relationships of nodes inside the AOC to the rest of the enterprise are the same as the external relationships of the AOC as a single node to the rest of the enterprise. A more common example is in a physical system, such as a city, where houses are nodes inside city blocks, but city blocks (made up of houses) are nodes inside a city, and a city is built up of city blocks. In an enterprise context, this type of aggregation helps us identify hierarchical level (or level of abstraction). For example, we could not reasonably place a tactical aircraft inside the AOC, indicating that it operates at a different level of hierarchy.

For the cases of combat air operations considered in this research, there are three levels of hierarchy: strategic, operational, and tactical and three main functions that can be performed (or directed) across the levels: sensing, deciding, acting. Within the combat air operations enterprise, there are the headquarters node (the AOC), second echelon nodes such as the Air Support Operations Center (ASOC), Airborne Warning and Control System (AWACS) and the Airborne Command, Control and Communications (ABCCC) aircraft, and tactical level nodes: aircraft. This is an example of a non-nested (or open) hierarchy (Allen 2006). The design problem is to understand the implications of connecting these functions within and across levels of the hierarchy.

What happens in our situation is that some nodes in an enterprise can be abstracted (nested) to create a hierarchical level. At the same time, hierarchical levels created in this way are also part of a non-nested or open hierarchy, where higher levels often direct or command lower levels. It may be possible to gather all of an air operations enterprise's nodes and their relationships and then analyze the resulting structure as a single network. This would provide us some useful information about the overall system. By aggregating (nesting) some nodes into higher level entities removes non-essential detail and allows us to concentrate on issues appropriate to our concerns: enterprise level properties and structures that enable them.

4.4.1.3 Flexibility, alternatives and paths

Flexibility is about having alternative ways of delivering system level function, whether we are discussing theory, practice or analysis. We have defined flexibility as the ability of using alternatives to handle certain changes in performance requirements with relative ease and in a time responsive way. We say that the ability to respond to these changes is enabled by the ability to choose alternative configurations of the system's parts—to have alternative sequences of steps through the system, alternative paths.[78] Therefore, the number of different alternatives (paths or sequences of steps to deliver

[78] As we noted earlier, systems engineers have used the system boundary as a demarcation point to distinguish flexibility from adaptability (Ross 2006). They also use the time dimension to distinguish flexibility from agility (Fricke et al. 2000). We do not make these distinctions. We view flexibility as an overarching '-ility', subsuming agility (flexible and fast), adaptability (flexibility over long time scales), robustness (maintaining function) and resilience (flexibility and robustness).

function or output value) can be used as a measure of flexibility. If we represent the enterprise as an information processing system, the number of alternatives for processing information to make a decision and the number of alternatives available for action after making a decision (possible paths) becomes a measure of flexibility (Moses 2003; Mandeles 2005).[79]

When military operations are represented as a networked structure and modeled as an input-output system, the idea of using path counting as a metric is natural. In fact, the use of paths as a theoretical and metaphorical metric has precedence across a variety of research domains. The ability to build reliable systems from unreliable components is based on the number of paths through the system (von Moore and Shannon 1956; Neumann 1956). In manufacturing, one way to measure flexibility is to count the number of paths from input to output (Fine and Freund 1990; Sethi and Sethi 1990b; Gerwin 1993; Jordan and Graves 1995; Graves and Tomlin 2003). In safety engineering, multiple paths have been proposed as necessary to avoid loss of essential information for decision making (Leveson et al. 2003). Research on future military organizations has identified communication paths as a critical structural consideration, as they offer potential for reducing uncertainty and decision making errors by enabling information combinations not possible via more traditional structures and operating rules (Mandeles 2005).[80] A similar approach has been applied in economics to models that emphasize the relationship between organizational architecture and screening functions to decision performance (Sah and Stiglitz 1986; Ioannides 1987). In product design and manufacturing, system level analysis indicates that having more possible paths for equipment, product and information exchange may be helpful in understanding change and innovation (Brusoni and Prencipe 2006). In the natural sciences, study of multiplicity of pathways in metabolic networks has exploded as a way to understand flexibility (and robustness) in biological systems (Papin et al. 2003).

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[79] Leveson, et al. have also offered multiple information paths as a way to increase system safety by providing a means for adverse information to reach decision-makers (Leveson et al. 2003).
[80] Though Mandeles does not go as far as relying on von Neumann and Moore-Shannon, the connection is obvious.

In our model, alternative paths in a structure indicate *potential* flexibility. Flexibility of a system is related to the total number of paths from a given node (input) to a set of end (output) nodes, assuming that no node appears more than twice in the path.[81] A system may have many cycles, but a counted path has a limit of one on the representation of a cycle within it.[82] To make this distinction clear, think of a decision loop or any feedback loop. We could conceivably go around the loop forever, but in the execution of real world events, the number of cycles (especially decision cycles) is limited by criteria that are extrinsic to the paths, so we will limit the counting to one.[83] Unfortunately, this limitation is also optimistic on the confusion side. If there are many cycles, there can be a lot of confusion. We do not address how cycles are broken, only noting that in practice they are broken all the time (Arrow 1974; Wasserman and Faust 1994). Our focus is on structure and its relation to flexibility.

4.4.1.4 Drawbacks of having alternatives

In many complex systems, especially enterprises, it is difficult to know all of the possible situations that may arise and require attention. This is particularly true in combat operations. During Operation Desert Storm, the enterprise assembled to plan and control the air sorties had “so many linkages and pathways that naming, let alone tracing, all the connections may be impossible” (Mandeles et al. 1996, p. 81). Mandeles, et al. document numerous instances of bypassing formal structures and processes in Operation Desert Storm as well as the difficulty of gaining precise and detailed knowledge of events: “…neither planner nor General Horner, the joint force air component commander, knew the details of what was happening in the air campaign or how well the campaign was going.” (Mandeles et al. 1996, p. 82.) Other conflicts are filled with

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[81] Most complex systems have feedback loops (cycles). If we do not limit the counting of paths with cycles, the number of paths is infinite. An alternative is to count only all paths of length up to (n-1), where n = the total number of nodes in the system. This counts some cycles many times, but also captures all possible paths that do not have a cycle (the longest non-cyclic path is one that goes through all nodes in the system once, from input to output, also called a Hamiltonian path) (Wasserman and Faust 1994).
[82] We limit ourselves here to one cycle because our purpose is to look at alternative ways to get from input output in the system. In some contexts, such as product development or voting, assessing the dynamic impact of cycles is important for understanding the stability (or instability) of the system.
[83] I claim this is reasonable. In combat air operations, or in any military operation, when decision cycles occur, they are usually broken by the necessity of making a decision, which exits the cycle. In any case, our focus is not on cycles but on options—physical options (configurations) that can generate real action.

similar accounts (Davis 2004b). Maintaining adequate control and accountability is critically important, but absent a coherent, well thought out architecture that recognizes the inherent uncertainties of combat, as we are attempting to develop here, it may be difficult to balance these priorities with needed flexibility.

4.4.1.5 A simple example

A simple example illustrates how flexibility can be represented as the number of paths in a system and how different types of hierarchical connections can impact flexibility. Assume for simplicity that there is a single input point, the top of the hierarchy, and that all outputs are at the bottom. If we begin with a simple binary tree with three levels below the root node, there are eight alternatives, if we count from the top. If we add a single lateral connection, such as the one shown in Figure 17 between nodes 2 and 3, there are 8 additional paths. If we add a vertical edge between nodes 1 and 5, we add 2 additional paths. This demonstrates that adding lateral connections increases flexibility more than a vertical connection: one added lateral edge provides four times as many alternatives as the added vertical edge.[84] If we measure system level flexibility by the number of paths per node (as a minimum, counting paths from the root node to the bottom nodes), architectures that have more added lateral connections than

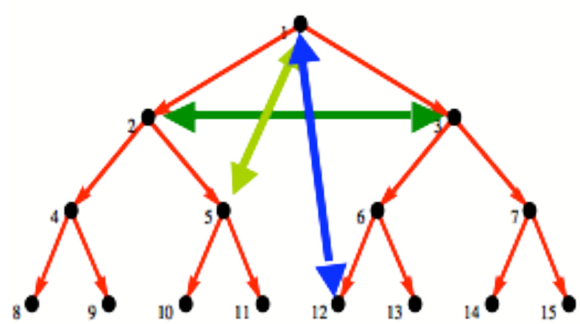

Figure 17: Tree structure with various shortcuts

vertical ones are more flexible, in terms of alternatives per node. A tabular summary of the effects of adding single edges to a base tree is shown in Table 1. We can also look at the marginal impact on flexibility as well by examining the number of paths per added

[84] Note the number of added alternatives varies with the level at which the edge is added. This is true for both vertical and lateral edges.

edge (column 4) in Table 1). Again, adding a lateral edge results in more additional paths than adding vertical edges across levels.

Structure	Paths (root to bottom)	Increase above base	Paths/edge
Base	8	-	0.57
Add edge **(2,3)**	16	8	1.06
Add edge **(1,5)**	10	2	0.625
Add edge **(1,12)**	9	1	0.6

Table 1 Number of added paths to a tree with shortcuts (from Figure 17)

There are many issues surrounding the value of alternative paths in a particular architecture. Some of the new alternatives are longer paths, implying higher coordination costs or more time to execute than purely tree-like paths. These are important factors and are addressed by other studies (Kometer's is one). Our focus is on the relationship between these extra interactions and system level flexibility. As we noted in the beginning of Chapter 2, a major impediment to gaining cooperation, especially between the Air Force and ground forces, is a lack of appreciation for flexibility at multiple levels of combat, not just the geographic flexibility inherent in the technology of air power.

4.4.2 Operational Model: Sense-Decide-Act

Many models of information-enabled combat operations rely on variations of three basic functions: sensing, deciding and acting. The network-centric warfare operational concept is based on using widely shared sensor information to generate a common situational awareness. This shared awareness enables a different command and control process model, one that relies on bottom-up organization (self-synchronization). In this model sensors feed information to decision-makers who, in turn, direct shooters. A visual depiction of the Network Centric Warfare (NCW) model is in Figure 18,

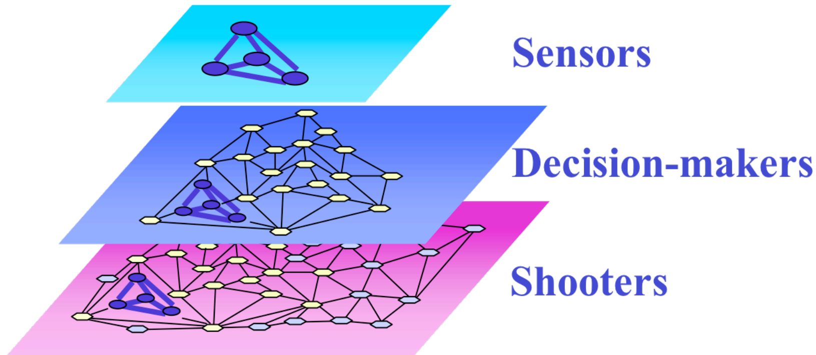

Figure 18: Network Centric Warfare model

showing a sequential (hierarchical) relationship from sensing to shooting.[85] The NCW model does not address hierarchical interactions nor provide a hierarchical view of military operations or command. Its focus is on tactical level engagements and almost total empowerment of tactical level forces to accomplish broadly defined missions under "carefully crafted rules of engagement" (Cebrowski and Garstka 1998). It does not address the question of the type of enterprise needed to coordinate across geographically dispersed theater organizations and among multiple tactical units; it implicitly assumes a "flat" structure (Alberts and Hayes 2003; Kometer 2005; Scott 2006).

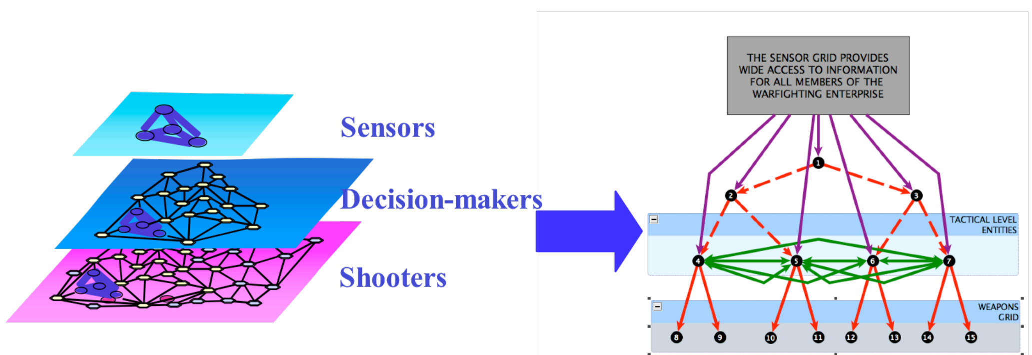

Figure 19: Hierarchical representation of NCW

The main focus of NCW is at the tactical level of combat and is specifically aimed at shortening the sense-to-act sequence via robust information sharing and collaboration. The role of upper command levels is not clearly addressed. A hierarchical perspective of the NCW model is shown in Figure 19. The core NCW concept is bottom-

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[85] Graphic is taken from a briefing titled "Network Centric Warfare, Briefing to Naval War College", by Mr. John Garstka, Joint Staff/Directorate for C4 Systems, dated 6 Dec. 2000.

up organization of combat actions, with little top down direction. This is represented by the many lateral (green) connections among tactical level units and the dashed command connections (red) from upper levels of the enterprise.

The NCW model is similar to Boyd's Observe-Orient-Decide-Act (OODA) model.[86] Boyd's model aims to represent and understand the dynamics of competition in air-to-air combat. A diagram of the OODA loop is shown in Figure 20. The main idea behind the OODA loop is to understand what is necessary to sense and respond *faster than an adversary*. This is one aspect of flexibility as we have defined it, but is only

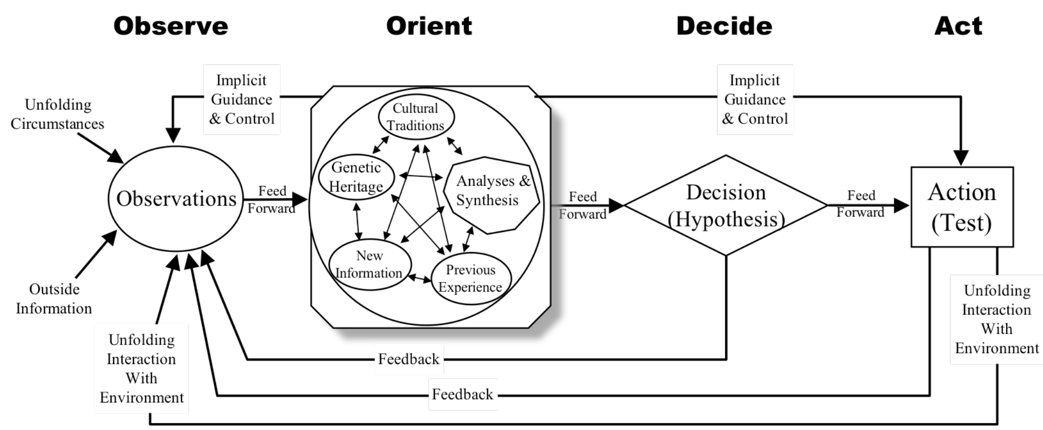

Figure 20: Boyd's OODA Loop

aimed at one level of hierarchy at a time. Though the OODA loop model has been applied to other competitive situations, such as business strategy, it is silent on issues of structure—how differing levels of effectiveness might be achieved by different structures—it does not discuss the implications of hierarchical organization.

We can examine the application of OODA loops within a hierarchy by a visual representation, such as that shown in

Figure 21. In the diagram, we have placed the OODA model on top of each node that can sense and process information and then make a decision. While we can conceptually treat the entire enterprise, or subsets of it that consist of more than one node, as a single entity that has an OODA loop, the basic model does not help us with the

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[86] Col John Boyd was a U.S. Air Force fighter pilot who has acquired legendary status as strategic thinker, brilliant tactician and innovator. A good biography is Coram's *Boyd: The Fighter Pilot Who Changed the Art of War* (Coram 2002).

fundamental problem, which is understanding how individual OODA loops interact impact higher level OODA loops. Stated slightly differently, each stage in an individual OODA loop can be connected to another stage in a separate OODA loop. We have no way to understand the implications of this using Boyd's model. While strategic or operational level OODA loops can be defined, there is no

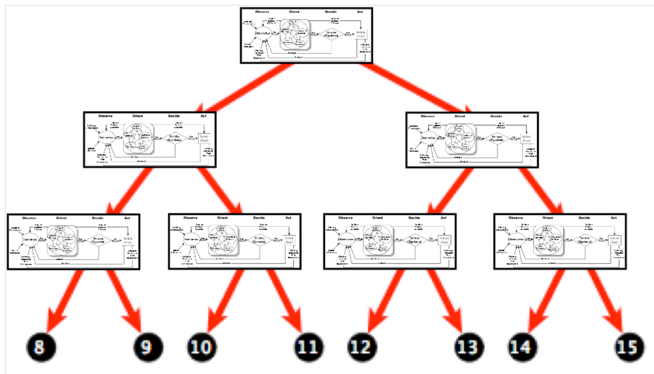

Figure 21: OODA loops in a hierarchy

framework for examining the impact of connecting several of them together, each operating at a different level of abstraction.[87]

A third model of combat is the Information Age Combat Model (IACM). This model aims to highlight structure, process and evolutionary dynamics of combat simultaneously by leveraging network-theoretic constructs. A two-sided model, shown in Figure 22, it consists of sensors (S), deciders (D), influencers (I) and targets (T) (Cares 2004). The IACM contains the same basic functions as other combat models, sensors provide information to decision nodes and deciders provide direction to influencers (usually, but not always, weapons). Influencers act on targets (not necessarily in a destructive manner), which are sensed by sensors, completing a loop that starts the basic model sequence over again. Because it explicitly includes targets, this model can

[87] We must be clear on this point: the extent of our investigation is to understand the impact of architecture on flexibility at the enterprise level. We are not going to address impacts at the level of individual or even collective OODA loops.

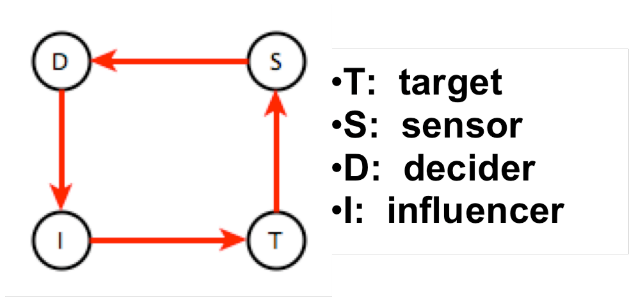

Figure 22: Information Age Combat Model

be used to model two-sided combat. The IACM is silent on issues of coordination and control—the "decide" portion of the model–how different decision nodes address issues of coordination or resource allocation. It is also explicitly "flat"—there is no hierarchy in the model, though a fully developed example would probably show clustering of connections.[88] The IACM's value is found in the ability to be specific about, and explore in more detail, complex combat-related issues that the OODA and NCW models cannot. This model allows issues such as the structural and dynamic implications of enabling wide access to sensor information to be explored with a more computationally oriented approach explicitly amenable to network theoretic tools.

We can also examine how the IACM relates to our hierarchical framework. The IACM aims for a comprehensive model of combat processes, dynamics, structure and evolution. A more complete representation than that shown in Figure 22 is shown in Figure 23. The IACM does not address hierarchical relationships among decision makers, nor does it address issues such as skipping over layers of decision makers. The IACM

[88] Cares discusses the concept of autocatalysis enabled by certain network structures (that include clustering) and the benefits that may accrue from it (Jain and Krishna 1998; Cares 2004).

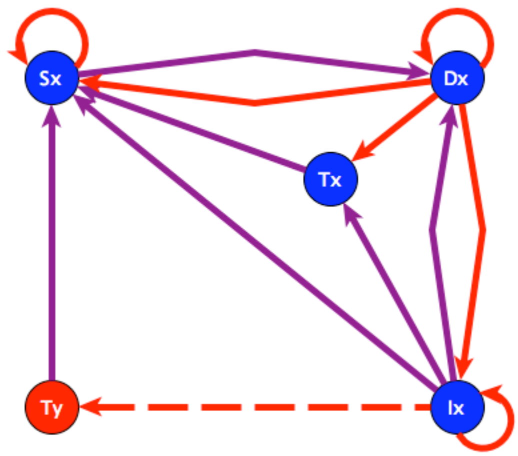

Figure 23: More detailed IACM

also addresses interactions that command (move) sensors, as well as other information flows and relationships related to combat. Our goals are focused on flexibility (as we have already specified). Also, though some sensors are primarily designed for strategic purposes and some for operational purposes, with increasing information connectivity, these distinctions are beginning to blur. The same is true for many influencers in the IACM. We examine the hierarchical relationship among the controlling aspect of the system—the decision nodes. A simplified example of how the IACM looks in a hierarchical representation is in (Figure 24). Figure 24 does not represent adversary targets (red) in Figure 23, nor does it depict all of the possible information flows.

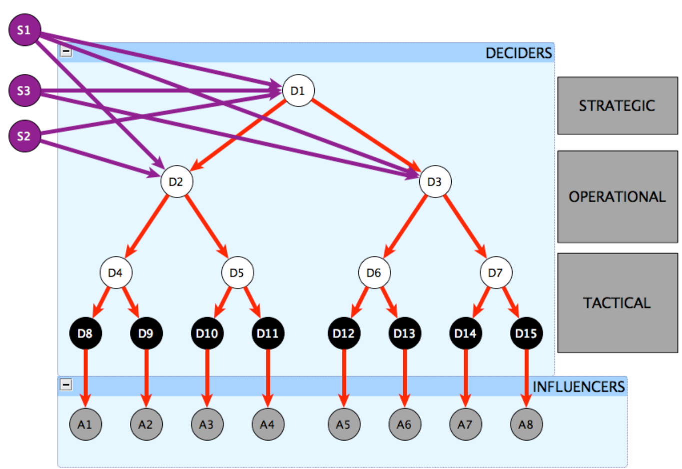

Figure 24: Hierarchical representation of IACM

All of these models are information processing perspectives of operations. Information from the environment comes into the system, is processed in some manner, and an action is chosen and executed. Once the action impacts the environment, the process repeats. None of these models addresses the issue of hierarchy, a necessity if we are to honestly address *operational* issues, such as how to design specific properties into our social and technical systems and how to "solve" the complex and interdependent problems that must be addressed by a modern enterprise.

We simplify these information-processing perspectives to create a Sense-Decide-Act model. In this model, the environment is sensed by the enterprise, information is processed, a decision is made and action chosen is then carried out. As events unfold over time, the process is repeated, once the environment has "processed" or responded to the action by the enterprise. The basic visualization of the model is shown in Figure 25 and a summary of the models at Table 2.[89]

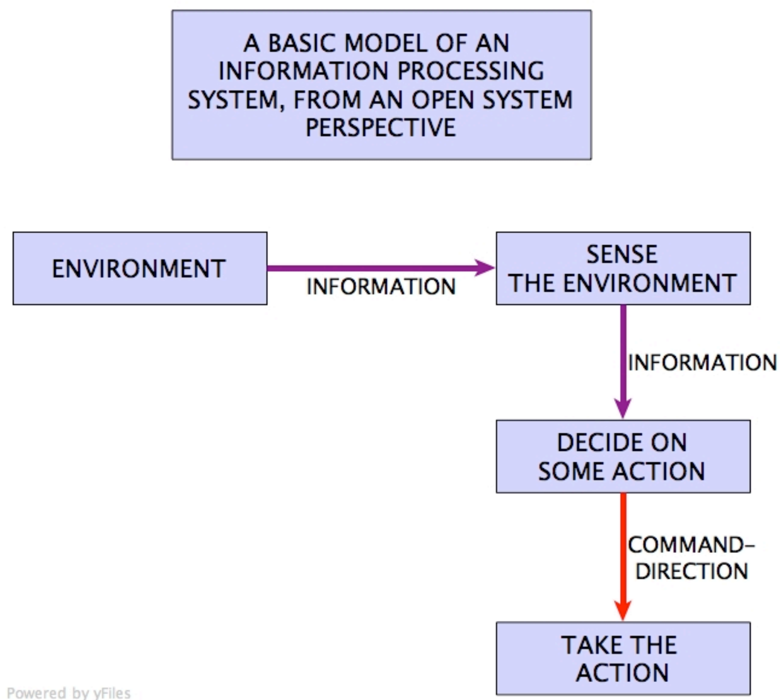

Figure 25: Sense-Decide-Act model

Model→	NCW	OODA	IACM	SDA
Input	Sensor grid	Observe-Orient	Sensor	Sense

[89] This is a very general model of systems, especially information processing systems. It has been used as a model for the brain, for biological organisms and for organizations (Thompson 1967; Holland 1996). It is also a simplification used in robotics (Brooks 1987b).

Processing	Command-control grid	Decide	Decider	Decide
Output	Weapons grid	Act	Influencer	Act
External			Target	Environment

Table 2: Summary of various models of combat operations

If we expand the representation in Figure 25 and show a more complex representation of the decision structure, we can begin to appreciate the complexities of operational decisions at multiple levels of abstraction and hierarchy. Figure 26 shows a decision hierarchy containing a single command node (white circle) and non-command

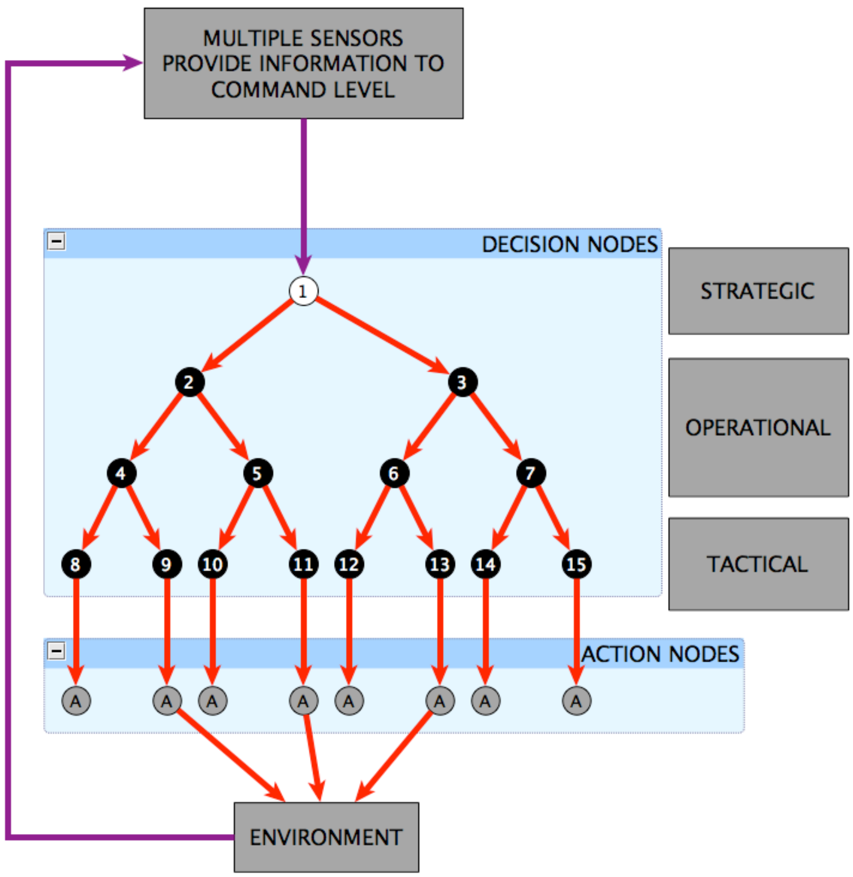

Figure 26: Hierarchy with one command node

nodes (black circles). For simplicity, we show only a generic sensor box representing possible sensor inputs to the command node. In this representation, the command node can sense the environment and direct lower level nodes to take appropriate actions that result in an interaction with the environment through the "action nodes" at the bottom of the diagram. Nodes at each level of command have different priorities based on the capabilities at their disposal (tactical level nodes (shown as black circles)), area of responsibility and associated time horizon. If we expand the ability to access sensor information to lower levels of hierarchy, the commander (node 1) can authorize lower level nodes (nodes 2 and 3 in Figure 27) to make decisions. But at the same time, these

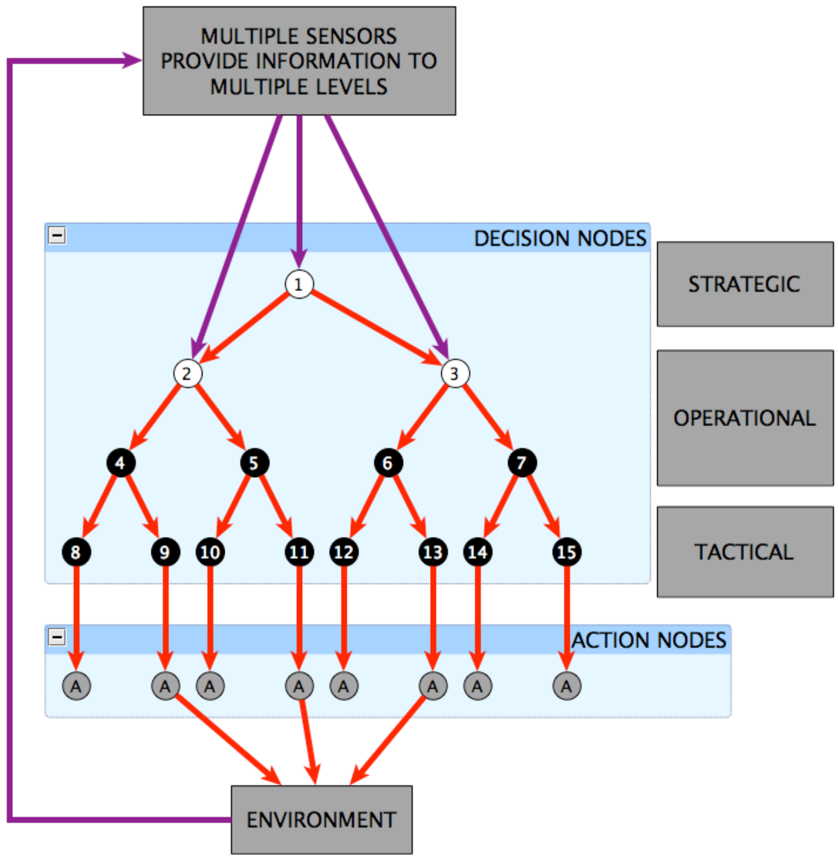

Figure 27: Hierarchy with two levels of command

lower level nodes will have different time and space horizons (operational vs. strategic, (i.e., shorter vs. longer in time and smaller vs. larger in geography)) than the command node, #1. In addition, if nodes 2 and 3 are decomposed by function (e.g., air vs. ground), their decision criteria are going to diverge from each other as well as from the overall commander, increasing the difficulty of coordinated action on and in the environment. We can further increase the sensing distribution through the hierarchy and create another level of command nodes, as shown in Figure 28. Inspection of the diagram shows us further potential divergence of priorities, interests and capabilities.

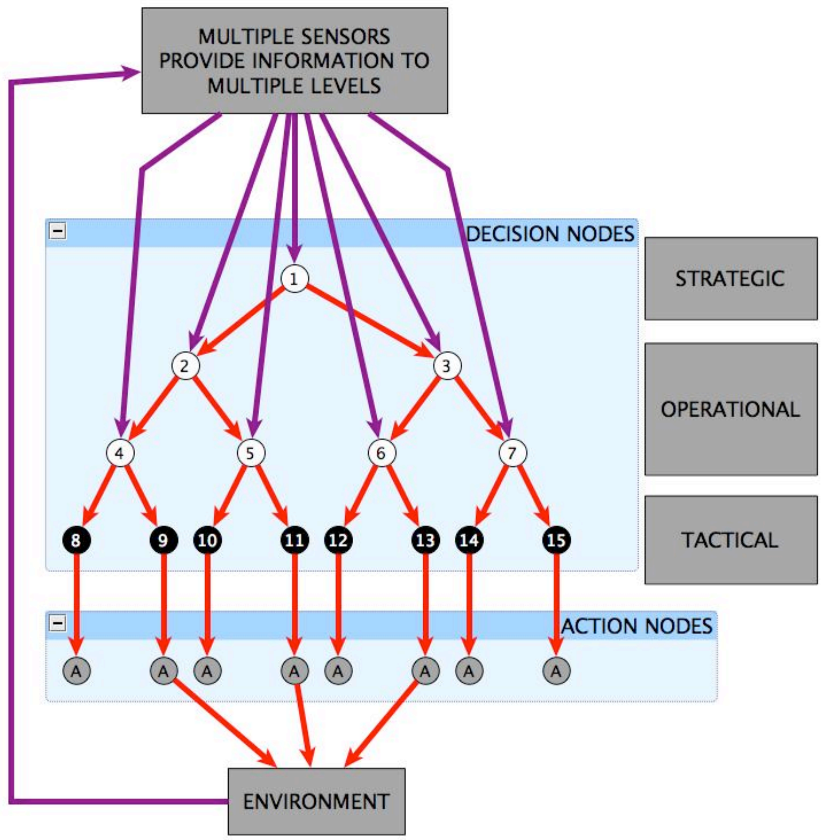

Figure 28: Three levels of command decision-making

Our model of enterprise structure is grounded in a synthesis of theory that views complex systems as naturally hierarchical. Hierarchy and abstraction are useful in managing complexity because humans have limited cognitive and physical resources, whether operational, technical or social (Simon 1996). But pure hierarchical decomposition—a tree structure—is not sufficient to help us with the problems we aim to address. When problems are complex, strict tree hierarchies can become exponentially large, cumbersome and inflexible. In addition, _*natural*_ interdependencies in the system may preclude an effective tree-like decomposition, even if only for analytical purposes; as discussed in section 4.4.1.4, interactions driven by the need to address unforeseen situations can create structures that are not trees.

One solution to this challenge is layering and lateral interactions, as we discussed earlier. Layering is a way to manage the challenge of complexity, to separate concerns in the design and development of systems (Parnas 1972; Eppinger 2003; Moses 2003; Yassine et al. 2003; Yassine Ali et al. 2003). Though interaction details within levels can be complex, specific attention to managing interactions within system levels as well as between them can improve overall organization performance in practice (Carpenter 1995; Sosa et al. 2004; Roberts 2006). For example, a comparison of Army-Air Force structure to the Marine Corps' structure in Operation Iraqi Freedom showed the Marine's to have more interactions at low command levels (more complex) compared to the Army-Air Force side (Roberts 2006). Because of these lateral interactions on the Marine side, aircraft were managed more efficiently. On the Army-Air Force side, there were robust lateral interactions at higher levels, but fewer at lower tactical levels. This resulted in overload of the higher headquarters and inefficient employment of aircraft.[90] We will discuss this in more detail in our case analysis in Chapter 5.

We can show in a simple hierarchical diagram how lateral interactions can address the issues of diverging interests as the hierarchy gets deeper as well as how more

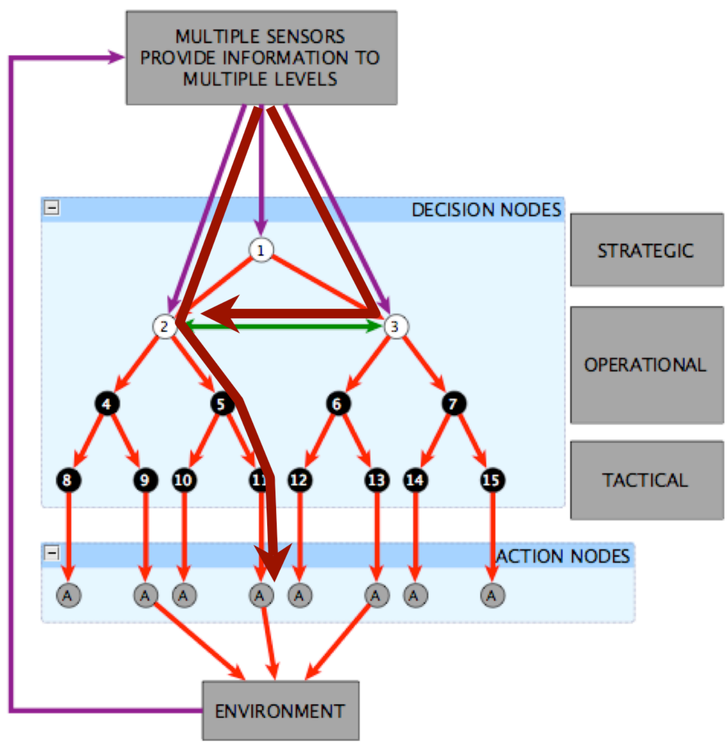

Figure 29: Impact of lateral interactions

[90] This is a relative comparison between the Marine's and the Army's methods. Operation Iraqi Freedom was notable for its overall highly flexible and effective use of air and ground power together (Kirkpatrick 2004). We will discuss Army-AF air power operations in Chapter 4

paths from sensing sources (input) to action nodes (output) are created by them. This is shown in

Figure 29, where we have added a lateral interaction between nodes 2 and 3. Here we can see how the addition of a lateral interaction can help reduce divergence of interests by enabling both nodes to share understanding and perception of the information provided by the sensing system at the top of the diagram. We can also see how a sense-decide-act path can be created by passing information, by collaboration and by direction.

Few studies or models look at enterprises—groups of discrete organizations bound together by intersecting and sometimes conflicting interests. Fewer still have proposed frameworks that can holistically grapple with hierarchical differences and system level flexibility—most models are "flat". Moses has proposed some general concepts to address this deficiency, which we use as a foundation for our architectural framework and model (Moses 2003; Moses 2004a).

4.4.3 Structural baseline: Representation of the system as nodes and edges

4.4.3.1 Defining connections and relationships

To specify a model that emphasizes laterality, we need to define the structural orientation of interactions among the components of the enterprise. There are two broad classes of connections in a hierarchy, vertical and lateral. There are two types of vertical connections in addition to the parent-child connections in the base tree structure: parent-grandparent connections and aunt-uncle connections.

4.4.3.2 Vertical

Vertical connections in a tree structure are parent-child relations (Figure 30). Vertical connections in information or social systems generally involve commands or

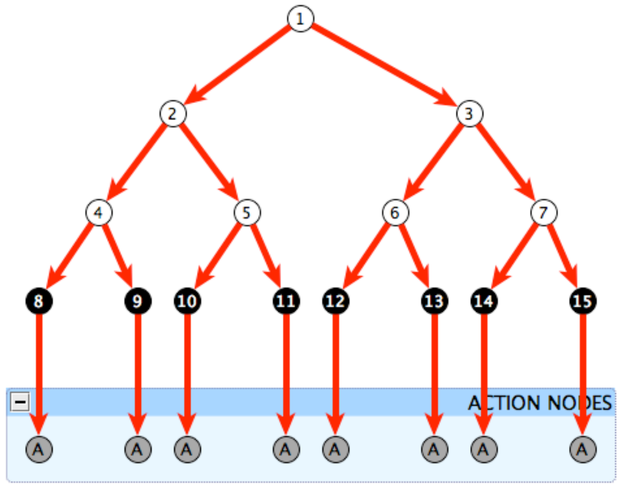

Figure 30: Tree structure; parent-child relationships

directions between parent and child, an exchange of information in either direction, or sometimes an attempt at negotiation or bargaining. Normally a node in a tree has only one parent at any moment in time, but parents can shift over time, especially in operational situations (Figure 31). For example, if a combat aircraft has different command authorities as it transits from its base to its assigned mission potential flexibility is increased: the mission assignment may be adjusted by an appropriate

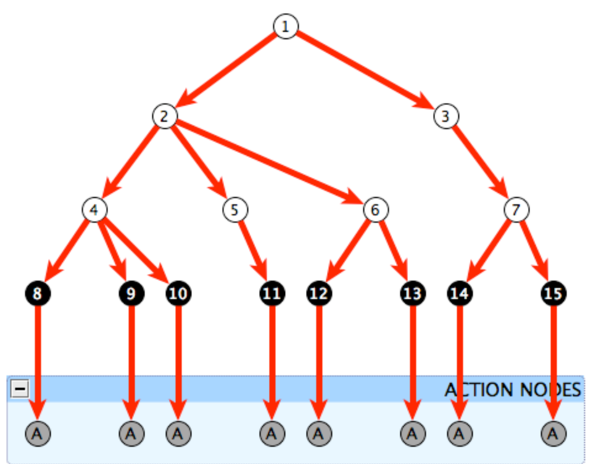

Figure 31: Examples of parents shifting over time

authority as the aircraft transits to its assignment. For example, in Figure 31 node 10 has shifted parents from node 5 to node 4 and node 6 has shifted parents from node 3 to 2.

Grandparent and aunt-uncle connections can also exist in a hierarchical structure. Grandparent connections arise when a node skips intermediate levels to interact directly with nodes that are more than one level away in hierarchy. Some grandparent

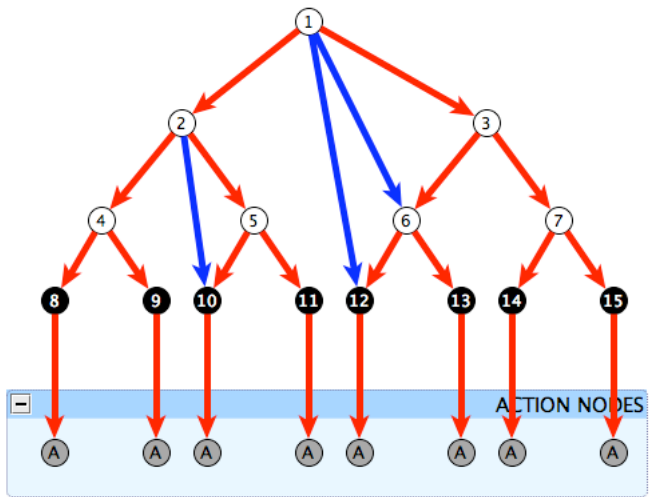

Figure 32: Grandparent connections

connections are shown in blue in Figure 32 (the connection between node 1 and 12 is technically a great-grandparent connection).

Complications arise when a node has two or more input nodes (parent, uncle, grandparent) that can give it orders/direction at about the same time.[91] This can cause confusion over the meaning or intent of the direction in at least three ways. First, conflicting direction may be given. Second, if interactions skip a level (a level violation), such as a grandparent or great-uncle connection directing action) the receiver may misunderstand the meaning of the direction, or the sender may misunderstand the capability of the receiver or have incomplete information about the situation of the receiver. Third, an ongoing operation may be disrupted by a higher-level node if it re-directs resources or mission assignments with inadequate knowledge of the tactical situation. Aunt-uncle connections are shown in blue in Figure 33. Non-vertical connections: lateral vs. vertical structures.

[91] Note that, in an environment of ubiquitous communication, the potential for this situation to exist is high. This places a premium on the type of planning that creates the depth of command advocated by Kometer.

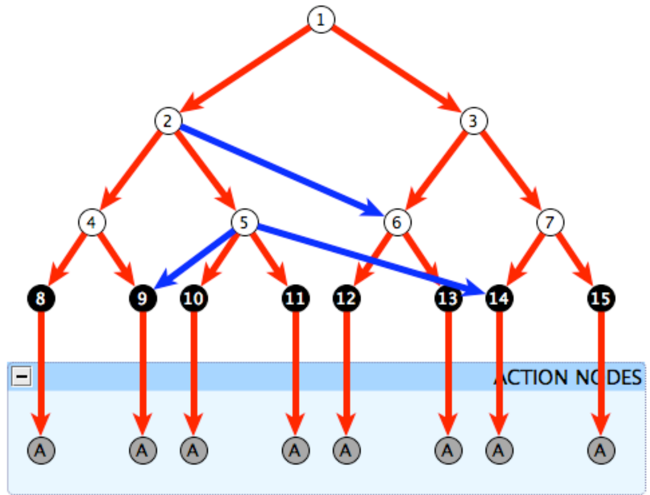

Figure 33: Aunt-uncle connections

An uncle connection need not be fully hierarchical in nature—in many operational cases, uncle connections are only information passing channels.[92] However, if an uncle connection exerts directive authority it may cause legitimate confusion over mission tasking or orders.

Brother-sister/cousin connections are those that connect nodes at the same layer of hierarchy. We call these *lateral* connections. They mainly involve information exchange, coordination, and collaboration, and occur between peers—nodes *at the same layer of hierarchy*. Lateral (cousin) connections are shown in Figure 34. Coordination and alignment attempts are *enabled by the structure* but the motivating force for these attempts is a feature of nodes. While node behavior is important, it is not our focus. Our primary interest is in understanding how structural relationships enable flexibility.

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[92] This was a dominant theme in the reporting of Operation Desert Storm, both in press and in formal analysis by the Gulf War Air Power Survey (GWAPS). Extensive informal connections across multiple levels of hierarchy were reported (Atkinson 1993b; Cohen 1993; Mandeles et al. 1996)). These connections can serve as van Creveld's "directed telescope" as envisioned by Kometer (see discussion in Chapter 2), but for multiple higher-level decision-makers, not necessarily those in the operational enterprise.

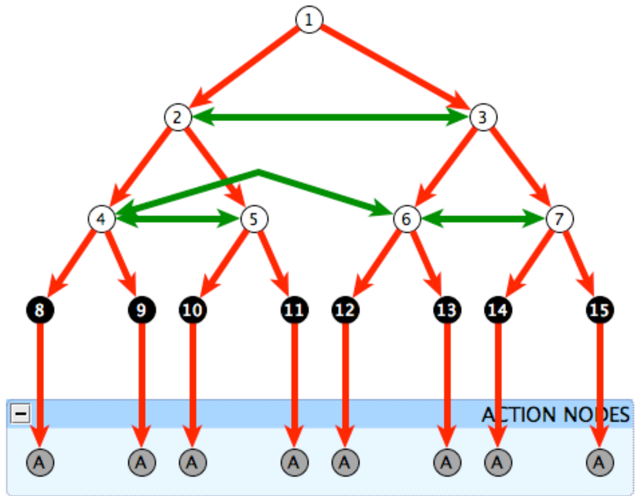

Figure 34: Cousin (lateral) connections

4.4.3.3 Laterality

We define laterality as the ratio of the number of lateral connections to the total number of connections in a system. When the laterality of a system is zero it is a tree, when it is one it is essentially a one layer (flat), fully connected network, with no hierarchy. Most systems of interest have laterality measures between 0 and 1. We define a layer as a horizontal division of a system or organization according to criteria deemed operationally relevant. A fully connected single layer by itself is called a network.[93] In this approach, layer identification is determined by information imposed on the system by virtue of design knowledge, intent or analysis that enables the identification of a consistent abstraction that defines a set of nodes. This makes abstraction a key factor in our analysis, very similar to its importance in information system design. In software, middleware is often used to connect nodes to a layer and thereby to other nodes connected to the same layer (serving as a lateral connection). In organizations, laterality arises when decision authority or other value added interactions occur across formal organization boundaries at the same hierarchical level (Chisholm 1989; Galbraith 1993; Mandeles et al. 1996). Though there are many dimensions along which to classify layers, usually one dimension is more significant than others, such as seniority, rank or perhaps,

[93] Network as a term can be used very generically; technically a hierarchical tree is network. Here, we consider network as it tends to be used in the organizational forms literature, which tends to place networks as a new form along with markets and bureaucracies (Powell 1990; Romanelli 1991).

operational level, such as strategic, tactical or operational. This last dimension is what we emphasize in our model of combat operations.

4.4.4 Scenario examples

We will present an illustration of the operational implications of different architectures using two simple scenarios. Each will provide a general discussion of the overall structure of the enterprise and the implications of these structures in terms of system properties and operational effectiveness.

4.4.5 Top-down tree-like architecture with no laterality between units

We start with a simple hierarchical tree structured enterprise, and employ it in a complex operational situation. Assume in this case that the two main components of a fighting force are separated operationally. There is coordination, but it is minimal, formally arranged and not collaborative. This can be represented by a simple tree structure, where there is a single supervisor and two subordinates, each conducting their own operations. Operating this way requires separation of forces in time and space for safety reasons, in both planning and operations. When separation is not possible, the supervisory node coordinates operations. This situation is shown in Figure 35

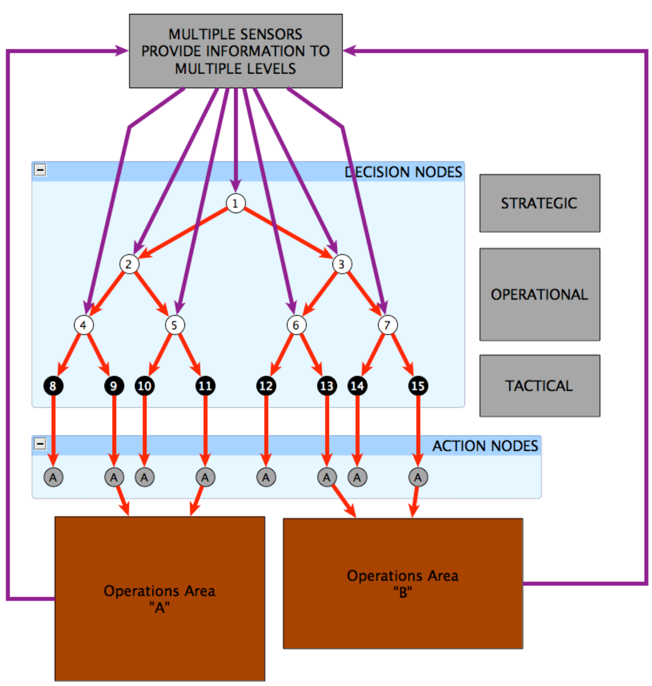

Figure 35: Tree Hierarchy—Physical separation of operations

This illustrates the limited flexibility of a strict tree-like structure. The benefits of this structure are that it is simple and efficient from the perspective of information transmission and control; information flows in well-defined ways. Responsibilities and accountabilities are easily defined and conflicts easily resolved. From the commander's perspective, alignment is simple as well—everyone follows directions from the top. There is little uncertainty inside the enterprise about roles, resources, overall strategy, procedures, etc.

The challenge comes when the environment begins to change and coordination requirements increase beyond the capacity of the supervisor (commander). Limited communication paths of the tree create an inability to process information from the environment (fewer information flow paths), which results in a limitation on the number of alternative force arrangements possible. The limited ability to reconfigure interactions limits flexibility. What was efficient in the previous circumstance becomes inefficient—no matter how much effort is exerted, it is unlikely that effective action can be taken. The result in a situation like this is that people will work around the architecture (work around the system), creating new patterns of interaction (Chisholm 1989; Mandeles et al. 1996). Under the right circumstances, these new patterns (new structure) can create a cascade of problems, causing accidents or other types of unexpected behavior. Kometer names this phenomenon "organizational drift." Achieving flexibility in this way is a problem because enterprise leadership no longer has control over the structure of the enterprise.[94] Strategic coherence can be impeded and likelihood of accidents may increase, both of which lead to decreased effectiveness and increased inefficiency.

4.4.6 Layered hierarchical architecture with lateral interactions at multiple levels

If we have an enterprise similar to the last example, but that is laterally connected at one or more subordinate levels, the ability to respond better to uncertainty and changing external requirements can be improved. If the environment is complex or changing rapidly, the ability to coordinate at lower levels enables better responsiveness—

[94] This effect can be analogized to the complex systems concept of Highly Optimized Tolerance (HOT) (Doyle et al. 2005).

effectiveness can increase (Galbraith 1993; Joyce et al. 1997). Not all information must go to the top for decision, not all disputes over possible responses require top-level arbitration. This enables resources available at lower levels to be recombined faster—flexibility goes up. This increase in effectiveness is accompanied by an increase in efficiency, since there is a higher probability of generating an effective response (either responding before the environment changes again or responding with an action that is more likely to be relevant to the situation rather than irrelevant due to incomplete or inaccurate information). In Figure 36, sensing information is available at three levels

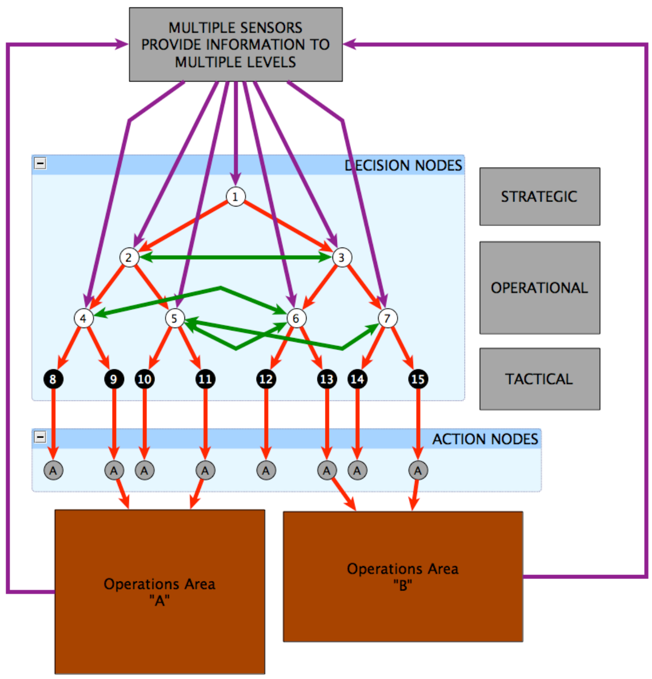

Figure 36: Lateral hierarchy with multiple levels of command

(white nodes). We can examine this diagram and notionally compare how adding lateral connections can enhance flexibility. To do this we will look at the average number and length of sequences from a sensor input location to one of the three action nodes at the bottom that interact with the environment.[95] If node 1 is the originator of an action, there are 24 possible sequences (paths) through which the decision must pass to get to an appropriate action node. The average length of these paths is 4.7 steps. If we allow

[95] Our assumption here is that nodes 9, 11 and 13 are the only appropriate nodes for action based on the sensor information.

nodes lower in the hierarchy to act (node 4 for example), there are fewer alternatives, but the path length is only about half as long, indicating a faster response time. A summary of the number of paths and paths lengths is given in Table 3.

Level	Node	# paths	Avg. path length
1	1	24	4.7
2	2	12	3.7
2	3	12	3.7
3	4	3	2.7
3	5	3	2.7
3	6	3	2.3
3	7	3	3

Table 3: Summary of available paths and path lengths

Figure 36 is reproduced in (Figure 37), showing two possible sense-to-act sequences, providing a visual demonstration of the differences in time responsiveness (represented by path length). The path from sensor

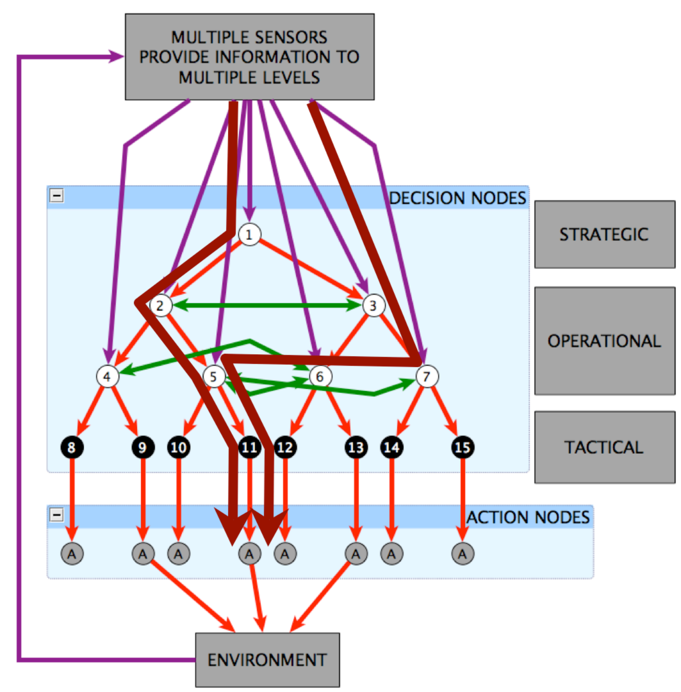

Figure 37: Lateral connections at lower levels enable shorter sense-to-act paths

input through node 7 is only two steps, with a peer-to-peer interaction, instead of the path through node 1, which is three steps, through hierarchical connections.

Figure 37 can also show us how the architecture can be flexible to unknown circumstances. For example, when sensor input from the environment to decision node 4 requires action, node 4 does not have the best capability. In this case, the lateral connection between node 4 and node 6 can enable the use of the action node capability directed by node 12. This is shown in Figure 38 with the previous paths from Figure 37 deemphasized by coloring them gray.

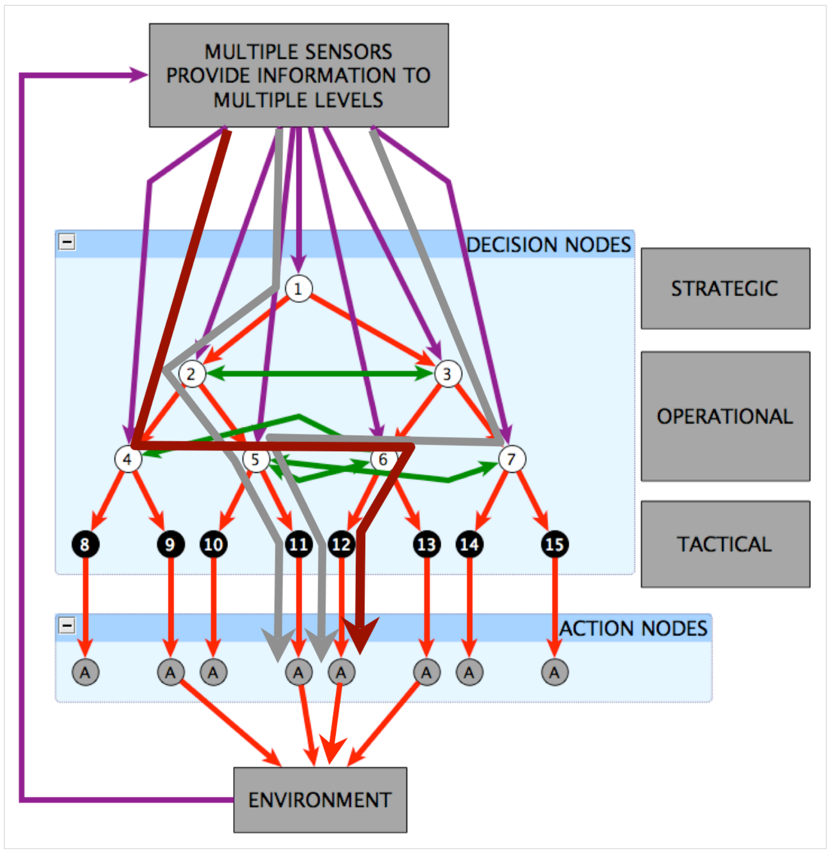

Figure 38: Use of alternate paths

We can also take another view. With lateral interactions, the complexity of managing the enterprise increases and efficiency decreases. There are more interactions and more autonomy among the members of the enterprise. So to keep the chances of error from increasing, more attention must be paid to the rules governing interactions among subordinates, more training and exercises must be conducted to practice using these rules. The lateral architecture is more complex, both structurally and operationally. It can also be viewed as inefficient or ambiguous when accountability is important. Not all possible information flow channels or resource combinations will be needed all the time. So there is investment that may not be fully employed all the time.

4.4.7 Trade-offs

Our net assessment so far is that lateral architectures can be beneficial in complex environments. They enable a higher level of increased flexibility compared to other means of gaining flexibility; the increased flexibility comes at increased cost, but this cost can be mitigated over time by learning (Arrow 1962a). The complexity cost of managing a lateral architecture can also be mitigated by taking account of the benefits it provides in comparison to the opportunity cost of a less complex solution. An efficient system that cannot respond to a changing environment is not very useful— it becomes a wasted resource. Inefficiencies that arise from implementation of a lateral architecture can be addressed by refinement of the architecture, learning and training, with evaluation of flexible architectures clearly tied to the operational environment. We will examine these trade-offs in more detail in Chapter 6.

4.5 Summary and Discussion

Flexibility is an operational imperative at multiple levels of enterprise activity, from strategic to tactical. Enterprises have been identified as a new form organizational form, or at least a new level of organizational analysis. We know little about how to explicitly design enterprise architectures so that they can be pro-actively guided or managed with respect to desired properties such as flexibility. Our goal is to apply concepts from technical systems architecture and complex systems to extend existing organization theory and to build a simple model of enterprises with a framework in which to conduct architectural analysis. Our model rests on the idea of hierarchical abstraction and on the goal of explicitly designing interactions in the enterprise that are usually treated as informal or *ad hoc.*

Many concepts and theories of complex systems break them down hierarchically, either according to a "scale" of description or by decomposition into parts (Simon 1962; Bar-Yam 1997). Most architecture concepts in engineering (outside of computer science), do not address hierarchical abstractions well, except in the area of systems integration (usually organizations that perform systems integration). These limitations rest on the idea of minimizing design challenges in physical systems and on the observation that for many physical systems, interactions introduce complexities that can detract from overall performance or function delivery. In general, information systems, while suffering from these same problems, do not suffer them with the same impact on performance as in other engineered systems. The ability to separate interactions more cleanly and to build abstractions that can simplify complex lower level problems is a key distinguishing feature of information systems and the main parallel to operational enterprise issues. We also recognize that Simon's idealized model of "near decomposability" does not recognize all of the interactions in an organization (and by extension, an enterprise). Explicit recognition of lateral interactions and of layered structures may add a helpful degree of richness to Simon's construct.

We combine layered architectures from computer science with the observation that organization science typically treats cross boundary interactions as "unprogrammed" or informal. This allows us to take the perspective that we can design enterprise architectures to have specific, desired properties by explicit design of interactions that will allow uncertainty to be handled by the formal structure. Lateral and layered interactions are enablers of flexibility that, when placed in an overall hierarchical structure, allow us to balance flexibility with the need for stability and control. Our emphasis is on the operational side of enterprise architecture—multiple organizations and sub-organizations working together to achieve specific outcomes. Kometer's 2005 analysis of combat air operations and his recommended concepts provide a starting point for exploration of this framework. Our architectural analysis of Kometer's cases is presented in Chapter 5.

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Chapter 5

Architectural analysis of the Combat Air Operation System (CAOS)

5.0 Introduction

In this chapter, we examine the conflicts that Kometer used in his analysis. Rather than teasing out the implications of constraints on behavior and potential outcome, we examine these conflicts from the perspective of system level architecture. We do not mean to imply that details—that understanding how various constraints and orders are translated to action and the implications for combat outcomes—is not important. Quite the contrary. We feel that, in addition to understanding how constraints effect behavior and outcomes, it is important to have an understanding of how structure effects overall system properties and that properties are a critical enabler to crafting and enabling desired outcomes.

Increased collaboration and cooperation among the military services is a key goal of the Department of Defense (DoD). Using information technology to enable this cooperation and collaboration is a central tenet of the Department's Network Centric Warfare concept, which aims to make military forces both more efficient and more effective in an environment of increasing uncertainty and tighter resource constraints. A desire to transform the Department of Defense by leveraging advanced technology in conjunction with new concepts of operation helps explain Secretary of Defense Rumsfeld's push to use a smaller ground force when planning Operation Iraqi Freedom in 2002-2003 than was used in Operation Desert Storm (Franks 2004, p. 135; Woodward 2004; Feith 2008).[96] Missing from most accounts and analysis of efforts to increase

[96] The extent to which that Secretary Rumsfeld may have pushed his commander, Gen. Franks, on this point is debatable. There were many political and strategic considerations driving the development of the second Iraq war plan. Feith's account in *War and Decision* notes that Rumsfeld cautioned against the overwhelming force used in Desert Storm as "remarkably wasteful". Feith also notes that Franks' emphasis as the plan developed was on surprise (due to strategic considerations, both military and diplomatic), which argued against a long build up of a large force. Woodward's account in *Plan of Attack*, chronicles the overall evolution of the Iraq War plan, OPLAN 1003, from the "on the shelf" version of 1998 to the implemented war plan of March 2003. The main theme running through Woodward's account is the continual iteration of the plan to meet the strategic intent of the President, as shaped and translated by Rumsfeld, which included both internal and external political constraints. Franks' own account emphasizes his tendency, throughout his career, to innovate with new ways of operating and the overall goal of strategic surprise that shaped the plan.

enterprise flexibility is an appreciation for the relationship between architecture and more effective and efficient operations. Simply cutting the ground force and relying on advanced technology in Operation Iraqi Freedom is insufficient; effectiveness of the force is, at least in part, a function of architecture.

Most information-age operational concepts do not address the role of structure well and often explicitly de-emphasize the role of hierarchy, relying instead on notions of extreme decentralization: bottom-up, self-organizing combat (Cebrowski and Garstka 1998; Alberts et al. 1999). Amplifying on the prevalent theme of decentralization, "edge organizations" have been proposed as a major organizational form for network-centric operations (Alberts and Hayes 2003). In this form of organization, all actors are able to make well-informed and "skilled" decisions; little decision or authority hierarchy is implied. From a hierarchical perspective, the organization is "flat"; from an information access perspective, it is "flat" as well. In edge organizations, all actors and all organizations have equal access to all possible (and relevant) information.[97] While delegation of decisions to the lowest practical hierarchical level may be a good idea in many complex battle situations, there are theoretical, practical and sometimes legal problems with this type of structure (Kometer 2005; Scott 2006). The Network-Centric Warfare focus on bottom-up organization may be useful for tactical level activities, but it is unclear how this concept scales to higher levels of operations—how numerous tactical level activities can or should be coordinated to achieve operational level goals and strategic ends in an information-rich environment.

In short, there is little to guide military commanders and other decision makers in design, management and evolution of information-age organizations. Enrichment of Kometer's process-oriented case studies using an architectural perspective can help us with the challenge of designing flexible military organizations. This research aims to develop a more formal description and analysis of emerging trends toward information-intensive military operations.

[97] While edge organizations lack a concrete definition, the characteristics they are deemed to hold imply this general characterization. For a thorough review and critique of the concept, please see (Scott 2006).

This chapter serves two purposes. The first is to enrich Kometer's analysis by connecting his empirical observations with an architectural perspective of combat air operations and the overall warfighting system. The architectural transformation of U.S. military operational forces between 1991 and 2003 is highlighted in Table 5. The second is to examine the connection between structure, flexibility and laterality in these case examples. Focusing on architecture enables us to highlight more precisely the tradeoffs of different architectural approaches to military command and control in the information age. We will examine tradeoffs in Chapter 6.

5.1 Architectural analysis

Kometer is concerned with the nature of interactions among different components of the Combat Air Operation System (CAOS).[98] He addresses hierarchy from the perspective of how authority relationships impact individual or organizational behavior—the characteristics of nodes in the system. Kometer's aim is to understand practice and process—*how* to do things, concluding that it is important to "make decisions about who makes decisions." This is another way of saying "pay attention to the design of the enterprise" and he provides two tools with which to do this: a general formula for command and control and his depth of command concept.

Our focus is on *architecture design* of flexibility in enterprises. This chapter applies the framework developed in Chapter 4 to examine its potential utility for design. We know that hierarchical features of complex systems and lateral interactions are one key to understanding system properties in general and flexibility in particular (Galbraith 1993; Simon 1996; Moses 2003). As reviewed in Chapter 3, Kometer looked at four conflicts from five different perspectives, integrating these individual views to assess air power command and control. Our analysis will examine each conflict once, looking at hierarchical structure, lateral interactions and how they relate to, or impact, flexibility. By highlighting this single dimension of combat air operations, architecture, we aim to illuminate the relationship between laterality, flexibility and layered architectures.

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[98] "CAOS" is a term coined by Kometer to describe the totality of people, organizations, institutions, systems and relationships involved in planning and executing the application of combat air power. It includes the Air Operations Center (AOC).

Architectural analysis and model building of this type must have three components:

1. Identification of the architecture rules and the connection of these rules to the resulting structure. Kometer established a clear and compelling connection between political constraints (strategic level architecture rules) and the nature of command relationships. Missing from his analysis is a clear theoretical foundation that can help generalize his findings. This development was presented in Chapter 4.

2. An appropriate abstraction of the system that represents its structure in a way that (a) highlights flexibility in an operationally relevant way and (b) enables us to measure it.[99]

3. Extraction of enterprise structure from data (Kometer's case analysis).[100] The ability to capture structure in detail at the scale of joint military enterprises is difficult. But the nature of Kometer's analysis, supplemented by other reports and data sources, helps ensure that the overall patterns and broad constants of the system's structure and performance can be captured.[101] It is difficult to capture the <u>*totality*</u> of interactions in a system such as this, unless it happens to be fully instrumented. Several inquiries to organizations that might have such data revealed that it does not exist. One analyst from the 1994 Gulf War Air Power Survey made this comment: "...I started trying to count the informal and lateral links between people and organizations in theater and between theater and [the Continental U.S.]. I gave up because it was very difficult to count and the number was very high. I'm sure I remarked in the Survey that the number of formal lateral (i.e., specified roles and relationships) and informal connections was (a) very high, (b) very difficult to trace, and (c) these connections saved the formal

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[99] Koopman, *Search and Screening*, p. 251-252; Watts, *Small Worlds*, 42-44. Wolfram, *A New Kind of Science*, p. 991-992.
[100] See Krepinevich for a discussion of the difficulties in gaining a system level appreciation of events and outcomes in recent conflicts (CSBA report: "Operation Iraqi Freedom: A First Blush Assessment"). This is a separate, but closely related, issue to the challenges of effective architectural analysis of complex enterprises.
[101] Morse and Kimball, p. 38.

organization conducting the air campaign…the JFACC--from collapse by providing timely information, analysis, and instructions" (Mandeles 2006). In 2003, a detailed process analysis of time-sensitive targeting in Operation Enduring Freedom in Afghanistan, sponsored by Air Combat Command, noted a similar problem. Timing data on engagement decisions was not available, so process timelines, as well as judgments about engagement effectiveness, had to be estimated (LaVella 2003).[102]

We review Kometer's analysis at different levels for each case. First, we look at the operational level of interactions among the services (Army, Navy, Air Force, Marine Corps); second, specific engagements at the tactical level will be examined, which provides a mostly air-power perspective. The structure of each example will be analyzed in order to discern trends over time and to illuminate the connection between architecture and flexibility.[103] We classify architectures according to where in the hierarchy we see lateral connections by using a simple notation of L1, L2 or L3 to denote strategic, operational or tactical level laterality.

5.2 Summary of Kometer's main ideas and cases

Kometer aimed to gain a more fundamental understanding of command of air power and the drivers of operational outcomes than most previous air-power research (Kometer 2005). He looked at command and control of combat air power through five different lenses (chapter numbers listed below are from Kometer's thesis):

1. Control from the strategic level (Chapter 4)
2. Interactions inside the Combat Air Operations System (CAOS) (Chapter 5)

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[102] The issue of gathering relevant data on operational processes is significant, if we are to attempt more extensive investigation of enterprise architectures. The fact that a detailed study of a significant Air Force process was hampered by lack of data is a strong indication that there is poor understanding or appreciation for the important features of the time-sensitive-targeting process.

[103] We will also note the implications for sensor information access. Since laterality-enabled flexibility is dependent upon access to information, a desired enterprise architecture (or a class of enterprise architectures) can have implications for design of technical system architectures. We must reiterate that, for the purposes of our analysis our strong assumption is that information access is ubiquitous—information relevant to operations is widely available and widely shared. Where information asymmetries exist, they relate to an inability to transmit information in its full richness (we analogize this to the enduring nature of friction in combat discussed by (Watts 2004)).

3. Technical ability to gather and process information at a central point (Chapter 6)
4. Decision making inside the command and control loop (Chapter 7)
5. Impact of distributed and dispersed command and control functions (Chapters 8 and 9)

Kometer's *main observation and argument* is that Air Force command and control doctrine is imprecise and does not adequately recognize some recurring lessons of history. Specifically, he identifies a disconnect between preferred command and control methods for air power and the type of command and control necessary for effective air-ground operations. This disconnect is troublesome because of a trend toward increased emphasis on these types of operations in recent conflicts, the counter-insurgency campaign in Iraq in particular. This is a trend noted in by other analysts as well (Lambeth 2000b; Haave and Haun 2003). He recognizes the tension in trying to achieve optimal command and control relationships for different air power missions and the need to be able to shift control modes as the situation requires--flexibility. Kometer's *main recommendation* is to address this tension by developing depth of command, the ability to move decision-making to the lowest practical level in the hierarchy, depending on risk considerations. Kometer's *method* for achieving depth of command is through a "general formula" for command and control.[104] This general formula specifies a process whereby a commander's strategy is developed into detailed operational plans through multiple iterations across and within levels of the organization, often down to tactical level unit plans, creating depth of command by virtue of working through the planning process before combat starts. Together, depth of command and the general formula provide a means to design flexibility into the enterprise, to "adapt the hierarchical organization of the forces and arrange them to work together to do whatever the situation requires" (Kometer 2005).

5.2.1 Summary and overview of the four cases

[104] Kometer, p. 240.

Kometer used CLIOS[105] systems analysis to highlight the intimate relationship between behavior and structure in complex military operations: political constraints drive behavior of actors as they develop command relationships, but performance demands create individual and group incentives to modify these relationships, both formally and informally. These command relationships, in turn, impact system level outcomes. System level outcomes influence subsequent modification and interpretation of political constraints, beginning the cycle again.[106] His discussion and analysis expose important feedback loops in the system, helping us to understand enterprise level (strategic and operational) dynamics better and to identify key relationships for management attention with the goal of better enabling operational and tactical level flexibility.

Kometer does not connect constraints on interactions to specific types or classes of structure or to system properties such as flexibility, nor does he connect these structures with system properties. Our interest is only in a narrow aspect of the system, flexibility. We will not address the details of interactions, where they come from, or their motivating forces, but will examine only structure—interactions and their hierarchical relationships, with an emphasis on operational and tactical levels. Examination of these relationships, in context of an overall assessment of effectiveness will help us to understand the relationship of flexibility to architecture.

Air power was used for different purposes and was commanded differently in each of the four conflicts analyzed between 1991 and 2003: Iraq-I (Desert Storm, 1991), Kosovo (Allied Force, 1999), Afghanistan (Operation Enduring Freedom, 2001-2) and Iraq-II (Operation Iraqi Freedom, up to the end of Major Combat Operations in May 2003).[107] Because of differences in political objectives (constraints) and technical systems, we should see differences in structure across the cases. The overall technical trend across the conflicts was increasing sensing and information processing capability combined with increasing use of precision weapons, all tied together with robust

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[105] Complex, Large-scale, Interconnected, Open, Socio-technical system (Mostashari and Sussman 2009).
[106] This is a familiar logic chain in social science literature and has recently gained visibility in the growing literature on network theory (Ranson et al. 1980) (Sewell) (Watts and Strogatz) (Newman).
[107] Sometimes Desert Storm is called the First Gulf War and Iraqi Freedom the Second Gulf War.

communication systems. The main organizational construct for air power command and control did not change significantly over the cases. In each case, an Air Force officer in a centralized headquarters commanded air power. Even with this generally constant structure, there were observable architecture differences across the cases.

The key similarity observed across cases was the need to decentralize certain decisions to capture the full benefits of the inherent flexibility of air power, especially in air-ground situations. Another common theme is that this need to decentralize was (and remains) in constant tension with the desire to employ air power resources efficiently, a goal that drives toward centralization of command and control.[108] Centralization also develops when political risk tolerance is low. This generally happens when politicians want to ensure that chances of negative outcomes are minimized or when they have an expectation of being able to precisely manipulate the outcome of an interaction with an enemy. The doctrinal drive toward centralization is also in tension with a warrior culture that prizes initiative and 'can-do' attributes in pilots.[109] This is no accident—the Air Force (and the other Services) deliberately recruits, trains and promotes people for these attributes.[110] The main challenge in today's highly complex, interconnected and interoperable technical, operational and strategic environment is to channel these traits efficiently and effectively. We will address efficiency and effectiveness in Chapter 6

5.2.2 Summary Assessment of Air Operations Architectures:

5.2.2.1 Desert Storm

Operation Desert Storm (Iraq-I) was the first post-Cold War conflict and the first major military operation in the Goldwater-Nichols era.[111] It marked the first time that a

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[108] For airmen, efficient employment or air power is when resources are applied to achieve maximum impact on the enemy in furtherance of strategic objectives. Employment of air power in support of objectives that are not clearly and directly tied to achieving strategic level impacts are considered sub-optimal (U. S. Air Force 2003).
[109] Kometer highlights this fact and the effects of it in detail in Chapter 9, "System Accidents." He also repeatedly points out that pilots, finding themselves without targets, will "dial around the radio frequencies looking for work"; something that he implies has a strong likelihood of causing inefficiency and loss of strategic coherence of the air campaign (and that is also noted in Mandeles, et al. (Mandeles et al. 1996).
[110] My thanks to Dan Whitney for pointing this out, which prompted the follow-on amplification.
[111] The Goldwater-Nichols Act of 1986 (G-N) aimed to correct long-standing problems of inter-service cooperation and to streamline the military chain of command between the President and the operational military forces (the Combatant Commands). G-N stemmed from a desire to address lessons from the failed

Joint Force Commander exercised command authority over forces of all four military services and the first time all air forces were under the command of a single commander, a Joint Force Air Component Commander (JFACC) (Cohen 1993, Vol. 1, Planning and Command and Control).[112] Because of the relative newness and immaturity of the Joint command structure and poor doctrinal interfaces between services, there was minimal collaboration and coordination across service lines. Desert Storm has been characterized as four individual service campaigns integrated by Gen. Schwarzkopf and his staff at the top of the command structure, Central Command (CENTCOM) headquarters (Atkinson 1993b; Mandeles et al. 1996; Krepinevich 2003).[113] Architecturally, this describes a hierarchical tree structure. Planning and operational interactions between air and ground forces were mainly those necessary to ensure individual service plans did not interfere with each other and for safe execution of *planned* air operations in support of the ground force. In practice, however, significant ad-hoc interactions in both air planning and air-ground operations were necessary to achieve flexibility needed to address mismatches between the formal structure, the planning requirements for the air campaign and operational requirements of the battlefield (Cohen 1993; Mandeles et al. 1996; Kometer 2005). Our detailed analysis of Operation Desert Storm's structure in this chapter should show minimal laterality in the structure and flexibility in only some situations.

5.2.2.2 Operation Allied Force (Kosovo, 1999)

NATO's Kosovo operation was a limited objective, air power-only, campaign heavily constrained by political considerations.[114] At the operational level, political risk aversion removed the option of using ground forces. This decision limited flexibility by removing ground forces as a tool that may have helped achieve political objectives,

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1979 hostage rescue attempt in Iran and inter-service coordination problems during the invasion of Grenada in 1983. A useful short summary can be found at http://en.wikipedia.org/wiki/Goldwater-Nichols_Act, the legislation is reproduced at http://www.au.af.mil/au/awc/awcgate/congress/title_10.htm.

[112] The difficulties of command structure at the theater level were noted in the Strategic Bombing Survey following WW-II. Various solutions to this challenge had been proposed and tried since then, with the latest version the G-N Act.

[113] It is also well documented that Gen. Schwarzkopf's personality and top-down leadership style were significant factors in the ultimate architecture of the Joint Force (Swain 1994)

[114] There was, in fact, very little autonomy in decision making at the level of the air commander, Lt. Gen. Short. See Gen. Wesley Clark's account in *Waging Modern War* as well as press reports, speeches and interviews given by Gen. Short and VAdm. Murphy following the completion of the operation (Murphy 1999; Priest 1999b; Priest 1999a; Tirpak 1999; Clark 2001).

resulting in a less effective campaign and an inability to address unforeseen reactions of the Serbian leadership to the campaign (the ethnic cleansing of Kosovo).[115] Political considerations created a low risk environment with tight controls on action, creating a top-down structure for employment of air power. Politically driven targeting constraints coupled with lack of a ground force combined to create a relatively inflexible vertical structure, with little laterality in terms of overall force application.[116] However, for some types of missions, such as attacks against fixed targets or air defense sites in Serbia, lateral connections enabled flexibility and some notably flexible engagements occurred. But for the major campaign objective, attacking Serbian Army forces in Kosovo, the overall structure was vertical more than lateral, which limited flexibility.[117]

5.2.2.3 Operation Enduring Freedom (Afghanistan, 2001-02)

This operation was the United States' initial response to the Sept. 11, 2001 attacks. The architecture of this campaign is similar to Kosovo: there were relatively tight constraints placed on the use of air power. But unlike Kosovo, political goals were more aggressive and ground force was explicitly recognized as a necessary supplement to air power. However, geography, lack of operational plans, political sensitivities and a desire to act quickly constrained the size of the ground force. At the operational level, ground forces provided an additional option to the commander, complementing air power and increasing flexibility in its use. Tight operational constraints based on risk concerns created a tree-like structure between the strategic and operational headquarters and consequently enabling a lower level of flexibility at the operational level of the campaign than might otherwise have been possible. But looser constraints on some types of operations and lateral connections between air and ground forces at the tactical level

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[115] The effectiveness of the Kosovo air campaign is still the subject of debate, the recent death of Milosevic may forever preclude a precise answer to his decision to give up (Daalder and O'Hanlon 1999; Byman and Waxman 2000; McPeak and Pape 2004; Pape 2004)

[116] Even though air and ground operations were not well integrated in Desert Storm, the lack of a ground force in Kosovo removed even the potential of flexibility via air-ground coordination.

[117] Because of tightened rules of engagement (ROE), following an erroneous attack on a civilian convoy, Lt. Gen. Short held decision authority on engagement of Serbian Army targets for much of the campaign. This necessitated a "talk-on" procedure from the Air Operations Center (AOC) to the tactical aircraft, an interaction that normally occurs between two tactical level operators (a ground controller and pilot).

increased flexibility and effectiveness in air-ground support engagements. Overall, this campaign was tree-like at the top, but lateral at the bottom.

5.2.2.4 Operation Iraqi Freedom (OIF) (March-May 2003: Major Combat Operations (MCO))

OIF was the second major campaign in the global war on terrorism. Lessons learned from Afghanistan, a long planning timeline and different political guidance (tighter resource constraints, but more freedom of action) combined to create an operational and tactical structure different in character than both Enduring Freedom immediately before it and Desert Storm a decade earlier. For the duration of major combat operations, Iraqi Freedom was a more lateral structure that enabled more flexibility than Desert Storm, its closest analog. Other major differences from an architectural perspective were the political objective (regime change) and use of a ground force size one third that of Desert Storm.[118] Lessons learned from Operation Anaconda in Afghanistan the year before and the use of a smaller ground force combined to create closer interactions between the ground and air component.[119] This tighter integration between air and ground forces (more lateral connections at multiple levels of command), enabled increased flexibility in operations, making this campaign's structure the most flexible of the four cases.[120]

5.2.2.5 Summary

Overall, U.S. military operations have been highly successful over the period of these cases, though causal relationships between successful outcomes and mechanisms are the subject of recurring discussion and debate. An understudied aspect of military operations has been enterprise architecture. Based on technical and organizational

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[118] The size of the ground force in Desert Storm was two Army Corps and a Marine Expeditionary Brigade, about 500,000 U.S. troops. In Operation Iraqi Freedom, the ground force size was approximately 175,000 U.S. Troops. I have not included coalition forces or other U.S. service components.

[119] Operation Anaconda began as a relatively small operation at the end of Operation Enduring Freedom to round up remnants of Taliban and al Qaeda forces before they could escape to Pakistan. It became the largest ground operation since Operation Desert Storm. It also exposed significant problems with inter-service planning that were the subject of at least two studies, an Air University thesis by Maj. Mark G. Davis, USA, Operation Anaconda: Command and Confusion in Joint Warfare, and an unclassified U.S. Air Force Lessons Learned document (Davis 2004b; Jumper 2005).

[120] A detailed account of the Air Force-Army integration at multiple levels can be found in a study of Joint Fires during Operation Iraqi Freedom published by the Land Warfare Association (Kirkpatrick 2004).

literature on architecture, we expect to see a variety of *hierarchical structures* based on mission complexity and political and resource constraints (Alexander 1964; Lawrence and Lorsch 1967; Thompson 1967; Simon 1996). This is what we see—in each case, the architecture was different.

We do, however, see a common pattern across the four examples. In each case, where operational flexibility was needed, lateral connections developed in response to those needs. Also, while lack of lateral interactions at high levels of enterprise did not stop development of lateral interactions at lower levels, the asymmetry across the hierarchy had adverse effects. First, some potential lateral interactions at lower levels were inhibited, which limited overall enterprise flexibility. Second, lack of lateral interactions at high levels created tension over priorities and goals. In Desert Storm and Kosovo, this led to an inability to achieve overall alignment of strategic purpose, causing uncertainty in the value and purpose of lower level lateral connections. In Afghanistan, clearer guidance at the upper levels of hierarchy combined with a *relatively* simple operation to lessen the difficulties caused by lack of upper level laterality. In the last case, major combat operations of Operation Iraqi Freedom, there were robust lateral interactions at multiple levels of hierarchy, enabling more flexible and more successful operations under challenging environmental and resource constraints.[121] We will see a recurring pattern of development of lateral interactions (some successful, some not) at multiple levels. This pattern has implications for how we might begin thinking about enterprise design and a more pro-active (and less reactive) approach to management of complex operations.

Table 4 summarizes a qualitative assessment of structure and flexibility:

Campaign	Laterality	Flexibility	Depth	Notes
Desert Storm (1991)	Low	Low	Shallow	Ad hoc attempts to increase flexibility via lateral connections in planning and execution.

[121] The notable contrast is between Desert Storm, where the air campaign preceded the ground campaign, and Operation Iraqi Freedom, where the air and ground campaigns were simultaneous.

Kosovo (1999)	Low	Low	Shallow	Some narrow examples of flexibility and laterality, but mostly against targets in Serbia, not the Serbian army in Kosovo.
Afghanistan (2001-2002)	Mixed	Mixed	Medium; inverted	Lateral interactions at the tactical level enabled flexible air-ground operations; headquarters level laterality was low, inhibiting flexibility at the operational level.
Iraqi Freedom (2003)	High	Highest	Deep	Tight resource constraints and the lessons of Operation Anaconda generated increased lateral interactions at all levels.

Table 4: Trade-off analysis summary

5.3 Architecture Analysis of the Campaigns

A more detailed analysis of the four conflicts follows. Each campaign will be reviewed using the following framework:

1. Operational context and characterization of the conflict
2. U.S. approach to the conflict and structural features of our forces
3. Operational level discussion
4. Tactical level discussion
5. Summary

A summary analysis of all four cases will follow the last case.

5.3.1 Operation Desert Storm (1991)

5.3.1.1 Operational context and characterization of the conflict

The August 1990 invasion of Kuwait by Iraq created concern over stability of the Middle East, the sovereignty of a key U.S. ally and potential for a follow-on invasion of Saudi Arabia. U.S. political leaders built a broad coalition of states to eject Iraq from Kuwait and restore its government. The military was given clear goals and the Services threw enormous resources at the problem. Militarily, Desert Storm represented a classic Cold War engagement: two large, armored, mobile ground forces facing off against each other on fairly isolated battlefields, combined with air forces.

From a resource perspective, Desert Storm was not tightly constrained. The United States threw the bulk of its force structure behind the effort to eject Iraqi forces from Kuwait.[122] These excess resources brought a degree of flexibility to the system that reduced pressure to integrate across service component boundaries. But we are interested in flexibility as the ability to have alternative responses to internal or external demand; flexibility requires different arrangements of organizations and systems—the activation of alternative ways (paths) to deliver function (capabilities). In Desert Storm, excess resources allowed Schwarzkopf and his commanders the freedom *not* to force collaborative interactions among the services during planning. This allowed them to use *relatively* simple schemes based on spatial and temporal separation to keep forces from interfering with each other during the operational phases of the campaign (Atkinson 1993a; Gordon and Trainor 1995) .

5.3.1.2 U.S. approach to the conflict and structural features of our forces

Structurally, Desert Storm was a hierarchical tree that developed some *ad hoc* laterality. The Joint Force commander, Gen. Schwarzkopf, was in charge of all service components and responsible for the overall execution of the war. Desert Storm was also the first time a Joint Force Air Component Commander (JFACC) commanded all air assets in the campaign. It became the first real test of the core tenets of air force doctrine: centralized control, decentralized execution. Relationally and functionally, however, each service component operated independently:

> "Schwarzkopf's component commanders communicated with one another and served as effective deputies. But they divided the war into separate pieces and then fought these with little concern for each other's parts." (Mandeles et al. 1996)

Further, a close relationship developed between Horner and Schwarzkopf during the planning phase (Desert Shield). This strong vertical connection enhanced the tree-like structure relative to the other services:

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[122] The lack of resource constraints is widely accepted; evidence is found in statements from senior leadership (Atkinson 1993b; Gordon and Trainor 1995; Mandeles et al. 1996). It is also borne out by simple counts of percentage of aircraft in the U.S. inventory vs. the numbers used in Desert Storm (See Appendix A).

> "The down side of this one-on-one, quietly personal relationship was that Schwarzkopf's ground commanders were left out of it. In effect, there was no joint command at the highest level. Horner and the other deputies…did not work together under Schwarzkopf's guidance…Instead the component commanders planned separate campaigns that overlapped." (Mandeles et al. 1996) (p. 135)

To further describe the structure, relations between commanders of each service have been characterized as cordial but not collaborative (Mandeles et al. 1996). Where inter-service conflicts arose, the approach of the commanders was to avoid dealing with them. There were enough resources (forces and weapons) that, in general, more resources were added to solve problems rather than trying to collaborate and overcome inter-organizational differences to solve problems (Carpenter 1995; Gordon and Trainor 1995; Krepinevich 2003).[123]

This planning structure carried over to execution at the operational level. The ground forces (Army and Marine Corps) were geographically separated, operating independent and deconflicted ground campaigns. The air campaign was similarly separated, both geographically and in time from the ground campaign (Atkinson 1993b; Gordon and Trainor 1995; Mandeles et al. 1996). Both of these situations created an environment where little cross-organizational collaboration was required in order to execute the campaign effectively.[124] These observations paint a structural picture of branches feeding to a root, with the root (Schwarzkopf and his staff) directing each branch as independent parts.

5.3.1.3 Operational level discussion

Flexibility at the *operational level* of military operations comes from (1) combining forces of different services, with each service itself composed of different

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[123] Examples of service independence can be found in Gordon and Trainor's *The General's War* on p. 96-97, 159-162 and 311. Of particular note is the discussion of Schwarzkopf's handling of Marine and Army plans on page 162. Mandeles, Hone and Terry review the relationship of Lt. Gen. Horner, the JFACC, with the other component commanders and with Gen. Schwarzkopf in Chapter 5 of *Managing Command and Control in the Persian Gulf War*.

[124] Note that there were cross-organizational interactions, but that they were pro-forma, aimed at deconfliction and coordination of plans, not at flexibility in the face of changing requirements.

capabilities, and (2) from being able to change the mission and orientation of the overall force in response to external conditions. This allows commanders to exploit strengths and minimize weaknesses of each service, improving total force effectiveness while simultaneously working to maximize efficiency in a dynamic and uncertain environment. Unfortunately, only a minimal amount of this kind of flexibility occurred during Desert Storm. Two examples demonstrate this lack of flexibility.

Lack of a high level connection between Lt. Gen. Horner and the Marine Air Commander, Maj. Gen. Moore reduced flexibility. An early agreement between the two commanders traded Marine attack and electronic warfare aircraft for use in the strategic air campaign in return for allocation of Air Force B-52 and A-10 aircraft against ground targets in the Marine's area of responsibility (Gordon and Trainor 1995; Glosson 2003) (Mandeles et al. 1996). This type of layered flexibility could have enabled a more optimal allocation of air assets, enhancing overall campaign effectiveness. But as the campaign progressed and the date for commencement of ground operations approached, the Marines withdrew their aircraft from support of air campaign missions to focus on missions in support of Marine ground operations.

Carpenter's analysis of Joint decision-making in Desert Storm provides another example (Carpenter 1995).[125] Early in the Desert Storm air campaign, Army Advanced Tactical Missiles (ATACMS) were used in a responsive attack against an Iraqi air defense site.[126] However, attempts by the Air Force planners to schedule more ATACMS strikes were unsuccessful. Army doctrine reserved ATACMS for the Army Corps commander's use in the deep battle.[127] Staff-level attempts by the Air Force to leverage these assets in support of the air campaign were unsuccessful because of the army's adherence to its doctrine and the unwillingness of the air commander (Lt. Gen. Horner) to

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[125] A detailed discussion of this example can be found as a case study analysis of Joint decision-making in the Desert Storm (Carpenter).

[126] The use of an ATACMS missile against an air defense site frees up substantial aircraft for other missions, a potentially useful trade-off that could increase efficiency as well as effectiveness of the overall force, but would, at the same time reduce the number of ATACMS available to the Army commander when the ground campaign began (It is important to note that the ATACMS system was new in 1991 and fielded in limited numbers).

[127] Deep battle is a term used for attacks against targets geographically remote from the current battle, but relevant to near term future operations.

raise the issue with his counterpart (Lt. Gen Yeosock). While the initial use of ATACMS was a good example of how flexibility could be enabled by lateral interactions in the architecture, there was little coordination of this type beyond the single engagement.[128] Carpenter's final assessment is that the overwhelming size of the U.S. forces allowed commanders to side-step difficult collaboration issues, relying only minimally on cooperation and heavily on separation in time and space (i.e., there were essentially no resource constraints).

More important than these examples was that the lack of laterality between the Army and the Air Force limited ability to agree on or to update targeting priorities and to adjust battlefield coordination lines. This lack of flexibility created motivation to skirt normal processes for target approval and allowed operational havens and escape routes for Iraqi Republican Guard troops late in the ground campaign (Carpenter 1995; Gordon and Trainor 1995; Glosson 2003). Many writers have offered reasons for this lack of interaction and integration, but it is more helpful to understand the potential operational benefits that lateral connections might have enabled.[129]

A simplified representation of the enterprise architecture in Desert Storm is shown in Figure 39, showing only Army and Air Force organizations. This diagram shows both hierarchical relationships between different organizations as well as information flows between them (red lines). Inspection of the diagram shows that if both the Army and the Air Force have capability to attack a certain type of target, there are four ways to do it: Central Command (CC) can delegate the task to either the Land Component (usually the Army) or the Air Component (usually the Air Force). Alternatively, CC could develop a solution and direct one of the services to execute it. This alternative places a large burden on the CC node, especially when there are other

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[128] It is important to note, as Carpenter does, that use of ATACMS or Army armed helicopters for some air campaign missions may not have been the best decision at the campaign level. But, as General Horner observed, the fact that the discussion could not be had prevented the option from being explored (Carpenter 1995, p. 58, 65).

[129] Many assessments of these faults in Desert Storm have been attributed to a lack of trust in the Air Force and its command and control process by the ground force. A lot of progress has been made since Desert Storm on inter-service trust, mostly evidenced in air-ground operations of Operation Iraqi Freedom. But there are lingering problems, which have manifested themselves in the control and allocation of unmanned air vehicles in Operation Iraqi Freedom. (Odierno et al. 2008; Osborne and Hoffman 2008).

service components in addition to Army and Air Force that require coordination. The burden on the top node is further increased when we consider that the details of a particular problem and how best to solve it, (a) may not be knowable to the CC node and/or (b) may require a mixing of ground and air resources of which the CC node may not have full understanding. Also, since information and direction must move up and down the structure, time delays can occur that inhibit effective enterprise-level response to changes in the environment. We assess laterality in this diagram as "zero."

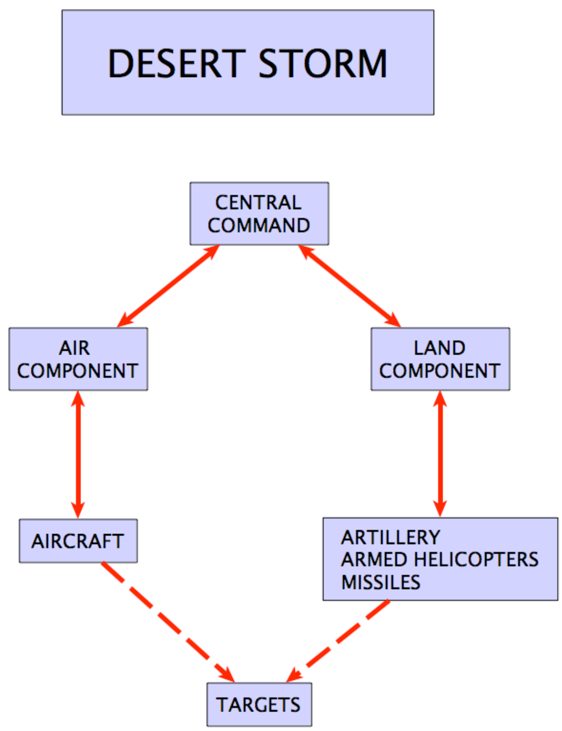

Figure 39: Desert Storm architecture (Army and Air Force)

Kometer's prescription for solving this problem is depth of command—identifying situations where the Air and Land Component Commanders are empowered to make decisions and take action.[130] A diagram showing depth is at Figure 40. In this

[130] Note that this diagram does not show sensor inputs. At the level of the components, we assume that each node has access to the same information: Central Command, Air Component and Land Component all have the same information access, enabling delegation of decision authority to the lower level.

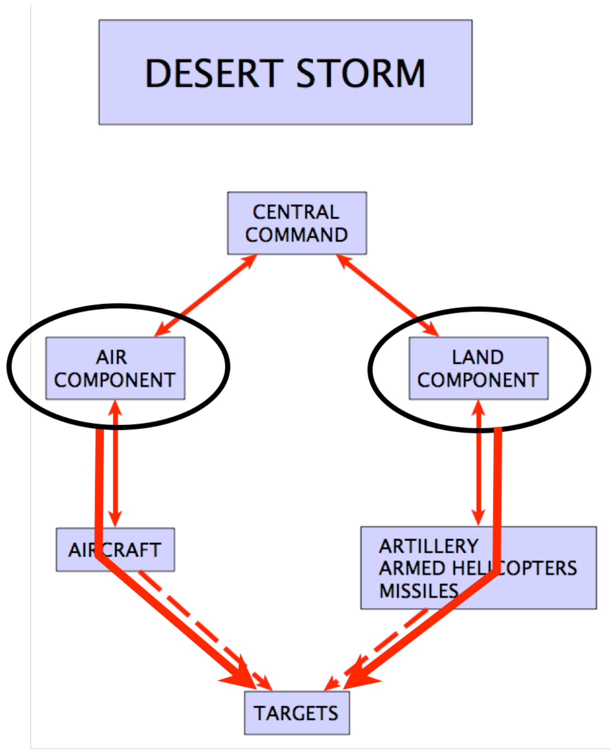

Figure 40: Desert Storm architecture indicating depth of command

diagram, both the air and the ground component can make decisions about attacking the target (we denote this by the circles around those nodes). This unburdens the Central Command node by requiring intervention only when risk or other circumstances warrant. In turn, the Air component and the Land Component can delegate further decision making to lower levels of their respective commands (not shown in Figure 39 or Figure 40). However, without a lateral connection between Air and Land components, coordinated action or collaborative re-allocation of resources becomes difficult, and must be done at the higher level (Central Command). This lowers the number of possible force employment alternatives available to Central Command.

Next, we view this architecture in terms of sensor inputs as well as the decision hierarchy. In Operation Desert Storm the same sensor data were available at multiple levels of hierarchy. Figure 41 shows that moving decisions to the Air and Land Component level shortens the path (time) required from input to output (sensor data

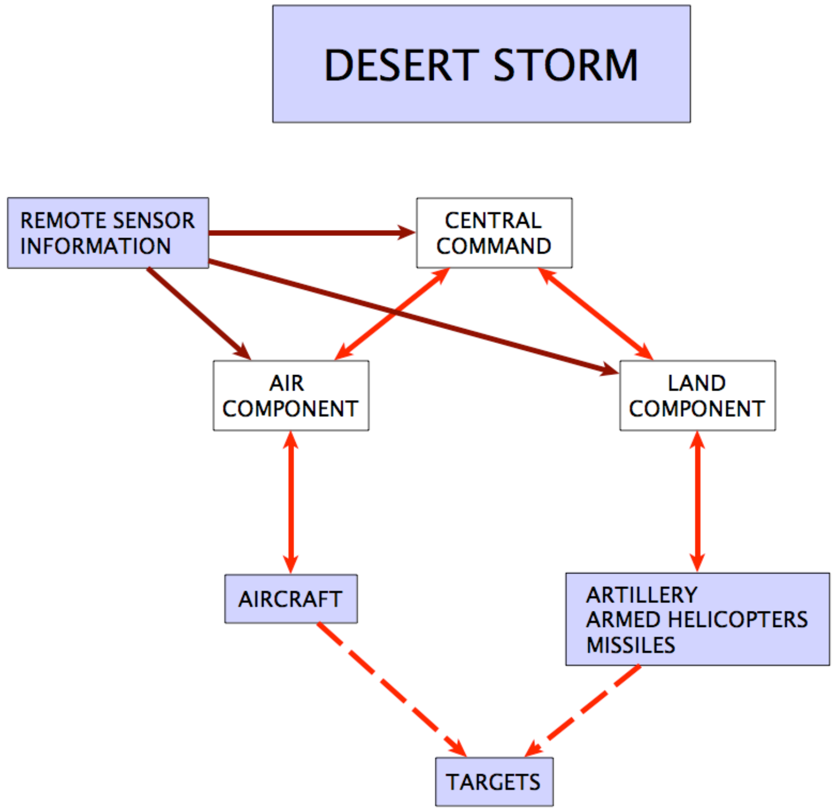

Figure 41: Moving decisions to lower levels of hierarchy

inputs are indicated by the dark red lines. In this figure we have colored decision-making nodes white, to separate them from the sensing and action (aircraft, and ground unit) nodes.

5.3.1.4 Tactical level discussion

At the *tactical level*, flexibility is necessary to adjust to competing demands for air assets as the battle unfolds. Examples of flexibility at the tactical level are the ability to change the mission assignment of an aircraft (the "action" step of the basic model), or to coordinate unplanned operations between air and ground forces. Because of centralized command of air power, arms-length relationships among the service component commanders, and the sheer complexity of allocating and scheduling the thousands of sorties necessary to execute the Desert Storm air campaign, tactical level flexibility was limited (Carpenter 1995) and attempts to achieve it were only marginally successful (Mandeles et al. 1996). It was difficult to modify resource allocations or to adjust target or mission assignments.

Consequently, Operation Desert Storm was a mostly vertical structure at the tactical level. The Tactical Air Control Center (TACC) developed the air campaign strategy, which was then used to build the Air Tasking Order (ATO).[131] Air wings and squadrons conducted detailed mission planning using the ATO. This cycle, from the beginning of ATO planning to execution, was nominally 48 hours, but occasionally was as long as 72 hours. Airborne command and control aircraft (AWACS and ABCCC) used the ATO to execute the plan, directing aircraft and providing flexibility in terms of attacking targets not specified in the ATO. Some of these targets were identified and reported via radio to the airborne command nodes by both aircraft and ground forces. Unfortunately, the ATO planning cycle could not keep pace with changes in the ground situation at the operational level—it was not flexible enough to address changing interdiction requirements as defined by the ground commanders. This fact generated *ad hoc* organizational responses to achieve needed flexibility. We show this general situation in Figure 42 (we have deemphasized the common sensor inputs on the left side

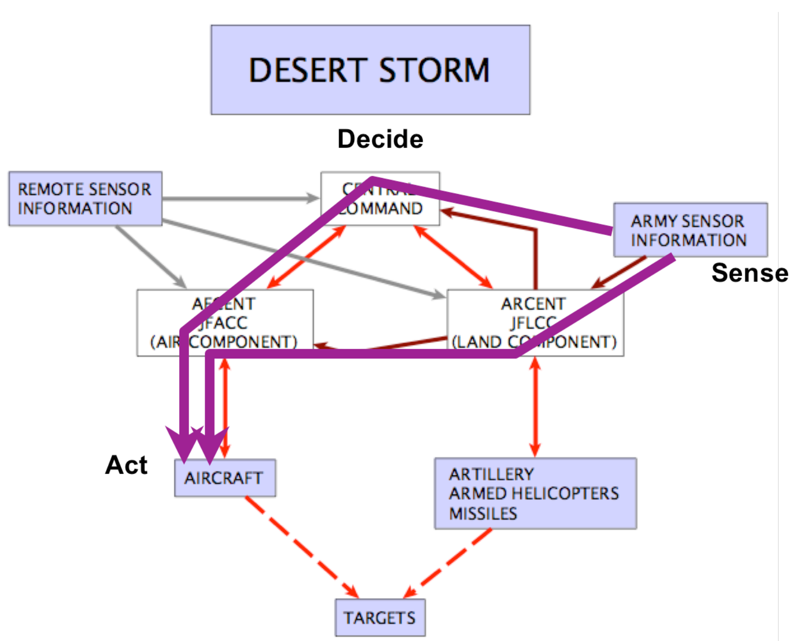

Figure 42: Possible sense-to-act sequences with unique sensor information

[131] The ATO is the commanding document for the air campaign. It specifies missions to aircraft, times, airspace assignments, refueling assignments as well as non-attack assignments such as intelligence, surveillance and reconnaissance missions.

of the diagram). We will discuss this in more detail later, but Figure 42 shows how, when information available to one component must be made available to another, along with the need for an engagement decision, there are multiple ways for it to flow and multiple places where the decision could be made. In Figure 42 the information would go to Central Command for decision and direction of the Air Component. We show an information flow connection (dark red) to the Air Component from the Land Component, but no collaboration mechanism to facilitate a decision at that level of the hierarchy. We could also consider that a connection can be made directly from the Land Component to an aircraft (a cross-layer connection, also not shown). Each of these could enhance flexibility and lower the decision burden on the Central Command node.

Interdiction missions are used by ground commanders to shape the battlefield for upcoming operations, so are geographically at a longer distance from our troops and do not require as much detailed tactical coordination with friendly ground forces.[132] Early Desert Storm interdiction efforts were ineffective because the proposed targets moved between the time Army requested they be attacked and the time that the ATO process addressed them with an interdiction aircraft. In response, the air component created "Killer Scouts."[133] Killer Scouts aimed to improve the results of air interdiction missions by providing local direction of incoming sorties toward valid targets. Structurally, Killer Scouts created lateral connections at the tactical level of operations among aircraft, but maintained vertical connections to the operational level within the air component (Kometer 2005). Killer Scouts are an example of a lateral connection (between the Killer Scout and an interdiction mission), increasing flexibility by creating a new, shorter and better-informed engagement path in the system.[134]

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[132] We address interdiction missions here because close air support (CAS) was conducted via a "push" process. Air sorties were "pushed" through the control points for CAS; if they were not needed, they proceeded on to another mission, which could have been interdiction. Also, it was in the interdiction mission where architectural issues of flexibility and laterality became important.

[133] The Killer Scout concept was derived from similar operations (and a similar need) in Vietnam. Then, as in Desert Storm, there were certain ground support missions that had to be directed locally in order to be effective. The concept involves a dedicated aircraft to conduct scouting of targets in an interdiction area. The Scout conducts its interdiction mission, then remains on station and directs other aircraft to valid targets.

[134] It is also an example of depth of command—moving decision-making to a lower command echelon in order to add flexibility and increase effectiveness and efficiency in the interdiction campaign.

A second organizational response to the dynamic changes on the battlefield was the placement of ground force liaison officers on board airborne command and control

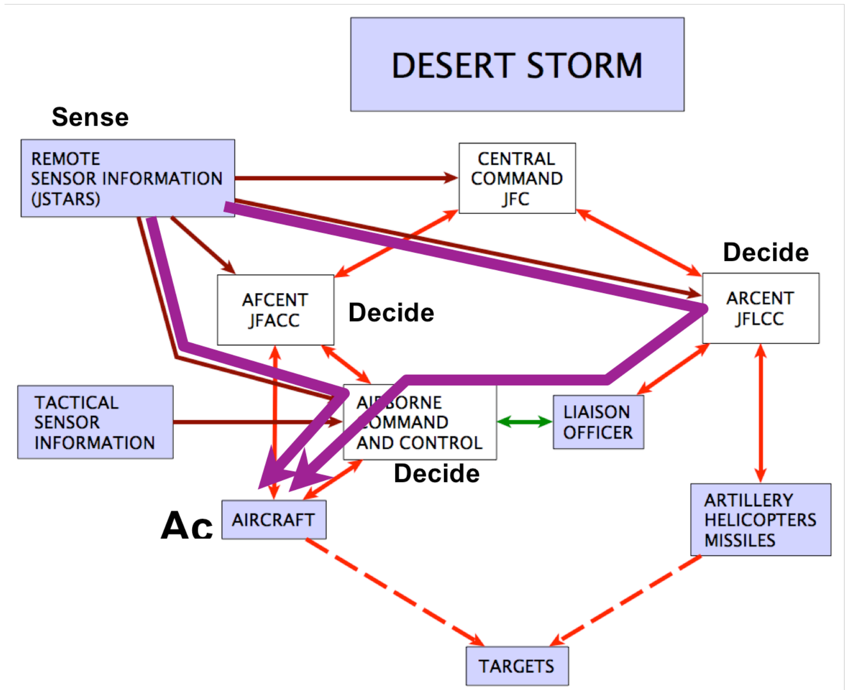

Figure 43: Adding Liaison officers to Airborne Command and Control platforms

aircraft (ABCCC). The role of these officers was to work with the onboard commander to adjust ATO targeting priorities so that they would more closely align with current ground force priorities (Cohen 1993; Kometer 2005). In addition, the Joint Stars aircraft (JSTARS) passed ground targets to the ABCCC, adding another sense-decide-act path to the system (Figure 43).[135] Both of these modifications are shown in Figure 43 (collaborative connection with the liaison officer in green). Two possible paths are shown in Figure 43, one that goes through the JFLCC and one that goes directly form JSTARS to the ABCCC node. We can see how the lateral connection made by the liaison officer provides a path for Army priorities to be transmitted to the Air Force side.

These examples illustrate an increase in laterality at the tactical and operational levels as Desert Storm evolved. Killer Scouts moved decision making lower in the organization by connecting a new sensor and decision maker (the Killer Scout), to action

[135] Joint STARS (JSTARS) was a prototype moving ground target radar used in Desert Storm. It provided near real time ground target information to headquarters organizations. As the campaign developed, operators on JSTARS began to provide ABCCC aircraft with ground targets for engagement.

nodes (interdiction aircraft). But the Killer Scouts were working in areas and with targeting priorities defined by the air component. This is an example of using flexibility to increase efficiency by adding new alternatives—incoming interdiction sorties were not wasted because they lacked available targets: Killer Scouts targeted them. The use of Army and Marine liaison officers on ABCCC aircraft is another example of flexibility. The one-way lateral connection between air and ground forces was created in order to point the air power system toward different targets.[136] A diagram of the structure created by adding JSTARS as a target sensor for the ABCCC aircraft and adding liaison officers is shown in Figure 43. This is an example of laterality at the operational level (L2).[137]

5.3.1.5 Summary

In Desert Storm, every example given by Kometer of the need for timely or more effective response to external demand required decentralization of decision making coupled with connection of timely sensing information to those decision makers. Structurally, these modifications created interactions within the system that were closer to lateral (peer-to-peer, collaborative) than they were vertical (senior-to-subordinate, directive). These connections also increased the number of alternatives (options) by which the enterprise could achieve its goals.[138] However, some of the lateral connections at lower levels of hierarchy (ground liaison officers) were in tension with concerns for accountability and coherence of the overall air campaign strategy. These are central concerns in military operations: the chain of accountability and strategic coherence. Kometer is meticulous in ensuring this issue remains clear in his concepts. From this perspective, there is *never* a lateral structure—somebody or some group is ***always*** 'above' or 'in charge' when decisions are made. There is always a tree hierarchy. This is

[136] Once again, the effectiveness of this connection can be debated. The priorities were an amalgam of existing ATO targets, updated interdiction targets from the ground force and real time requests from ground forces (Cohen 1993; Kometer 2005). The air force argument is that these changes could potentially undermine the Commander's strategic priorities and suboptimize the application of air power, therefore decreasing efficiency and effectiveness.
[137] Though the Killer Scout can be considered a lateral connection, since we are interested in enterprise level laterality—laterality between organizations—and this is a lateral connection inside the Air Force, I have not scored Desert Storm with a lateral connection at the tactical level (L3).
[138] The Gulf War Air Power Survey also addresses this in its findings on Command and Control (Cohen)(p. 334). Though most of these decentralized interactions were one-way (directive instead of collaborative or cooperative), they increased flexibility in the sense that they enabled the air power system to respond better to changing external requirements.

true in virtually every decision-making context, something that Arrow showed us many years ago (Arrow 1950). So, for the purposes of architectural analysis in Desert Storm and all other cases, we define lateral interactions as those interactions (even if they are directive in nature) that occur at similar levels of abstraction (hierarchy).[139]

The main operational issue in Desert Storm was *ad hoc* interactions that developed to make the well-scripted Air Force plan more operationally responsive to the dynamic and changing ground situation.[140] These interactions generally resulted in a change in the flow of aircraft to targets by increasing the number of information paths in the CAOS and increasing the number of command decision locations. These interactions improved efficiency, effectiveness or sometimes both.[141] The difficulty in relying on these types of interactions and information flows is that they are not formally managed and it becomes difficult (potentially impossible) to know what targets are being attacked, whether they are priority targets from the strategic perspective and what the net effect of the attacks are on the enemy. Where these interactions were most effective in terms of responsiveness to uncertainty and change, they were lateral ones that moved decision-making to lower hierarchical levels, effectively increasing the possible engagement alternatives that the system could generate.

A key architectural observation from Desert Storm is that the lateral connection between the air and ground forces (liaison officers on ABCCC) was limited in effectiveness. We have classified this connection as an operational level one (L2). The liaison officers were acting in response to the Army Corps' priorities and mainly addressed their concerns at the operational level of war—interdiction missions that were of longer-term impact than immediate engagement with the enemy. This connection was

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[139] We know from Arrow's General Possibility Theorem that there is always a "dictator" or "decider" upon whom the ultimate decision depends, whether the situation is collaborative or directive (Arrow 1963). The potential consequences of this theorem for autonomous machines (software driven collaboration) has been explored as well (Meyer and Brown 1998). By accepting this phenomenon and viewing the problem from a layered hierarchical perspective, we open the door to another way of understanding the operation of complex systems. We don't consider the micro-scale dynamics of the situation, but only the overall flexibility in the system. Also, see the discussion of lateral connections in Chapter 3.

[140] Similar types of interactions developed in the planning organization, but are not discussed here.

[141] Because of the difficulty in assessing effectiveness of attacks, something Kometer reviews in detail and that is comprehensively covered in the Gulf War Air Power Survey (GWAPS), evaluations of effectiveness in these *ad hoc* interactions is difficult. This challenge still exists, more than a decade following the GWAPS (Krepinevich 2003).

only able to influence the assignment of aircraft to specific targets or target areas, not the allocation of aircraft to missions, something that is generally a strategic level concern. In addition, the liaison officer was not assured of influencing the on-board commander, who was charged with faithful execution of the air campaign plan according to the ATO. With this *ad hoc* change to the architecture, there was always a question of whether the revised targets were in alignment with the overall campaign strategy and whether it was possible to gather accurate damage assessment information. Lack of higher-level collaborative connections between the air and ground force inhibited this kind of alignment (Atkinson 1993a; Carpenter 1995).[142]

As we have previously noted, lateral connections have been identified as a key enabler of flexibility in organizations (Galbraith 1993; Joyce et al. 1997). But the existing research generally ignores the issue of multiple levels of lateral connections, preferring to address lateral interactions in limited contexts. These examples provide an initial indication that, to enable flexibility and increase alignment with an overall strategy, lateral connections must be built from the top of the enterprise and work downward.

5.3.2 Operation Allied Force in Kosovo (1999):

5.3.2.1 Operational context and characterization of the conflict

Operation Allied Force in Kosovo was a conflict with unclear objectives, marked by near continuous disagreements at the strategic and operational levels over both policy goals and an appropriate strategy to achieve them.[143] The campaign was conceived as a limited use of force operation to coerce Serbian leaders from suppressing Albanian separatists in Kosovo. This situation created an operational context where tolerance for risk (collateral damage, loss of aircraft or personnel) was low and where air power was perceived as a low-risk, possibly quick and precise, way to achieve political goals. Based on expectations of a quick capitulation by Serbia, and high estimations for air power

[142] It is also important to note that the ABCCC and the on-board commander were also part of the close-air support process, so the ABCCC *as an organization*, straddled tactical and operational levels of the campaign.
[143] Details of the political and strategic context can be found in numerous places, but a reasonably clear picture can be found in Gen. Wesley Clark's book, *Waging Modern War*. Bacevich, in *Limits to Power* (p. 149-150) provides an interesting assessment of the campaign from a strategic perspective.

effectiveness, an early political decision was made to remove ground forces from operational planning. Unfortunately, shortly after the campaign started, Serbian leadership began a campaign of ethnic cleansing in Kosovo, raising the stakes for NATO.[144] This change confused the operational challenge by moving the focus of attention from coercion of Serbian leadership to prevention of ethnic cleansing in Kosovo.

5.3.2.2 U.S. approach to the conflict and structural features of our forces

The U.S./NATO approach to this conflict was tightly controlled application of precision air power. Risk aversion at the strategic level caused Gen. Clark, the NATO commander, to maintain control over many details of the air campaign, sometimes down to weapon selection (Clark 2001). As a result, of high sensitivity to errors, the AOC retained more decision-making authority on tactical level action than it might have otherwise (Lambeth 2000a; Haave and Haun 2003; Kometer 2005). The political constraint on resources reflected low risk tolerance of senior political and military leaders and impeded development of an architecture that could have enabled flexibility (Kometer 2005). Strategic level risk sensitivity percolated down to the tactical level, reinforcing the top-down decision making structure and limiting lateral interactions (Haave and Haun 2003; Kometer 2005).

5.3.2.3 Operational level discussion

In Allied Force, the initial enterprise architecture was developed to accomplish narrow strategic objectives. Removing NATO ground forces as an option was considered appropriate, given the theory of the campaign: coercion with air power.[145] This architecture may have been effective, had the theory held. Unfortunately, the Serbian leader, Milosevic, was not coerced; he changed his strategy and tactics, stepping up the oppression of Kosovar Albanians with his army. This shifted operational priorities away from strategic targets and coercion of Milosevic and toward the Serbian Army in Kosovo.

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[144] Bacevich, p. 149.
[145] See Bacevich, p. 149 for a succinct discussion of Clark's theory of victory.

Lacking a ground force with which to detect, attack and influence the Serbian army, achieving campaign objectives became difficult. NATO was left without the flexibility provided by an air-ground combination of forces, which would have been more effective (Tirpak 1999). This difference is shown in Figure 44. With a ground force, targets would have been vulnerable to three kinds of force: manned aircraft, cruise missiles and ground forces. Limiting options only to aircraft and cruise missiles may not have been a problem, if the pattern of the conflict had unfolded as expected. As noted earlier, fixed infrastructure or air defense systems are well suited to attack by air power,

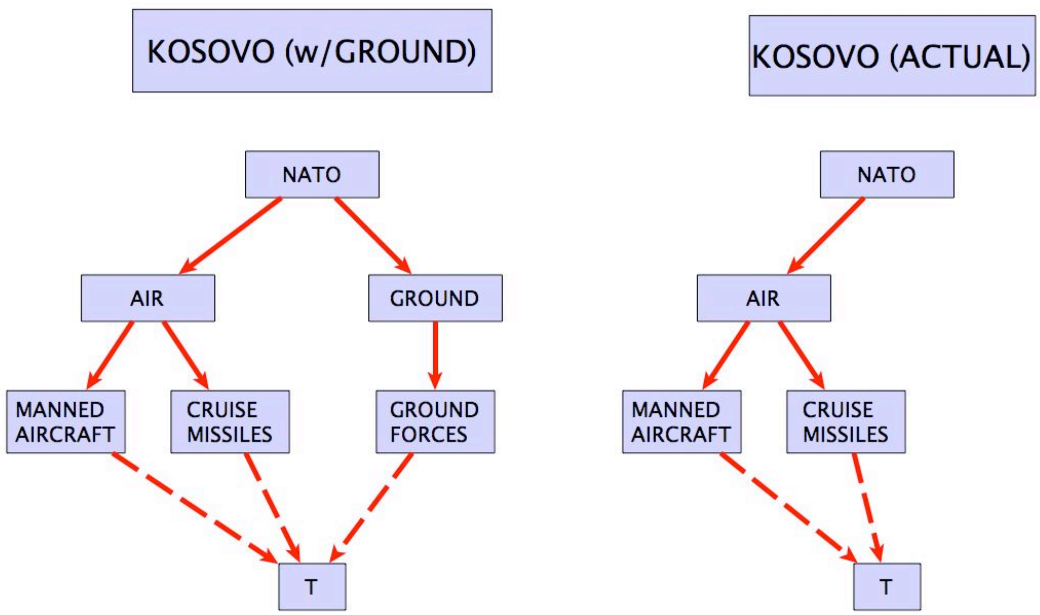

Figure 44: Kosovo architecture representations

but it is difficult to use air power alone against a ground force (Tirpak 1999).

At the next level, inside the air power structure, flexibility is still possible (right side diagram of Figure 44). Two types of air power, manned aircraft and cruise missiles, provided operational level flexibility. For many targets inside Serbia, it was possible to trade-off cruise missile missions for manned aircraft missions, flexibility helped adjust for weather, equipment, target characteristics and other factors. But once the focus of the campaign shifted to Kosovo, lack of a ground force both to enable flexible air operations as well as to hold territory (maintain direct control of or influence on Serbian Army actions) proved problematic.

Architecturally, the command structure for manned aircraft and cruise missiles was split.[146] The air commander, Lt. Gen. Short, was in command of both Navy and Air Force manned aircraft. The naval commander, VAdm. Murphy was in command of both Navy and Air Force cruise missiles. Both commanders had established a good working relationship and lateral interactions between their two command centers, which enabled flexibility. Flexibility at this level consisted of shifting missions between cruise missiles

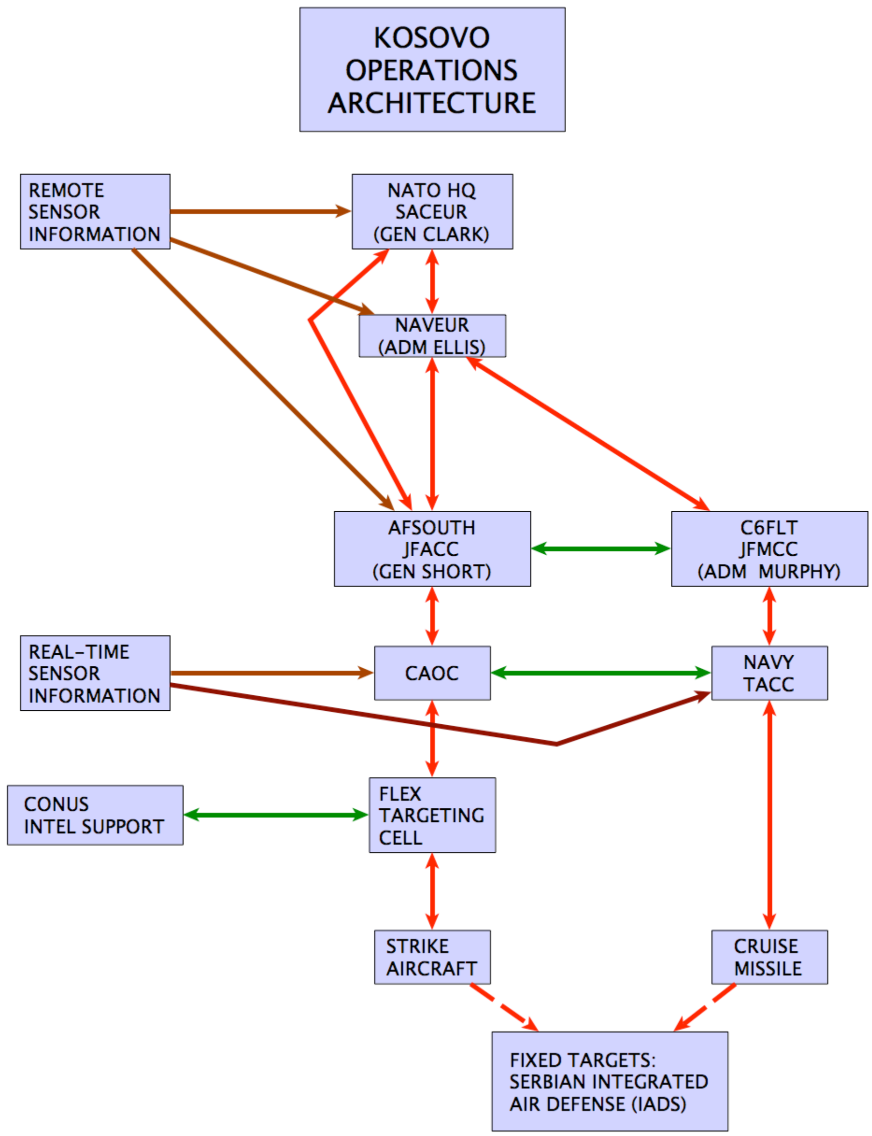

Figure 45: Kosovo fixed target architecutre

[146] This command structure is discussed in the DoD After Action Report on Kosovo to Congress (31 Jan 2000).

and manned aircraft as well as between Navy and Air Force squadrons.[147] Flexibility here comes from having multiple systems with redundant and complementary capabilities and from organizational interactions at multiple levels that enable shifting assignments among these systems, providing operational responsiveness to unforeseen demands.[148] A diagram of this structure is shown in Figure 45.

Analysis of the Kosovo conflict remains contentious regarding the appropriate strategic approach to the campaign and the employment of air power as a coercive tool. For example: "What caused Milosevic to give up?" Was it the effectiveness of strategic targeting or was it the combined threat of a ground invasion and loss of Russian political support? (Byman and Waxman 2000; Stigler 2003). A frequently cited reason for any ineffectiveness of air power in the Kosovo campaign is a general claim that air power was not employed properly (Priest 1999b). When analysts of the Kosovo conflict deviate from this pattern of arguing over strategic approaches to the conflict, the effectiveness or ineffectiveness of air power and the reasons for it, they mainly focus on the technical and procedural aspects of engaging time-sensitive targets.[149] Little attention is paid to the architecture of the organization and technical systems (the enterprise) and even less to its flexibility, particularly at the tactical execution level. The next section addresses architectural aspects of tactical operations.

5.3.2.4 Tactical level discussion

For the Air Operations Center, the main problem became an exercise in rapid, or time-critical, targeting. The Serbians had learned the lesson of Desert Storm: if you are exposed and stationary, the U.S. Air Force can hit you. They were effective in hiding and

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[147] VAdm. Murphy provided an example of this type of lateral connection during October 1999 Congressional testimony.

[148] There were both exploited and unexploited flexibilities in the form of capabilities of the Navy's Carrier Air Wing. Some aircraft carried reconnaissance systems that could have been used for real time battle engagements. But because of organizational preferences or poor communications between operational staffs, these capabilities were only used for battle damage assessment. Also, the Navy's Air Wing was used for a time sensitive strike against the Podgorica airfield when the CAOC could not alter the ATO quickly enough (Lambeth 2000a).

[149] Though searching for moving (time-sensitive) targets was a problem in Desert Storm, the Kosovo campaign was the first campaign where new technical systems existed that could support efforts to attack these types of targets with some expectation of success. Most of these early attempts (and many of the current ones) focus on streamlining procedures to reduce the time from sensor detection to engagement with a weapon.

moving their air defense systems. Once Milosevic began operations in Kosovo, engaging the Serbian Army added to the challenge. To hit these moving targets, Lt. Gen. Short created a Flex Targeting Cell. The Flex Targeting Cell was composed of two parts. The Fielded Forces Attack Cell was aimed at the Serbian Army and the Integrated Air Defense Systems Cell was aimed at Serbian air defense systems (Kometer 2005). In essence, these cells represented a new organization in the AOC, specially designed to process information and make decisions faster than the formal structure. To achieve needed flexibility, new technology was applied (new types of targeting workstations and processing software applications) and lateral connections between dispersed organizations were created. The architecture was still vertically oriented overall: the Flex Targeting Cell was located in the AOC and passed its targeting information vertically to tactical level aircraft. But at the level of the Air Operations Center, there was an increase in laterality as formal information channels (mostly military intelligence channels) were bypassed and information passed peer-to-peer. The net effect of these cells was to increase lateral information processing connections and to move decision-making lower in the AOC command hierarchy (Kometer 2005).

The Fielded Forces Attack Cell (FFAC) targets were the more challenging of the two types of target. While air defense systems are vulnerable to electronic and signals detections, which makes finding them and generating targeting data largely an exercise in automated information processing, the Serbian army in Kosovo was a more difficult target. They controlled their radio emissions, hid under forests and in buildings and used proximity to civilians as a shield. The FFAC had access to Predator UAV video, sometimes JSTARS sensors and, toward the end of the campaign, ground-based radars from U.S. Army units in Albania. These types of sensors required more interaction with tactical level aircraft than the automated information generated by the IADS cell. Without a tactical ground force to coordinate with tactical aircraft, it was challenging to deliver appropriate sensor information from decision-makers to an attack aircraft on timelines that could engage the Serbian Army before it moved.

The challenges of passing information from the AOC to aircraft inhibited the responsiveness of the FFAC. The flexibility of the fielded forces cell also varied with risk sensitivity. Early on, rules of engagement allowed Airborne Forward Air Controllers

(FAC-As) to detect targets and either take or direct action, an example of flexibility and laterality at the tactical level. FAC-As, when directing other aircraft, created lateral connections to strike aircraft. But when errors were made, risk tolerance decreased. Specifically, rules of engagement were tightened and Lt. Gen. Short withdrew decision authority from the FAC-As, moving decisions to the FFAC (sometimes to Lt. Gen. Short), creating a vertical structure. Kometer defines this variation as depth of command, the ability to move decision authority up and down command levels as the situation changes.

As the risk tolerance of strategic level decision-makers dropped, lower level decisions were not allowed, decreasing flexibility—there were fewer alternatives (paths) for engaging targets. Architecturally, when the CAOC became the decision maker in

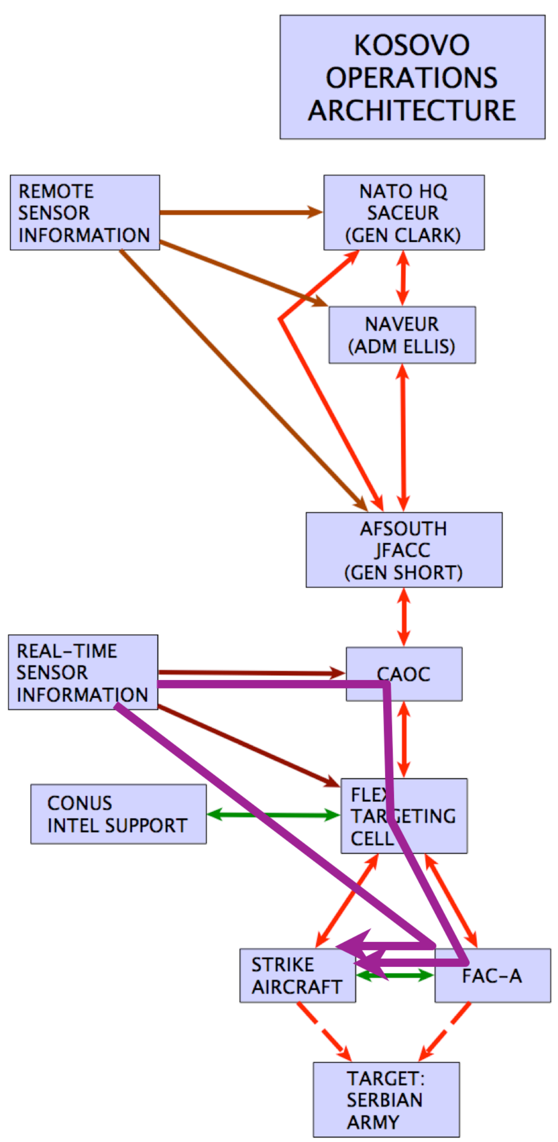

Figure 46: Kosovo architecture showing vertical interactions and two engagement paths

engagements against fielded Serbian army forces, there was only one path, from the Predator or JSTARS sensors (Remote sensor in Figure 46) to the CAOC, then down to either the FAC-A or a strike aircraft. That is, there was only one 'legal' decision node in the system, limiting the number of paths. In some cases, this limitation (lack of flexibility) kept the system from reacting to emerging targets in time. When risk tolerance increased, and decision authority was allowed to move down the hierarchy, JSTARS was sometimes able to detect targets and pass information to the FAC-As or to other strike aircraft, another lateral interaction (Cohen 2000). A simplified architectural diagram of these missions is shown in Figure 46.

At the *tactical* level, the architecture in Kosovo showed both vertical and lateral structures as commanders tried to balance risk management with the need to adjust information and decision paths to meet the operational demands of hitting moving targets. When constraints eased, lateral connections at the tactical level enabled flexibility to adjust to moving targets (Serbian Army units). When constraints increased, decisions were passed vertically through the architecture from operational headquarters (CAOC) to the tactical units (aircraft). This lowered flexibility, by removing engagement paths and by increasing response time, allowing Serbian Army units to escape attack (Lambeth 2000a; Kometer 2005).

5.3.2.5 Summary

In Allied Force, the main architectural issues concern attempts to achieve flexibility inside a tightly controlled hierarchical command structure.[150] There are two core observations from our architectural analysis of this case. First, lack of ground forces removed potential lateral interactions and alternative information flow and action paths (Daalder and O'Hanlon ; Byman and Waxman ; Cordesman).[151] Without ground forces operational level campaign options were limited. Second, without ground forces the sense-decide-act architecture inside the air power command structure became critically important. Though there were notable successes, the vertically oriented sense-decide-act structure attempted to limit operational risk but at the same time limited tactical flexibility, especially against mobile Serbian Army targets.[152,153]

Our overall assessment of the Kosovo campaign is that it exhibited low flexibility and low laterality at the operational and tactical levels. Though there were strong lateral connections among the Navy and Air Force component commanders and their staffs, because of the top-down style of command these were not leveraged well, and were possibly inhibited. The use of information exchange capabilities enabled flexibility in gathering and processing information, but this flexibility mainly existed at the headquarters level. It was effective against targets vulnerable to electronic intelligence and targeting, but less effective against the more mobile and harder to detect Serbian Army.[154] It is important to note that the addition of more lateral connections through the availability of a ground force, or of more lateral interactions at the tactical level may not have solved the lack of flexibility in the Kosovo campaign, nor would it have positively prevented certain problems in the campaign (targeting errors, mainly). Choosing how and when to leverage flexibility in an operational situation is difficult, and will likely remain so. Our point is that without attention to lateral interactions and the effects of layers of hierarchy, flexibility will be a difficult property to achieve when it is needed. Attention to laterality and the effects of hierarchy beforehand can reduce confusion (friction) in operation—can enable flexibility.

Overall, flexibility was low due both to technical architecture limitations as well as enterprise architecture constraints.[155] In general, actions taken in the Kosovo

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[150] Kosovo remains a contentious conflict in terms of air power. When analyzing aspects of this campaign, there is a temptation to migrate into a discussion of the merits and demerits of the method of command and operational employment of air power chosen by Gen. Clark. These are interesting and useful issues, but not our focus, just as they were not the focus of Kometer's work.

[151] 21 days into the campaign, Clark ordered Army Apache helicopters deployed to the theater in an attempt to provide a capability to attack the Serbian army more effectively—to increase effectiveness of air power by adding a lateral connection between sensors (Apaches) and act nodes (strike aircraft). Some credit this move as a factor for the eventual capitulation by Milosevic, though there is debate on this point (Stigler 2003). Again, detailed discussion of causality in this context is beyond the scope of this analysis.

[152] Toward the end of the campaign, the ability to connect more sensors to tactical level units showed the promise of increase flexibility through added execution paths (Lambeth 2000a; Haave and Haun 2003; Kometer 2005).

[153] It is important to note that vertical hierarchies do not eliminate risk or error. The bombing of the Chinese Embassy is an example of tight controls and a non-moving target where we still made a mistake.

[154] Haave and Haun describe lateral connections at the squadron level, where the details of missions were planned. While this is important for efficiency and effectiveness at the tactical level, it does not significantly impact the flexibility of the enterprise in operation for the purposes of our analysis.

[155] Extensive discussion of these limitations, as well as others can be found in the DoD's After Action Report to Congress on Kosovo (Cohen 2000).

campaign to increase flexibility created lateral connections that improved efficiency and effectiveness of operational level activities, but did not significantly improve flexibility in tactical execution of missions.

5.3.3 Operation Enduring Freedom (Afghanistan, 2001-2002)

5.3.3.1 Operational context and characterization of the conflict

Operation Enduring Freedom in Afghanistan provides both contrast and similarity to the Kosovo campaign. The post 9-11 world is obviously different from that of the Kosovo conflict. In Afghanistan, the U. S. goal was to remove the Taliban regime, eliminate a safe haven for terrorists, hit al Qaeda and demonstrate U.S. resolve to engage and remove the worldwide threat of terrorism.[156] Unlike Kosovo, Afghanistan was geographically and operationally remote. The U.S. had no prepared operational contingency plan for fighting in Afghanistan and no access to nearby foreign bases from which to stage military operations.[157] In contrast to Serbia and the Serbian army, the Taliban military was poorly trained and equipped and Afghanistan had little valuable infrastructure to hold at risk with air power.

At the time of the 9-11 attacks, Afghanistan's rebel militias had essentially fought the Taliban military to stalemate in an internal civil war. For the United States, strong political resolve following 9-11 combined with a challenging operational context to create a need to think innovatively about military force employment. These two factors combined with the lessons of Kosovo to drive the creation of what became a standard, though innovatively implemented, air-ground campaign (Biddle 2003).

5.3.3.2 U.S. approach to the conflict and structural features of our forces

In Kosovo strategic guidance was unclear and risk tolerance low, leading to an air power-only campaign with limited flexibility. In Afghanistan, strategic guidance was clear and, in general, tolerance of risk higher. However, despite the strong resolve,

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[156] Feith, p. 88-89.
[157] Though the CIA had intelligence operators in Afghanistan before 9-11, there were no plans for combat operations "on the shelf". The CIA eventually developed the plan that evolved into the campaign run by Gen. Franks.

political concerns over being viewed as an invading force and an acute consciousness of the 1980s Soviet invasion and its outcome combined to place tight constraints on the operation. These conditions generated a tree-like campaign architecture at the operational level.[158]

Among the senior leadership, there was a perception that air power alone was a blunt instrument (at best) or ineffective (at worst), given the unsophisticated Taliban military and economic infrastructure.[159] This perception drove the Secretary of Defense to push hard for early use of ground force in the campaign. On the other hand, he was sensitive to the U. S. becoming perceived as an occupying force. This drove his desire to limit the footprint of U.S. ground forces.[160] There were also political concerns about minimizing collateral damage from air strikes (especially to structures such as mosques) as well as concern over targeting errors.[161] The result was that the top level of command, Central Command (CENTCOM) performed most targeting and operational level coordination among the component forces. Many key engagement decisions were made by Gen. Franks, in some cases higher, creating a top-down (vertical) structure with regard to air power.[162] To address these constraints, but still enable needed flexibility, the operational approach was to conduct an air-ground campaign using Special Operations Forces (SOF) and CIA paramilitary personnel as the interface between Afghan resistance forces and U.S. air power. The idea was to capitalize on precision air power to increase the effectiveness of the Afghan resistance against the Taliban.[163]

As we will see, the overall architecture of Operation Enduring Freedom was a tree hierarchy at the operational level, with CENTCOM at the root and a single layer of

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[158] There were also sensitivities about perceptions of the U.S. retaliating against the general population of Afghanistan as well as the wider Muslim or Islamic culture and not simply al Qaeda and their Taliban sponsors (Biddle 2003; Franks 2004; Woodward 2004; Rumsfeld 2006; Feith 2008).
[159] Biddle, p. 1.
[160] Feith, p. 76. Other discussions of the limitations on ground force size in Afghanistan can be found in (Davis 2004b) and Sean Naylor, <u>Not a Good Day to Die</u>, a journalistic account of Operation Anaconda and in Franks, p. 324.
[161] In testimony to Congress in July 2003, Gen. Franks testified to the value of limiting collateral damage in contributing the overall success of the campaign (HASC Testimony, JULY 10, 2003). Franks describes his concerns about targeting errors in *American Soldier*, p. 289-95.
[162] Kometer describes the operational impact of this constraint in detail. Also, see Franks, p. 289-95.
[163] Initial support was to the Northern Alliance. Later, support was provided to forces led by Pashtun warlords in southern Afghanistan.

operational level command organizations below that did not interact very much.[164] At the tactical level however, SOF and air forces were laterally connected, providing flexibility and responsiveness to the ground situation.

5.3.3.3 Operational level discussion

At the operational level, there were restrictions placed on the size of ground forces and restrictions on the use of force against certain targets.[165] Tight political constraints required Gen. Franks to hold key decisions at his level (or only delegate them to his immediate staff). This created an environment that limited operational level coordination among his service components. As described by Kometer, there was little interaction between the service component organizations and decision authority was "consolidated at CENTCOM."[166] The CIA (a non-DoD government agency) worked only for Franks, the Special Operations Force (SOF) ground detachments operated independently, coordinated by individual Northern and Southern Task Forces (SOTF) under Gen. Franks.[167] The Air Component Commander (JFACC/CAOC) operated based on targeting guidance, target selections and solutions determined by the CENTCOM staff.[168] As noted earlier, SOF and CIA forces connected Afghan resistance forces with precision air power.[169]

For operations with air and ground forces, this paints a picture of a tree-like

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[164] Davis, p.
[165] These were separate from fundamental physical constraints on moving a large number of heavy (or light) forces into Afghanistan simply because of the shear distances and geography involved.
[166] Kometer, p. 126.
[167] Early in the campaign there was no established Special Operations Component Commander (SOCC) (Davis, p. 18-19 and 128.)
[168] LaVella, p. 12-14; Fyfe, p. 10-12; Kometer, p. 126-128.
[169] Biddle's entire thesis is that the success in Afghanistan was unique and does not signal a transformational shift in the conduct of warfare. Biddle's argument is an example of the need to focus on flexibility in overall force structure design (the ability to use SOF to direct air power in a ground campaign) as well as to focus on flexibility when designing operational architectures (actually choosing to use SOF to direct air power).

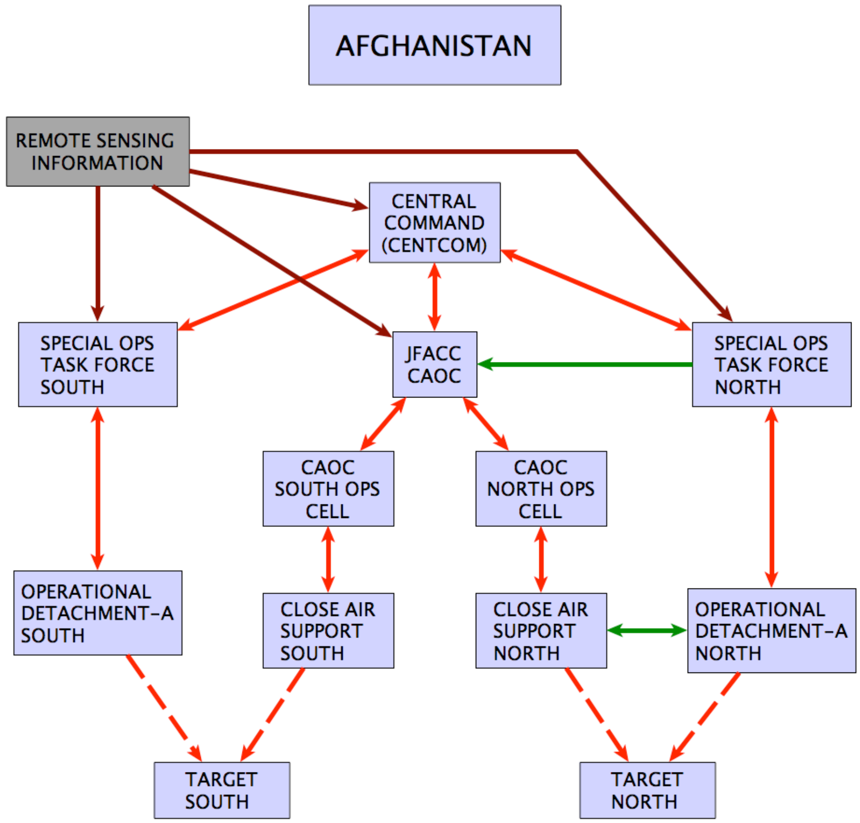

Figure 47: Afghanistan architecture for Special Operations Force ground operations

structure shown in Figure 47. The lateral connections between SOF-N and the air component are indicative of the interface between those two components, beginning about Nov 7, 2001, a month into the campaign. Also, note that this connection is unidirectional. The SOF forces were placing requests for air support to the air component; there was little two-way interaction, at least at the headquarters level, due to the nature of the operations.[170] The SOF-S component was initially not equipped to interface with air power at either the tactical or operational levels.[171]

In addition to the unique SOF-air interactions, there were other SOF operations underway—against al Qaeda leadership targets. Because of the nature and operating location of these targets, they were handled differently. There were wider considerations

[170] Davis, p. 39-59.
[171] This situation created problems as noted in (Davis 2004a) and (Kometer 2005).

than the ability to leverage flexibility to strike these targets immediately despite any real or perceived importance. For these targets, the National Security Council (NSC) set

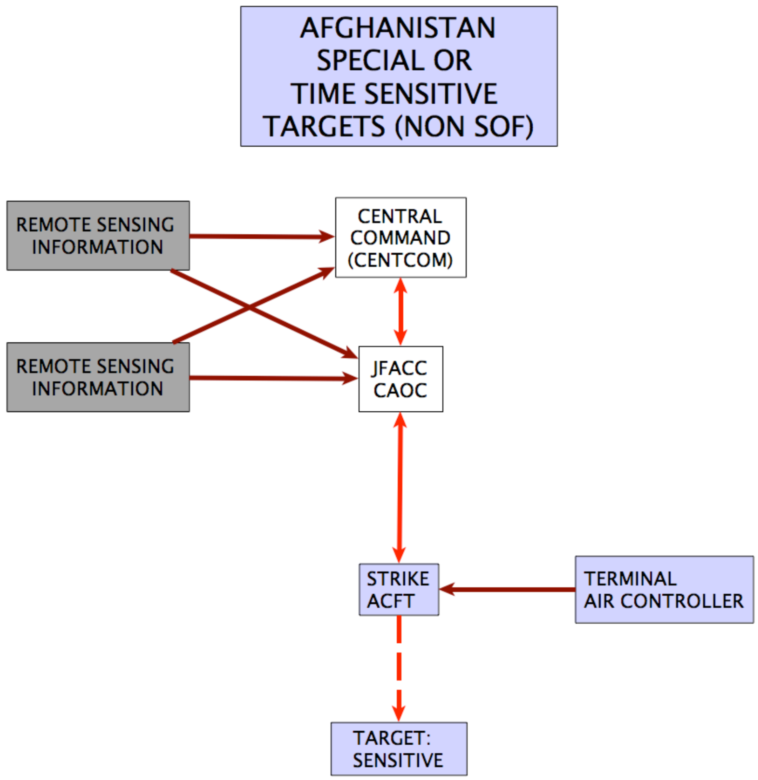

Figure 48: Afghanistan Time-Sensitive Targeting architecture

priorities and rules of engagement. These rules limited Gen. Franks' ability to delegate authority and limited his flexibility against these targets early in the campaign.[172] As was the case with SOF-directed air-ground engagements, the AOC was limited in its ability to engage targets—targets were selected and engagements directed from CENTCOM. Decisions flowed from the top level, limiting depth and flexibility.[173] The key architectural observation is that the overarching rules established in the White House and

[172] Kometer, p. 126.

[173] This observation mostly concerns time-sensitive targets, those of interest to Gen. Franks and higher levels of command. Even though the targeting process and decisions were conducted and made at CENTCOM, the CAOC performed its own independent targeting process. These parallel targeting processes increased friction when differences between targeting models and judgments arose between the CAOC and CENTCOM (LaVella, p. 19-20).

Pentagon drove the structure and delegation of decision-making authority, which limited enterprise flexibility. The structure for sensitive targets is shown in Figure 48.[174]

At the operational level, Afghanistan, like Kosovo, was a tree-like architecture with ground forces added, but this overall vertical structure and the consequent lack of flexibility were not overly harmful in Afghanistan. After an initial 11 days of strategic bombing, the air component's sortie load in support of ground operations was limited and manageable. The ground force was dispersed and relatively small, lowering the deconfliction/coordination load and there were plenty of aircraft overhead; the ground force was rarely lacking air support. Tactical level activities could be coordinated at the operational level headquarters without the need to have intervening layers of organization to handle large workloads or more complex coordination and collaboration.[175,176] However, unlike Kosovo, in Afghanistan there were lateral connections at the tactical air-ground interface, which increased tactical level effectiveness and enhanced operational level performance.[177]

5.3.3.4 Tactical level discussion

There were three basic classes of tactical operations in Afghanistan, there were targets identified by SOF forces supporting Afghan rebels, those identified by special SOF teams operating independently and those identified by CENTCOM or the CAOC using unmanned air vehicles (UAVs) or space-based sensors. The architectures for these targets were different in each case. We will deal with the first and the last cases, since the middle case involves highly classified operations where little open-source information is available.[178]

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[174] It is worth noting that both CENTCOM and the CAOC had access to the same sensor data. The different perspectives on targeting leadership targets generated friction between the air component and CENTCOM (LaVella 2003; Kometer 2005).

[175] Jumper (USAF Operation Anaconda Lessons learned), p. 42 discusses the CAOC Operations director's discussion of the workload issues in conducting tactical level functions in the CAOC.

[176] The large exception to this is Operation Anaconda, a complex ground operation that revealed weaknesses in the Operation Enduring Freedom command architecture. Davis and Kometer analyze this operation in detail.

[177] These connections were established after about a month of independent, uncoordinated SOF operations (Davis, p. 41-42).

[178] These operations were titled "sensitive site exploitation" operations

At the tactical level, the Afghanistan operation was a mixture of vertical and lateral structures. Special Operations teams provided lateral connections between U.S. aircraft and Afghan rebel forces. In situations where there were direct engagements with Taliban or al Qaeda, the air and ground forces were able to adjust as necessary to achieve objectives. It is also clear from the previous discussion that the structure of the enterprise was vertical when it came to operations against politically sensitive targets and in areas where collateral damage was possible.[179]

Kometer outlines the fundamental tactical level architecture in Afghanistan, which had to address these two major target classes. The first class of targets was handled by either the CAOC or a terminal air controller (TAC) who provided targeting information to the aircraft, with permission to attack granted by either CENTCOM or the CAOC, depending on the location and classification of the target (see Figure 48). The second type of target was handled more like traditional close air support: "[aircraft] followed direction from the CAOC for almost all mission details until they were directed to contact a ground team. After that, they were under the team's control."[180] Normal doctrinal connections between the ground force and the air force were not in place due to the non-traditional ground force used in Afghanistan and the lack of an advanced operational plan.[181]

Architecturally, a lateral connection between TACs and aircraft existed: "…several of the controllers related they had broad permission from the CAOC to work directly with the aircraft. They also had clear guidance on what types of targets they could have the aircraft attack without coordination, and what types required higher-level coordination."[182] This example demonstrates flexibility through lateral connections at the lowest level. For non-SOF designated targets, the CAOC or CENTCOM used UAVs and space-based sensors to develop targeting information, then passed it directly

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[179] Kometer, 126-127, Davis, p. 39
[180] Kometer, p. 181.
[181] Davis, p. 56 and 58. In many areas where the U.S. has long-term concerns, operational plans are developed and used in exercises, wargames and other venues to craft effective responses to contingencies. There were no such plans for Afghanistan in 2001.
[182] Kometer, (p. 202).

to the aircraft. Diagrams of the two examples of Afghanistan tactical operations are in Figure 47 and Figure 48. It is clear from the diagrams that flexibility (as well as

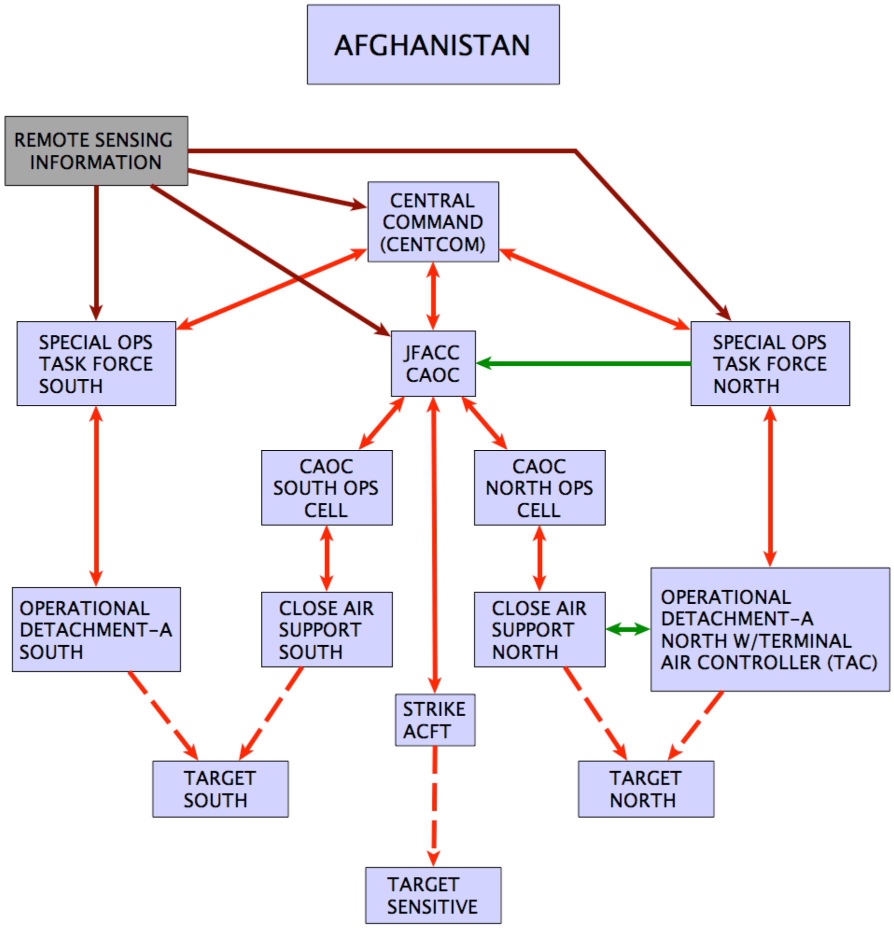

Figure 49: Overall Afghanistan architecture

responsiveness) can be enhanced by the use of lateral connections. A diagram combining the Time Sensitive Targeting and the SOF ground structures is in Figure 49.

5.3.3.5 Summary

The enterprise architecture in Afghanistan was similar to Kosovo, but with the addition of ground forces and a higher tolerance for risk at the strategic level. There were two major classes of targets: sensitive targets, controlled from top levels of command, and those similar to close air support (CAS) targets but that required a higher degree of lateral coordination and collaboration between ground forces to be effective.[183] This dual control scheme led to a mixed level of tactical flexibility in Afghanistan operations.

The mixed architecture generated both flexible-lateral and inflexible-vertical structures, corresponding to the conflicting needs of the overall strategic approach to the operation. For ground force operations against the Taliban army, the architecture was decentralized—lateral interactions at the tactical level enabled tactical level flexibility. There were also situations where pre-established engagement zones were in effect. In these cases, the CAOC and SOF ground forces had wide latitude to make decisions to achieve an objective. In these *special cases*, flexibility was high; lateral connections between air and ground forces increased efficiency and effectiveness of both air power and ground forces.[184]

High value targets, usually those with special political sensitivity, were handled with a vertical structure. For cases where the vertical structure dominated, flexibility, efficiency and effectiveness evaluations are problematic and highly dependent on hierarchical level: the context and priorities of the senior level decision maker, usually Gen. Franks.[185] From an air power control perspective, where direct support of SOF forces was necessary, decisions were delegated to low levels, but with the CAOC always providing detailed direction and coordination of the aircraft up to the point of hand-off to a terminal ground controller.

At the operational level, air and ground power combined to provide flexibility and effectiveness not achieved in Kosovo. Though the structure at the operational level was a tree, when combined with tactical laterality it proved highly effective: the Taliban

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[183] Kometer, p. 139 notes the gradual shift in character of air-ground missions from classic close air support and interdiction to a new type of mission based on time and target importance or sensitivity. He highlights the procedural and process changes that have occurred and that continue, emphasizing a trend toward decentralization (depth of command) necessary to achieve success. In *Air Power Against Terror: America's Conduct of Operation Enduring Freedom*, Lambeth also notes the qualitatively different nature of air support provided in Afghanistan compared with traditional close air support operations (p. 341).
[184] It is important to note that the ground force had very limited offensive capability, which made air power the dominant physical force. It is equally important to note that, until the SOF forces were able to direct the air power, it was of limited combat value. (Biddle 2003, p. 1, 7, 42).
[185] LaVella discusses the differences of opinion between CENTCOM and the CAOC in these situations. Franks, in *American Soldier*, provides his version of events for one particularly significant engagement (LaVella 2003)(p. 290-295)

government fell in 72 days, a stark contrast to the Kosovo operation and to the Russian occupation of Afghanistan in the late 1980s.[186] Ground forces, even though limited in size, connected to air power and enabled system level flexibility as well as increased effectiveness. As a cautionary note, the overall small size of the ground force, the relative low tempo and dispersed nature of operations did not stress the vertically oriented architecture until the last major operation of campaign, Operation Anaconda. This operation was envisioned as a "sweep-up" operation where little resistance and a small opposing force were expected. The intensity of the actual battle and the close physical space in which both ground and air power were employed stressed the command structure to the breaking point.[187] Kometer uses Operation Anaconda as a prime example of the consequences of low depth of command. Operations in Afghanistan were dispersed and low tempo, from the air command perspective. These types of operation do not always require depth of command or high degrees of laterality. Anaconda turned out to be a concentrated, intense, high tempo ground engagement that exposed tactical level control problems resulting from a lack of operational level coordination and collaboration. Kometer emphasizes lack of depth in relationships in this case, implying from top to bottom. What happened in this case, and what largely existed in all previous cases, was the inverse: lateral connections at the bottom, with a lack of connections at the operational level headquarters. In Operation Anaconda, however, there were other factors that exacerbated the problem of poor laterality at the top: lack of attention to the operation, focus on Iraq as the next step in the War on Terror are two of these factors.

In Afghanistan, in situations where air power operated in support of ground forces, there was low flexibility at the beginning (SOF-South), but when ground controllers joined the SOF-South forces, flexibility and effectiveness increased. In cases where there were highly sensitive targets, the architecture was vertical and less flexible.

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[186] Though there are many other factors that differentiate between Operation Enduring Freedom and the Soviet occupation of Afghanistan, there has been little argument over the effectiveness of the SOF-Air Force combination in this conflict.

[187] Kometer addresses Operation Anaconda in more detail than I have chosen to present here. The most comprehensive analysis of this operation is Davis' thesis from Air University. The Air Force lessons learned report also contains valuable information. Sean Naylor's *Not a Good Day to Die: The Untold Story of Operation Anaconda*, presents a journalistic view of the operation from the Army's perspective. Beyond these, there are few unbiased sources of information that could support more detailed architectural analysis.

When extensive flexibility was needed (Operation Anaconda), lack of lateral connections at the operational headquarters level caused tactical level confusion when flexibility at the tactical level was needed.

5.3.4 Operation Iraqi Freedom—Major Combat Operations (2003):

5.3.4.1 Operational context and characterization of the conflict

In a study of campaigns between Desert Storm in 1991 and Iraqi Freedom in 2003, these two conflicts serve as bookends.[188] These two conflicts are amenable to a side-by-side comparison. Though there are significant differences, there are enough similarities such that we can gain architectural insights from a comparison. The operational context of Iraq-II was dominated by the need to address what was assessed as a key threat in the post 9-11 security environment.[189] The U. S. had been engaged in a low level war with Saddam Hussein essentially since the end of Desert Storm through the enforcement of no-fly zones and oil embargoes. Over the decade since the end of Desert Storm, the Iraqi regime had progressively whittled away at the effectiveness of U. N. sanctions aimed at containing it as a threat to regional stability. As in Afghanistan, strategic, diplomatic and political constraints drove development of a plan that could be executed on short notice, which meant limited forces (resources).

Desert Storm left Saddam's Republican Guard largely intact, so the conflict was set up as a classic high-end armored ground campaign, combined with a dominant air force on our side. Though the forces may have been mismatched in technology, the capability imputed to the Iraqi army was not minor and overall success of the U.S. effort was by no means assured beforehand. As with Desert Storm, Iraqi Freedom can be characterized as relatively symmetric; both sides had similarly composed ground forces

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[188] Operation Iraqi Freedom is also sometimes called Iraq-II or the Second Gulf War.
[189] The motivation, rationale, political and factual support for the decision to invade Iraq and depose Hussein's regime is a volatile subject that will not be settled here. We ascribe honest, well-meaning, motives to those who made tough strategic and leadership decisions during that period. It will be decades before clarity and rationality on this subject prevails. While addressing Iraq as a strategic problem was a focus early on in the Bush Administration, the first reported direction for explicit consideration of attacking Iraq is November 2001 (Franks 2004; Woodward 2004).

with advantage to be gained through either larger more numerous forces or more innovative combinations and uses of those forces.[190]

5.3.4.2 U.S. approach to the conflict and structural features of our forces

The major differences on the U.S. side between Desert Storm and Iraq-II were available resources and strategic goals. In Iraq-II, physical resources were more tightly constrained, with the U.S. ground force about one third the size used in Desert Storm.[191] The overall U. S. approach in Iraq-II was to build a more highly integrated, cross-service effort—a more "Joint" campaign than Desert Storm or even Afghanistan.[192] This was driven in part by the limited force size—resource constraints forced operational integration of forces to compensate for smaller numbers.[193] In addition to reduced force size, lessons from Afghanistan and a year of planning contributed to development of better command relationships, which led to a lateral enterprise architecture, especially at the operational level.[194] Personnel stability was also a factor, with the senior leadership of the Afghanistan campaign continuing to work together as Operation Iraqi Freedom planning progressed.[195] These initial observations show a more lateral structure at the headquarters level than any of the other campaigns.

The overall operational differentiator between Desert Storm and Iraqi Freedom is that Desert Storm was designed as a sequential operation: the air campaign preceded the ground campaign. Iraqi Freedom was designed for simultaneity—a single air and ground

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[190] Both Iraq and the U.S. used innovative methods to gain advantage. Iraqi forces used urban areas, decoys and cover to hide and evade U.S. sensors and air power. The U.S. used innovative combinations of air and ground power enabled by pervasive sensor and communication technology to "overmatch" the Iraqis (Franks 2003; Rumsfeld 2003; Kirkpatrick 2004).

[191] Desert Storm was fought with about 500,000 American ground troops (Army and Marine Corps) and Iraqi Freedom with about 175,000 troops (Army and Marine Corps). In terms of air assets and resources, the level of effort was about the same in terms of the number of aircraft employed.

[192] (Franks 2004)Franks, p. 383.

[193] (Kirkpatrick 2004).

[194] Rumsfeld desired to limit the size of the ground force both for strategic and management reasons. Gen. Franks and his planners determined the final force size for the operation. Additionally, the last minute withholding by Turkey of access and over-flight rights caused further constraints on the deployment of men and equipment to Iraq.

[195] Kometer, p. 132. He also highlights Gen. Franks' focus on building command relationships at the component commander level during the lead up to the Iraq war.

campaign.[196] As a result, the overarching qualitative difference between Enduring Freedom and Iraqi Freedom was the delegation of more decision authority to component commanders.[197]

5.3.4.3 Operational Level Analysis

For Operation Iraqi Freedom, Gen. Franks implemented a Joint Guidance Apportionment and Targeting (JGAT) process that prioritized air power requests from all components. This created lateral information interaction at the headquarters level and was supplemented by a CENTCOM-led (top down) Combined Targeting Coordination Board (CTCB) (Kometer). In addition, to facilitate coordination and collaboration between other commanders and the air component, Gen. Moseley (the Joint Force Air Component Commander (JFACC)) created an additional organizational link, the Air Component Coordination element (ACCE).[198] The ACCE is specifically tasked with establishing lateral connections between commanders of other component operational commanders and the air component commander. This was an organizational change to "enhance the communication" between air and ground component commanders.[199] The addition of the ACCE is represented by the green lateral connections between the JFACC and the JFLCC and V Corps headquarters organizations in Figure 50.

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[196] Kirkpatrick, Land Warfare Paper 48, p. 6.
[197] Kometer, p. 185.
[198] A major contributing factor in the difficulties of Operation Anaconda was ineffective personal communication and coordination between the Air and Land component commanders. The ACCE was specifically aimed at correcting this problem by creating a direct connection between commanders (Grossman 2005).
[199] (Kometer 2005) and (Grossman 2005). Kometer notes this interface enhanced development of the overall plan before the start of the war and enabled flexibility in execution by allowing better coordination, especially in moving the fire support coordination line (FSCL) during the campaign.

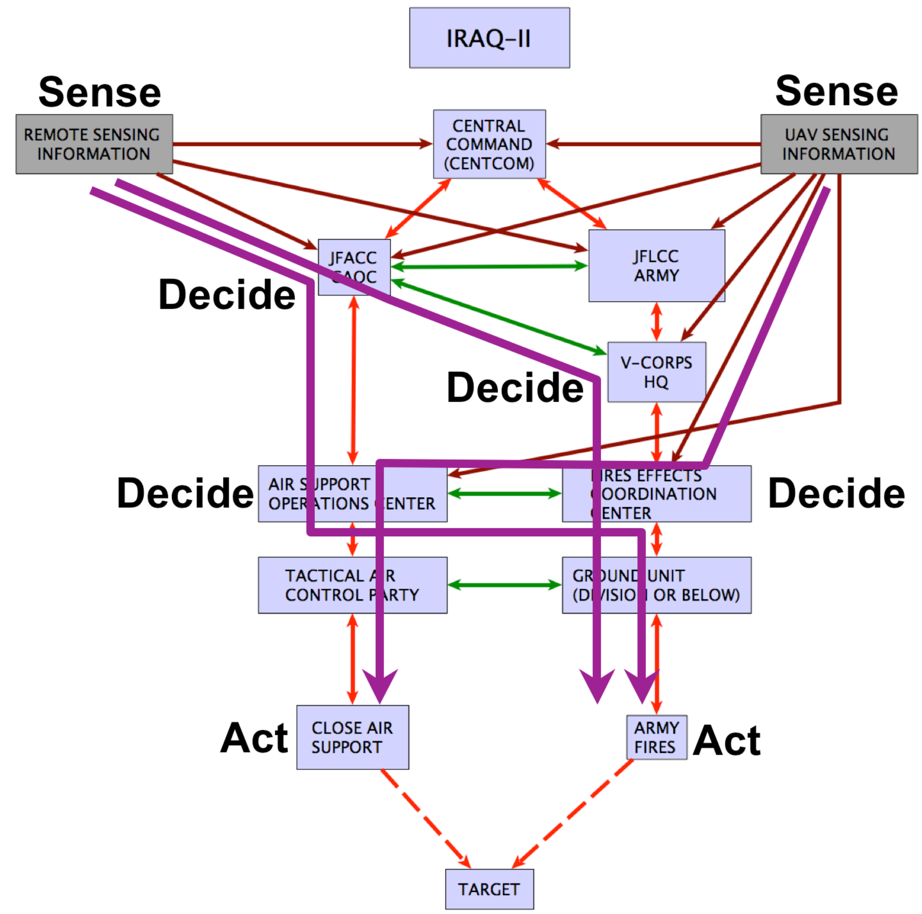

Figure 50: Iraqi Freedom V Corps-ASOC architecture

For simplicity, an architectural diagram of only the Army-Air Force interactions in Iraqi Freedom is shown in Figure 50. The lateral connections in Figure 50 below the level of the Air Force-Army connection are discussed in the next section, 5.3.4.4. Though sensor information was widely shared in Iraqi Freedom, there were some systems that were still service unique, such as some UAV sensor information. This is represented in Figure 50 by a second set of "remote sensing" inputs, some of which cross over service lines (e.g., the Army's sensor input to the ASOC).

5.3.4.4 Tactical Level Analysis

An important example of air-ground architecture in Iraq-II was the connection between the Army's V Corps (Lt. Gen. William Wallace) and the 4th Air Support Operations Center (ASOC). Wallace's ASOC developed an innovative concept to leverage access to sensor information (UAV, JSTARS and Strike aircraft) that it did not have in previous conflicts. The idea was to attack targets as they were found instead of placing them in the ATO targeting queue. In addition to better sensor information, the ASOC could talk directly with aircraft via satellite phone, also something not possible before. In order to implement this concept, the V Corps Fires Effects Coordination Cell (FECC) and the ASOC were tightly integrated before deploying to Iraq. This created lateral connections at multiple levels that allowed flexible control of aircraft and ground fires. In fact, during the famous dash to Baghdad, Lt. Gen. Wallace gave the ASOC authority to shape the Corps' battlespace beyond the Fire Support Coordination Line (FSCL), a task normally not assigned to a member of the air component.[200] Because of the new lateral interactions, the ASOC shifted from acting as a "traffic cop," directing aircraft to lower echelon forces for close air support missions, to being an integral part of the V Corps' fires team, making decisions and directing air and ground fires to achieve commander's objectives.[201]

Another example of depth and flexibility in Operation Iraqi Freedom can be found in the CAOC's Time Critical Targeting (TCT) Cell. For Operation Iraqi Freedom, TCT decision authority was delegated from Franks to Moseley, who delegated to the head of the Time Critical Targeting (TCT) Cell in the CAOC. The TCT Cell is an example of lateral interactions, in that it coordinated with the CAOC Strategy Cell and with ISR analysts in the United States to identify and develop coordinates on targets.[202] This is also an example of the CAOC, an operational level headquarters, operating at the tactical level of combat. At the operational level, we identify this as a vertical connection—the AOC directing tactical action, architecturally we identify it as "level skipping." But we can also see flexibility inside the TCT Cell itself. The TCT Cell was actually divided in to three parts: North, South and West in order to manage workload. Inside each cell, the interactions were laterally oriented, or "flat", with members of the cell working many targets in parallel.[203]

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[200] The "deep battle" is considered operations beyond the fire support coordination line (FSCL), an area of action normally reserved for the Army Corps, with the Air Force providing interdiction support.
[201] Kirkpatrick, Land Warfare Paper No. 48, p. 2-3.
[202] Kometer, p. 156-157,
[203] Fyfe, p. 20.

5.3.4.5 Summary

There were lateral connections at multiple levels during Iraqi Freedom, more so than in Desert Storm or the other two cases. The addition of the ACCE at the commanders' level and the much closer, more highly integrated ASOC-FECC connection at the V Corps level and below are the two significant operational and tactical level lateral connections that enabled flexibility. From a laterality perspective, we classify Iraqi Freedom as having L1/L2/L3 laterality.

5.3.5 Overall Case Analysis Summary

Kometer emphasizes distributed cognition, the fragmentation of kill chain functions among multiple, geographically dispersed organizations, and its impact on operational outcomes.[204] While he emphasizes the influence of hierarchical relations, he does not address hierarchy at the system level. Our focus is on the hierarchical aspect of the distribution of functions across organizations and how it relates to enterprise flexibility. A major trend in military operations since Operation Desert Storm has been for wider access tactical level information and, increasingly, for higher headquarters (specifically the CAOC and, in Iraqi Freedom, Central Command) to perform selected tactical level functions. This is a trend toward vertical structures and also toward more random structures that could inhibit desired flexibility as well as enable increased risk of accidents (Kometer 2005). Inattention to the impact of hierarchy on these properties may prevent development of effective organizations for dynamic and uncertain environments.

Over the period between Desert Storm and Iraqi Freedom, the sense-decide-act sequence has become fragmented. This fragmentation is the result of the diffusion of information systems and widely accessible data, which has increased the number of functions that can be performed by each entity in the enterprise, enabling a redistribution of functions involved in the planning and execution process. This enables many more combinations (alternatives) of people, organizations and systems to accomplish operational tasks —alternative to address uncertainty in the environment. Kometer discusses these changes in detail, chronicling technical and social factors that have

[204] He uses the Find-Fix-Track-Target-Engage-Assess (F2T2EA) model; recall that we have simplified this to sense-decide-act for the purposes of enterprise architectural analysis

influenced it, assessing the cost (system accidents) and benefits (more effective and responsive air power) of this fragmentation as a function of internal interactions and external operating conditions. In Desert Storm the number of aircraft that could be flown against targets, each executing the entire sense-decide-act sequence, limited the options—the degree of flexibility available to the commanders. Because of technical advances in sensors and communications, the challenge in Afghanistan and Iraqi Freedom became choosing a useful configuration from among the many possible configurations of the sense-decide-act sequence—designing architecture to deliver "overmatching power."

Overall, the picture painted by Kometer is that tighter controls result in less empowerment, and lower ability to innovate when it is needed. Looser control can enable the use of alternative combinations of functions (flexibility), but runs the risk of unintended consequences. In structural terms, tight control generally creates vertical structures while looser control creates interactions that cross organization boundaries more often. *In our examination of these cases, we see a pattern of increased flexibility when multiple levels are allowed to coordinate and collaborate directly to complete kill chains or other function/task sequences. We also see a common pattern of lack of lateral interactions at multiple, especially high, levels of command until Operation Iraqi Freedom in 2003.*[205] In addition, though technological challenges remain, the emergence and availability of new technologies have contributed to the creation of these lateral connections.

As sensor information diffuses to lower echelons and they become able to connect with each other in value adding ways, more options for employment are available—the system becomes flexible.[206] Representing the architecture as a series of sense-decide-act steps, we conceptualize these sequences as alternative paths through the system—representing more options for executing missions. What we have seen in this chapter is that descriptive accounts of these campaigns can be represented structurally, that there

[205] Recall that our definition of lateral interactions embodies collaboration among peers (organizations and people operating at the same level in the enterprise hierarchy).
[206] This is the implicit rationale for the current operational employment for tactical UAVs in Iraq. They have been placed under the control of tactical commanders, increasing flexibility at that level. This comes at the cost of possibly being unable to re-task these assets to higher priority missions should the need arise. (Odierno et al. 2008).

are hierarchical patterns to these structures and that these patterns correspond generally to the qualitative assessment of flexibility observed in each case. Table 5 summarizes the laterality in each of the case examples and illuminates the trend toward multi-level laterality.

Fig.	Conflict	Levels where lateral connections existed (L=Level)	Assessed Flexibility[207]
Figure 39	Desert Storm	0	Low
Figure 43	Desert Storm	L2	Medium (interdiction)
Figure 44	Kosovo	0	Low
Figure 45	Kosovo	L1/L2	High (fixed targets)
Figure 46	Kosovo	L3	Medium (moving targets)
Figure 47	Afghanistan	L2/L3	Medium (SOF-air)
Figure 48	Afghanistan	0	Low (sensitive targets)
Figure 49	Afghanistan	L2/L3	Medium (overall)
Figure 50	Iraq-II	L1/L2/L3	High (air-ground ops)

Legend:
L1: Strategic level
L2: Operational level
L3: Tactical level

Table 5: Summary of Laterality and Flexibility Across Cases

Kometer's analysis developed two concepts for building or evolving an enterprise that can respond effectively to changes in external requirements. We seek to add an architectural focus with our interpretation of his work based on original, focused, analysis of four major case examples. As our systems (and enemy systems) become more capable and interoperable, the number of possible arrangements for a military campaign increases exponentially. Senior leadership needs to think more carefully and clearly about design of their enterprises in this age. The design challenge that makes this problem different from the relatively unstructured approach assumed by most research is that for military operations control of the degree of flexibility is crucial, especially in combat. Kometer identified methods to manage this flexibility. By looking at hierarchical structures, we have started taking initial steps toward a design model of enterprises.

Key issues in choosing architectures or in evaluating enterprise structures are the trade-offs between efficiency, effectiveness, flexibility, risk and architecture. These

[207] This flexibility assessment is the summarized qualitative assessment from the case analysis earlier in the Chapter.

trade-offs are dependent upon operational context (the enemy and third parties), political objectives handed down from the strategic level of command and the conceptual level at which the trade-off calculation is made. Chapter 6 discusses these trade-offs.

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Chapter 6

A Trade-off Analysis:
Advantages and Disadvantages of Flexibility in Complex Operational Systems:

6.0 Introduction

If we focus on flexibility in systems, it is helpful to understand the advantages and disadvantages to having flexibility and the relationship of flexibility to other important system properties, such as overall effectiveness, complexity and efficiency. What does flexibility cost? What are its benefits? Is flexibility always good? How can we balance efficiency with flexibility, which requires slack resources at some level in the system and is therefore at least somewhat inefficient? This chapter examines complex military operations from Chapter 5 to highlight the relationship between efficiency, flexibility and effectiveness.

A major challenge in all forms of design is balancing many conflicting requirements. This challenge is particularly acute when considering flexibility as a system property. This chapter will discuss the relationship of architecture to flexibility, complexity, efficiency and effectiveness at different hierarchical levels of enterprise operations. Our main argument is that enterprises operating in dynamic and uncertain environments should have flexibility as a goal, possibly an overarching one. Flexibility and efficiency are multi-level concepts—they are valued differently depending on the hierarchical level of the enterprise at which their value is assessed. While flexibility is not necessarily free—there is usually a loss of some efficiency or some cost paid to gain greater flexibility—the central theme of this chapter is that traditional "either-or" trade-offs between efficiency and flexibility are less important in enterprises because the trade-off depends on the hierarchical level in the system at which the trade is considered. It is also our observation that system complexity plays a role in the trade-off as well, but that this cost can be mitigated by factors such as learning and trust. Learning and trust can mitigate the cost of added complexity, especially in information-intensive systems such as enterprises. Architecture is a key determinant of degree of added complexity for a given level of flexibility and can influence how effectively learning can reduce the cost of this additional complexity. A rich stream of empirical and theoretical literature supports this observation (Arrow 1962b; Adler et al. 1999; Koste and Malhotra 1999, Vol. 1, Part 2; Roberts 2006).

6.1 Enterprise compared to technical and organizational architectures

A significant challenge in physical system design is balancing trade-offs between desired system performance attributes. An emerging trend in system architecture is the tension between efficiency and flexibility, requiring an understanding of the trade-offs that must be made in system design. Product design and development and traditional systems engineering methods emphasize meeting requirements efficiently, usually by decomposing the system into components, designing these components and then integrating them into an operating product (Ulrich and Eppinger 1995; Eppinger 2003). One focus of research in this area is on designing processes and organizations to maximize efficiency by reducing "churn" and uncertainty, sometimes by matching organizational architecture to product architectures (Whitney 1990; Eppinger 2003; Yassine et al. 2003; Sosa et al. 2004). Software engineers and developers also emphasize meeting requirements through effective decomposition of systems into relatively independent modules (which allows efficient system development) (Parnas 1972). But they add an additional design consideration for architecture, composition, which is the consideration of overall system properties under a variety of system uses and changes (Garlan et al. 1992; Garlan and Shaw 1993).[208] Also, computer network architects are not dominated by efficiency considerations as much as other technical disciplines. In general they tend to give trade-off between efficiency and flexibility more importance than other trade-offs, such as specific performance parameters, because of the relative ease of changing information systems (Whitney 1996; Moses 2006b). Their method is to take a technologically informed approach to architecture design, with an understanding that technology and the overall system will change over time. Their main emphasis is on system-level performance goals and setting criteria (standards) that govern interaction among systems that compose the network (Clark 1988; Clark and Tennenhouse 1990;

[208] Composition in the area of software is more than just integration of components into a functioning whole. Software composition is consideration of how different parts of the system may be invoked (composed) at different times based on user needs, which can be widely variable. Consideration of the many ways that date can be accessed and manipulated is important in software.

Clark et al. 2005). Standards and performance goals in combination with more specific user requirements then drive detailed design decisions and system implementations.

Moving to organization studies and other branches of research, there is a long-standing debate over efficiency and flexibility (Astley and de Ven 1983; Scott 1992; Adler et al. 1999). In most frameworks, the choice has historically been considered "either-or", reflecting the general assumption that it is difficult to operate at any point other than at either end of a spectrum between an efficient (mechanistic, bureaucratic, hierarchical) and flexible (organic, networked) organization and that this is the critical strategic choice for management.[209] Along with this assumption is the corollary that efficiency and flexibility are incompatible, that it is difficult or impossible to craft a structure able to combine efficiency and flexibility. This assumption logically generates the view that, therefore, there is only a single choice to be made and where, once the decision has been made, all that management can do is hope the environment remains favorable to the choice (Hannan and Freeman 1989).[210] Adler, et al. present a succinct review of the pervasiveness of this dichotomy across disciplines and theoretical constructs (contingency, social-psychological) (Adler et al. 1999). A major finding of their analysis is to show how efficiency-flexibility trade-offs have shifted over a number of years at a Toyota and GM joint venture automobile assembly plant (NUMMI).[211]

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[209] A third choice is possible, derived from computer science. This is to craft a layered hierarchical system, one, which may be able to achieve a balance between efficiency and effectiveness in operation. This form is in use in some fields, such as law firms, the Catholic Church and some aspects of military organizations (Moses 2006a).

[210] Effectiveness of a system is supported by properties such as flexibility, change, innovation or adaptivity, which help to maintain a level of fitness with a changing external environment. Recent research in product development and manufacturing processes suggest that the choice is not "either-or." There are organizations able to respond to high-rate of change environments while still maintaining the necessary efficiency to remain competitive (Bourgeois and Eisenhardt 1988; Iansiti 1995a; Adler et al. 1999; MacCormack 2001). These organizations represent a "middle ground" that has not been deeply explored in research and not from an architectural perspective.

[211] NUMMI is a joint venture automobile plant in Fremont, CA between Toyota and General Motors. NUMMI has been used as a case study in lean production. Adler, et al. highlight management and leadership tools used at NUMMI that allow both flexibility and efficiency and that also identify causal relationships that allow conscious management of these two properties.

Something only tangentially addressed by the main body of research on organization and management is multi-level analysis.[212] At the enterprise level, many approaches lack explicit recognition that efficiency and flexibility exhibit a different character and different value at different levels of analysis and operation. Related to this is the lack of a temporal perspective that can account for improvement over time through learning (Arrow 1962a). We think these are major sources of confusion, resulting in inconclusive debates and seemingly inconsistent analytical results across research studies (Henderson and Clark 1990; Sethi and Sethi 1990b; Iansiti 1995a; Barki and Pinsonneault 2005).[213] Consequently, managers and senior leaders of organizations are presented with conflicting practical guidance. This problem is magnified when we move to the enterprise level.

The chapter proceeds with a general framework for thinking about flexibility in an enterprise context. We include a discussion of the advantages and disadvantages of alternative architectures, with special attention to lateral and layered structures. We then present some simple operational scenarios as examples of the differences between efficiency and flexibility across different levels of enterprise. We conclude with concrete examples taken from recent military conflicts, and discuss the ramifications of architecture on flexibility-efficiency-complexity trade-offs.[214]

6.2 Framework for analyzing trade-offs

The most fundamental goal of an architecture choice is to maintain effectiveness of the system in its environment. We have defined flexibility as the ability to change a system to meet new demands with relative ease (design flexibility) or to have alternative ways within the architecture of delivering value in a time responsive way in response to changing requirements (operational flexibility). We define efficiency as delivering the same output with fewer resources (planes, bombs, people, money) or by increasing output (maintaining ability to deliver value) with the same level of resources. In a military context we define effectiveness as the ability to exert some form of control over the

[212] The multi-scale and multi-level nature of complex systems is well documented (Anderson 1972; Mandeles 1998; Koste and Malhotra 1999; Bar-Yam 2003).

[213] Mandeles also discusses this in his case study of development of the B-52 (Mandeles 1998).

[214] The discussion that follows is based on Dr. Joel Moses' class lecture notes from ESD.935, Advanced System Architecture (Moses 2006a).

enemy or, more generally, control over the pattern of the conflict (Wylie 1989). This is a perspective that focuses on outcomes.[215] Though Wylie was mainly concerned with military strategy, the idea of control over an adversary is a valid concept at multiple levels of war.[216] At the operational level, control involves the movement of large-scale forces to shape enemy action or limit his options or his flexibility. At the tactical level of military operations, control mainly involves destruction of enemy forces, but can also entail the creation of conditions to shape the short-term actions of the enemy or to make him give up at the local level.

For relatively symmetrical competitive situations and similarly sized forces (e.g., sports such as football, or nation-state military combat) we consider two main competitive choices: (1) use more numerous and/or better systems, personnel, and specialized forces to outperform opponents or (2) use flexibility both to confuse opponents and to respond better to actions of the other side or to other aspects of the environment. Using systems that are more capable and people with more specialized skills can become expensive.[217] It can also place an increased decision-making and control burden on management because of the need to coordinate specialties to deliver system level functions. It is also important to note that use of narrowly focused, specialized skills is subject to strong diminishing return effects (Arrow 1962a). Competing with increased flexibility usually entails increased system complexity. This implies that there is a trade-off that must be considered when making strategic choices about how to compete. In relatively centrally managed competitive situations, where unequal sized forces are involved (resources are constrained on one side), flexibility (with a more complex architecture) can be used. Alternatively, a choice can be made to use excess resources or highly specialized and skilled forces (overwhelming force) to dominate the enemy (competition).

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[215] The importance of an outcome-based approach in military operations is discussed in detail by the Gulf War Air Power Survey, Volume 1, Planning and Command and Control (Cohen 1993).
[216] This idea also applies to business and political situations.
[217] This corresponds to the well-known "quality over quantity" trade-off, to which the counter is "quantity has a quality all its own," meant to capture the idea that having only a few highly specialized and highly capable people can add risk. The preference for one over the other is dependent on the specifics of a situation and the resources available, among other things.

We can use this framework to think through how laterality can be used to improve competitive advantage. Laterality, as an enabler of flexibility, can allow forces (commanders and operators) to be more effective with fixed resources or to maintain the same effectiveness with fewer resources (be more efficient). How does laterality accomplish this? First, it can enable "programming" the enterprise to shift the location of decisions automatically in response to events and to automatically shift resource allocations and action sequences. Second, at the tactical level, laterality allows people to work together based on local information, enabling action that can be both more effective as well as more efficient. Forces at the local level can shift objectives more easily, adjusting to changing requirements without the inevitable time delays and potential confusion associated with getting permission or decisions from higher levels. It also allows forces at the scene of action to capture fleeting opportunities that would otherwise be missed while waiting for a decision from above. Third, operating safety margins can be lowered while maintaining the same risk level, thus reducing the need for some resources. Laterality, used as a means to enable flexibility, can result in both increased efficiency *and* increased effectiveness. We should emphasize here that there is *no guarantee* that laterality will make the force more efficient or more effective. Humans will always be prone to errors and will make mistakes that create friction and loss of effectiveness and efficiency, something that appears to be a structural feature of war not likely to be dissipated by technology (Watts 2004).

A good example can be found in use of the Fire Support Coordination Line (FSCL) in Operations Desert Storm and Iraqi Freedom. The FSCL is the line on the battlefield beyond which air forces are allowed to attack targets without direct coordination with ground forces.[218] Traditionally, the location of this line has been controlled at the Corps level of Army command. In Operation Desert Storm, inability to move this line on short notice enabled the escape of some Iraqi Republican Guard forces (Atkinson 1993a; Carpenter 1995). In Operation Iraqi Freedom, a "Kill Box Grid" was in

[218] Targets in the area beyond the FSCL are, however, chosen based on ground force priorities, as modified by a dialogue between the Joint Force Commander and the Joint Force Air Component Commander (Force 2000).

use for part of the ground battlefield short of the FSCL as a supplement to it.[219] Kill boxes can be opened or closed more easily than moving the FSCL, providing more areas for air power to operate without the need for direct coordination with ground forces. Use of Kill Boxes increased alternatives (that is, flexibility) for employing air power by allowing air power assets more freedom of action (decision), and requiring increased lateral interactions at tactical levels in the air campaign during Desert Storm and between ground and air forces in Iraqi Freedom (Cohen 1993, Vol. 1, Part 2, p. 310; Roberts 2006). This increased both efficiency and effectiveness of the air and land battles. It also increased safety margins for ground forces when aircraft operated short of the FSCL during Operation Iraqi Freedom, because closed grid boxes were easily specified, reducing potential confusion.[220]

6.2.1 Defining effectiveness

The most general definition of effectiveness in war is the ability to impose some form of control on the enemy (Wylie 1989). In general, this amounts to disrupting, destroying or manipulating the enemy's structure.[221]

Controlling the enemy is a goal of both the Army and the AF. The AF likes to emphasize breaking structures deep inside enemy territory.[222] The object of strategic bombing and of air interdiction is to break the will of the opposing people and their national leadership and to disconnect the enemy army from its support structure. These arguments of early air power theorists such as Douhet and Mitchell have been carried

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[219] Kill Boxes are an innovation developed in Desert Storm by the Air Force for operations beyond the FSCL. The concept was extended in Operation Iraqi Freedom to operations short of the FSCL. Kill Boxes are 30x30 nm^2 in size, keyed to geographic coordinates and demark sections of the battle space that are either open or closed to attack from the air. This enables more discrete (flexible) application of air power when in proximity to ground forces. If ground forces are inside a kill box, the box is closed; if not, the ground commander can open the box for air attack. A more thorough discussion of Kill Boxes can be found in (Roberts 2006) and (Cohen 1993, Vol. 1, Part 2). Coordination is required when moving the FSCL to ensure that it is not inadvertently moved beyond open Kill Boxes.

[220] The use of GPS navigation systems enabled precise locating of friendly forces. This information was disseminated in a system called Blue Force Tracking (BFT), which enables wide dissemination across all command echelons of locating information of friendly forces.

[221] Breaking structure does not have to mean physical destruction, but in our cases, this is the primary measure. There has been a great effort by the DoD in recent years to understand the non-kinetic (destructive) means to achieve control on the enemy. This discussion is beyond the scope of the present analysis.

[222] This emphasis can be traced to the earliest air power theorizing by Douhet, Mitchell and others (Mitchell 1925, 1988; Douhet and Ferrari 1998).

forward, driving the centralized command and control architecture of today's Air Force.[223] In contrast, the Army likes to emphasize breaking the structure of and out maneuvering the opposing army, and then keep it from reconstituting by remaining on the scene of action after the battle. The Army's goal is to control the enemy by physical occupation of space.

The Air Force can break structures deep inside enemy territory but has difficulty sustaining these breaks (the enemy can repair or work-around the breaks after the Air Force leaves).[224] The Army has a better chance of sustaining breaks in the opposition's structure because it does not range as far or as fast as aircraft, so can maintain persistent presence in an area.[225] In Operation Iraqi Freedom, the Air Force and Army worked more closely than ever before. The Air Force enabled the maneuver of the Army by attacking Iraqi troops on the ground. Likewise, the maneuver of the Army forced Iraqi Army units to expose themselves and created opportunities for the Air Force to attack. The two forces were complementary to each other. This complementarity improved overall effectiveness in the eyes of the V Corps Commander (Kirkpatrick 2004).

While we have discussed only military operations, Wylie's idea of control or manipulation of outcomes as a measure of effectiveness can be generalized to other forms of competition or operational activity.

6.2.2 Defining efficiency

A relatively simple traditional measure of efficiency is output divided by input resources. Efficiency is an internal metric. It is a measure of stewardship or how well resources are being used, *inside a given process* or system. Efficiency is also dependent upon a chosen value set. In technical systems, once the performance measures of the system are set, optimization generally centers on efficiency metrics: how much input does it take to deliver the specified output? Where can waste be eliminated? How do I minimize chances of system failure? In these cases, the system boundary is well defined

[223] A good summary of Douhet's arguments can be found in J. C. Wylie, *"Military Strategy: A General Theory of Power Control"*, p. 36-41.

[224] This is a complaint that the Army makes about substituting close air support aircraft for artillery. Artillery provides persistence (makes the enemy keep his head down so the Army can maneuver); aircraft come and go, allowing the enemy to recover before the Army can maneuver.

[225] These are variations on arguments made by Wylie.

and accepted. For example, the efficiency of a Rankine thermodynamic cycle is well accepted as a performance measure of a steam plant. But efficiency of the plant does not tell us anything about whether the Rankine cycle is the best selection for power generation.

Efficiency is not, however, a universal metric. The value of efficiency is contingent upon the values that drive the selection of the system that is being measured. The efficiency of thermodynamic cycles varies based on the nature of the energy conversion and extraction process. One can be said to be more efficient than another in a technical sense, but the selection of a specific technology is driven by other factors, usually those of mission requirements. The same can apply to enterprise or organization architecture.

Bureaucratic organizations have historically been characterized as the most efficient form of organizing. Bureaucracies, if properly designed to their mission, minimize unnecessary interactions and distractions and they make maximum use of input resources. But if the architecture becomes mismatched to the problem, inefficiencies develop. In the extreme, where the problem changes very fast, a network, which is intrinsically flexible, may become the most effective and efficient structure. Short communications paths, many possible communication paths or many possible function combinations characterize network forms of organization (Moses 2006b). These attributes enable fast response and/or provide many alternative responses. The increase in the number of alternatives and faster response can be viewed as both effective and efficient in a changing environment, but also can make the system difficult to manage.[226] In this case, the efficiency metric might become: "*effective* output/input resources" or "# *of used and useful alternatives/# of total alternatives"*.

The bottom line is that discussions of efficiency must always be accompanied by a discussion of the problem or mission context and the strategic choices exercised when developing the system architecture.

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[226] This difficulty is rarely or poorly addressed in many discussions that attempt to operationalize network-theoretic concepts such as Network Centric Warfare. Our hierarchical approach is an attempt to address this gap; it offers a way to balance the potentially overwhelming complexity of networked operations with the demand for flexibility in operations that is both enabled and created by information technology.

6.2.3 Summary

Our framework shows us two ways to use flexibility at the enterprise level. First, we can make the opponent's problem harder to solve while using the same level of resources. This entails competing by creating or identifying new opportunities and/or giving the opponent a higher number of alternatives to counter (creating confusion). Using flexibility to compete in this manner increases the complexity of our operations mainly because of external factors. We call this externally focused complexity. Second, we can maintain the same level of performance with fewer resources, competing efficiently (more output with fewer resources) by having the ability to implement more alternative combinations of forces in response to the uncertain and changing battle environment. Using flexibility in this manner increases the complexity of our operations because of internal factors. We call this internally focused complexity.

The alternative is to use excess resources in both number and quality, competing by using overwhelming force and skill. The trouble with this approach, at least in modern high-end warfare, is that many combat systems have improved to the point that there is little difference in ***technical capability*** between opposing sides at the tactical level of combat.[227,228] This drives advantage to the operational and strategic levels of competition, where novel combinations of systems and organizations—architectures—are important (Watts 2008b). Another issue is that overwhelming skill and force drive enemies to work around this advantage—they change the operational problem. In cases such as insurgencies, competition is less symmetric, and is usually based on flexibility. In asymmetric situations, commanders can use flexibility to present more complexity to the opposition (externally focused). Sometimes this flexibility is enabled by complex internal architectures.[229] Leveraging or enabling flexibility usually increases internal complexity at the same time as it provides a more varied response to their external environment or competitors, as summarized in Table 6.

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[227] There are also national fiscal constraints that make system improvement without consideration of complementarities with other systems prohibitive.

[228] Dr. Barry Watts of the Center for Strategic and Budgetary Assessments (CSBA) recently reported on this phenomenon. Improved technical capability of combat systems is leading toward a high probability of tactical parity in future operations (Watts 2008b).

[229] Improvised Explosive Devices (IEDs) are an example of innovative use of stand-alone technical systems to create difficult problems for the opposing side to solve.

Scenario	Resources	Complexity	Flexibility	Efficiency	Effectiveness
1.	Lower than others	Moderate	Use flexibility to maintain effectiveness	Same or better effectiveness with fewer resources	Winning, surviving, controlling
2.	Same as others	High	Use flexibility to increase complexity for the opponent; or to respond faster to changing requirements	Maintaining effectiveness without needless use of excess force	Winning, surviving, controlling

Table 6: Various trade-offs for flexibility

6.3 Flexibility-efficiency trade-off

Flexibility is not always worth the cost in terms of lost efficiency or gain in effectiveness. It comes with costs and benefits, which have been discussed in the economics literature since the mid-20th Century. Flexibility was neglected for decades in organizational and mechanical (production systems and product systems) disciplines, but surged in importance starting in the 1980s, as manufacturing machinery became more automated and globalization surged. Economists, operations managers, systems designers attacked the changed context of competitiveness from many perspectives. In hindsight, the core findings from these lines of research are obvious. While flexibility is necessary to compete in a changing environment, its value is dependent on the specific problem and the measure of merit chosen to evaluate it. Flexibility can be achieved in many ways and for many objectives. It is a multi-dimensional attribute of complex systems, with motivation from a number of different sources both internal and external to the system. We seek a deeper, more general understanding of flexibility, one that can be used at the enterprise level.

How does an organization choose how much flexibility to “buy” and choose where to locate it in its overall enterprise? A wealth of literature shows us flexibility is not free; operations researchers have demonstrated the capability of optimizing processes and manufacturing operations by using flexibility (Fine and Freund 1990; Sethi and Sethi 1990a; Suárez et al. 1991; Jordan and Graves 1995). But when we consider multiple levels of system hierarchy and analysis in situations that require timely response, the utility of operations research based optimization methods becomes less clear—especially in high-paced military operations, they cannot optimize the system faster than environmental demand changes.[230] When the environment introduces changes faster than the ability to calculate cost-benefit trade-offs and subsequently rearrange equipment or processes, we need to take a new approach. Because it is generally more difficult to design flexible matter-energy systems than it is to design flexible information-intensive systems, an emerging trend is to expend more analytical effort on understanding the costs and benefits of flexibility in the very early stages of the design process. Methods to address these issues in matter-energy systems are embodied in multi-dimensional optimization methods and multi-attribute utility analysis, which rely on understanding uncertainty in future requirements (de Weck et al. 2004; Silver and de Weck 2006; Ross et al. 2008). These design problems become even more challenging when moving to a socio-technical operational context, where uncertainty can be very large, its type unknown and originate from both internal and external sources. To address the design problem of flexibility in operational military enterprises, we need to understand the nature of military operations from an analytical point of view.

War is complex, non-deterministic, fundamentally uncertain, and fraught with fog and friction that is unlikely to be dissipated any time soon (Clausewitz 1984; Watts 2004; Mattis 2008). Based on our discussion in Chapter 4, this makes war a multi-level, stochastic, phenomenon—it takes place at multiple levels of abstraction. Because of this, commanders and political leaders balance the risk of error and loss of strategic focus with the necessity of enabling flexibility within resource limitations. The tensions involved in this balancing act pervade virtually every aspect of the military enterprise. Since the operational military force is composed of independent technical systems and organizations, each with its own internal measures and guides for efficiency and effectiveness, the central design challenge is developing an architecture by which these systems can be integrated to achieve enterprise-level effectiveness while maintaining a balance with service organization-level effectiveness.[231] A central tension in this area is

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[230] The computational demands of optimization in many problems can grow exponentially in size. This prevents real time optimization using computers (at least so far), so we must craft the system to have flexibility "in real time".
[231] A key focus of many defense acquisition reform efforts is to get individual services to craft program requirements that enable interoperability with other service systems or that enable use of the system by

how to balance efficient employment of combat (air) power with the structural uncertainty and dynamics of war, which may demand some inefficiency from an air power resource perspective in order to integrate with other combat arms; integration that can enable enterprise level effectiveness. We will discuss this trade-off in this chapter.

6.3.1 Flexibility-efficiency in air power

Kometer addresses air power across three levels of war: strategic, operational and tactical. Air Force doctrine states that air power can be applied effectively at all three levels. This makes it a uniquely flexible combat arm. Given the multi-level and context dependent nature of flexibility as a concept, the Air Force emphasis on flexibility and efficiency presents an architectural challenge. While flexibility can confer significant advantage in battle, the multi-level nature of war makes flexibility a relative term in practice.[232] The ability of the AOC to shift mission assignments of aircraft across the theater is an example of flexibility. But for a ground commander planning an operation, the possibility of losing the use of an air asset based on an emergent higher priority tasking by the Air Component in response to its own, more globally focused, priorities, complicates planning. This complication can take the form of contingency planning or establishment of excessive reserves as a way to increase flexibility for the tactical ground commander, but that simultaneously reduces efficiency for the air commander.[233] An additional factor in operational flexibility regarding the control of aircraft is related to the physical distance that an aircraft must cover when required for emergent support as well as the time required to establish coordination with ground forces when arriving on scene. Despite the flexibility of aircraft to range the depth and breadth of the battlespace, it still takes time to move across larger distances. And despite the proliferation of technologies that enable sharing information between ground and air forces, it still takes time to synchronize awareness and understanding when aircraft arrive to support a ground force.

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multiple services. An early effort in this area was the TFX, a 1960s effort to build a fighter usable by the Air Force and Navy. Its descendent is today's F-35 (Joint Strike Fighter).

[232] This usage risks confusion. We are mainly concerned with flexibility as a system property. When considering trade-off analysis, the "value" of flexibility must be considered. In general, value judgments are highly context dependent—in particular, dependent on the level of analysis.

[233] An example of this is the Marine Corps during Operation Desert Storm. In this case, the Marine Air commander intentionally requested more air support than he could use, knowing that he could cancel what was not needed. This was done to insure that he had enough to support his plan once all mission requests had been prioritized (Atkinson 1993a; Mandeles et al. 1996).

The control architecture can limit the tactical flexibility of aircraft when response timelines become very short.[234] Again, what is efficient at one level of war may not be efficient at another level.

In Kometer's view, the risk a commander takes in empowering lower levels of command is two-fold: risk of accidents and loss of strategic focus. The net result of these types of errors is a less effective application of air power and/or damage to the success of the overall campaign. A claimed benefit of tight (top-down) control is increased efficiency and lower risk of error.[235] Specifically, top-down direction can ensure that targets attacked with air power are supportive of the commander's overall strategy. This type of control (architecture) claims to ensure effectiveness and, usually, efficiency. Air Force Doctrine Document 2-1, Air Warfare, specifically addresses efficiency-effectiveness in the use of air power (U.S. Air Force 2000). When discussing development of an air campaign strategy and the choice of employment of air power against certain classes of targets, the preferences are clear: air power should be prioritized so that its employment is efficient. There are some cases, such as close air support of ground forces, where inefficiency at theater level must be accepted to have effective employment at the local tactical level.

Kometer's recommendations attempt to balance the conflicting demands of warfare with the doctrinal preferences of the Air Force. He seeks to enable *flexibility* in order to balance the need to address uncertainty and change in combat with the demand for *efficiency* in resource allocation across various missions in order to control an adversary and better maintain strategic focus. Air Force doctrine aims to achieve efficient application of air power so that its inherent geographic flexibility is used to greatest possible impact on the enemy. The Air Force emphasizes an ability to impact the enemy at the system-level, aiming to coerce the enemy without the need for ground operations. In this vein, "efficient" is defined as: achieving the maximum possible effect

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[234] Recent analysis at the Joint Forces Command has indicated that when timelines drop below about 2-3 minutes, it becomes difficult to call in a non-organic air asset to support the ground force.
[235] Error is assumed to come from a combination of lower experience and knowledge and lower levels or poorer quality information at lower levels of command.

on the enemy with the least amount of effort.[236] "Flexibility" is defined as the ability to move aircraft across theater-level distances quickly in response to changing priorities of the Joint Force Commander. Air interdiction and close air support are given lower priority; flexibility and efficiency across these missions are less important (U.S. Air Force 2001).

One of Kometer's unique contributions is to show *how* tactical level actions can percolate up to strategic levels and how difficult it is to predict how strategic level intent is translated to tactical action. He also demonstrates that it is difficult to direct tactical level employment of aircraft from high command levels with necessary precision in many important situations. Effectively, the multi-level nature of warfare requires first, decomposition and second, decentralization in many situations. However, tension arises because of feedback loops in the larger system. In the years since WW-II, media and other information sources have increased the flow of tactical level battle information to the strategic (social and political) levels. The trend for politicians to use military force in a broader range of situations, along with the wider media coverage and tactical level events, can have more immediate strategic impact. Kometer concludes that the media feedback loop, coupled with increased precision in targeting and global communication capabilities, creates a tendency for political leaders to retain control (create vertical shortcuts) and place tighter restrictions on the use of air power, lowering flexibility.

The same issue of hierarchical level impact on the evaluation of efficiency and effectiveness is also true of flexibility. What is flexible at one level may be inflexible at another. This sensitivity to level is a general property of complex systems (Simon 1996; Bar-Yam 1997; Meyer 2000). For example, Air Force doctrine argues that assigning air

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[236] For detailed references on the air power theory of war on which doctrine is based, good sources are Douhet's The Command of the Air, and Billy Mitchell's, Winged Defense: The Development and Possibilities of Modern Air Power Economic and Military, and Robert Pape's Bombing to Win: Air Power and Coercion in War. For a systems level discussion and brief but comprehensive overview of air power theory, J. C. Wylie's, Military Strategy: A General Theory of Power Control is superb. It is important to note that the validity of air power theory is still much debated in professional and academic circles (Pape's book and a subsequent series of articles in the journal International Security are examples). Even though the U.S. Strategic Bombing Survey following WW-II demonstrated the ineffectiveness of strategic bombing, it became, and in many ways remains, the centerpiece of Air Force thinking. A detailed discussion of the theory and evidence, as well as the institutional and cultural issues that drive Air Force doctrine, is beyond the scope of this research.

assets to be commanded directly by ground units is inefficient because it removes the inherent flexibility of air power.[237] A ground unit may not be able to use the assigned air asset effectively or efficiently from the perspective of the operational level of war (U.S. Air Force 2001). Once the ground commander has an air asset assigned, he (or she) may be reluctant to give it up to another unit. From the ground force perspective, an assigned air support asset serves as an operational option—it provides flexibility against unforeseen combat needs. From the Air Force perspective, it looks like unnecessary hoarding of assets that may be more effectively employed elsewhere in the theater. Contributing to the problem is that procedures for transferring the air asset to another unit may also be complex, further reducing flexibility in the system. This is the core rationale for centralized control of air power—to avoid lowering theater-level flexibility.[238]

Providing an asset to the ground force that enables flexibility at the tactical level can hamper flexibility and lower efficiency at the operational and strategic level. Since a fundamental operational capability that aircraft bring to the combat problem is the ability to enhance flexibility at the theater level, the Air Force prefers to control at and optimize aircraft employment for the operational and strategic levels of war. For the Air Force, the cost of assigning aircraft to ground (tactical level) units (a form of lateral architecture) is too high in terms of the complexity of retaining operational level flexibility. Not addressed in this scenario is the possibility of crafting an architecture that can enable effective sharing of assets and efficient adjudication of inevitable disputes that will arise if lower level commanders are given control of air resources.

Air Force preference for central control of air power dates to World War II and the Battle of Kasserine Pass in North Africa. In this battle, the division of air power into "penny packets" by placing them directly under the control of the individual, separated, ground commanders resulted in the inability to shift the air power focus of effort against the German Army. A similar situation to penny packets exists in today's counter-

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[237] Air power's inherent flexibility comes from its ability to respond across the depth and breadth of the theater of operations quickly, whereas ground forces are limited by geography and mobility.

[238] This issue is normally cast as one of local vs. global optimization, which is an appropriate view when the rate of change is such that we can optimize a system and make these kinds of choices. But in a higher rate of change system, we must have flexibility to shift from a local to a global focus sometimes quickly.

insurgency campaign in Iraq, though modified by Air Force doctrine: aircraft are assigned to work with specific ground units, but are centrally controlled by both air and a ground headquarters (instead of individual ground commanders, as was the case at Kasserine Pass).[239] Major Robert Seifert, in a 2007 *Joint Forces Quarterly* article, describes the inflexibility of this command architecture for employment of AC-130 gunships. As employed, gunships are assigned to specific ground units for the duration of their mission, with multiple higher headquarters controlling reassignment to other ground units. Gunships have robust sensor and communication capabilities, so can detect formative stages of insurgent activity across a wide area and can communicate with both tactical and theater level organizations. If a gunship detects insurgent activity, but this activity is not actively threatening or engaging the ground force to which the gunship is assigned, it is difficult to change the mission or ground unit assignment. The gunship must request permission from the AOC and the AOC must request permission from another operational level organization in order to change its mission assignment. Lateral connections exist at the headquarters level, but are not allowed at the tactical level. This has resulted in ground force casualties and escape of insurgents (Seifert 2007). This is an example of how centralized control can be inefficient and inflexible at the tactical level. Information available to tactical level ground and air units cannot be acted upon in a time responsive way because of the need to obtain permission from operational level headquarters. This situation is illustrated in (Figure 51). Siefert argues that if the AC-130 were allowed to collaborate with multiple ground units (lateral interactions), better effectiveness against insurgents would result.

[239] We distinguish here between the Major Combat Operations (MCO) phase of the Iraq War (March-May 2003) and the ongoing Counter-Insurgency Operations (COIN), from which the following example is drawn.

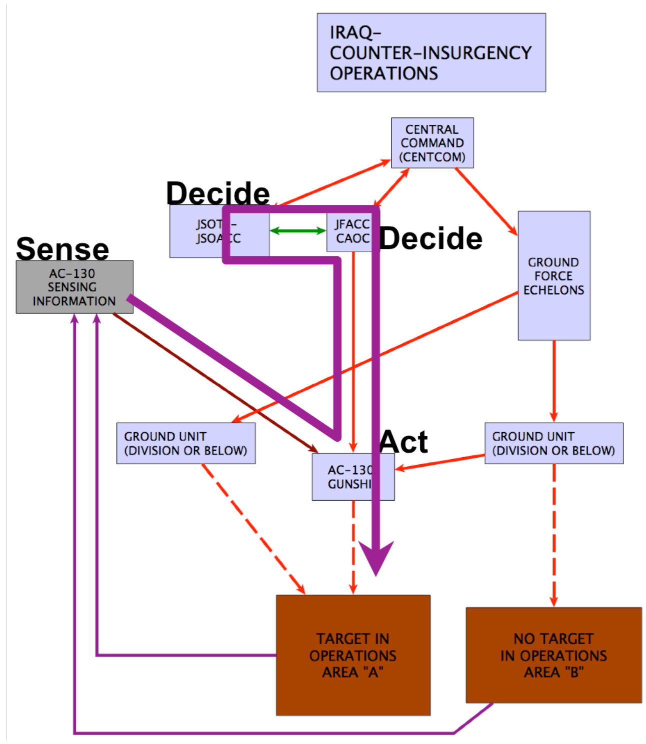

Figure 51: AC-130 air-ground operations without laterality

This example provides an interesting picture of the mixing of doctrine aimed at correcting the problem of Kasserine Pass (centralized control of air power by a ground force commander) with the operational requirements of the modern battlefield (need for timely air support to ground forces). In Iraq, air assets are relatively plentiful, and the need for theater-wide control in many cases is low. Centralized control of air power is aimed at providing operational level flexibility, but this hampers tactical level flexibility, especially important in the counter insurgency campaign. The result is that ground commanders are provided assigned air support, but have no ability (flexibility) to allow the aircraft to perform other missions—if an unforeseen need arises, the process for getting or transferring an air asset may be cumbersome. Aircraft remain under operational control of the headquarters organization(s). A lateral architecture, where aircraft are subject to multiple controlling authorities based on operational and tactical level circumstances, could provide both theater and tactical level flexibility. In architectural language, this is Seifert's proposal and is shown in Figure 52.

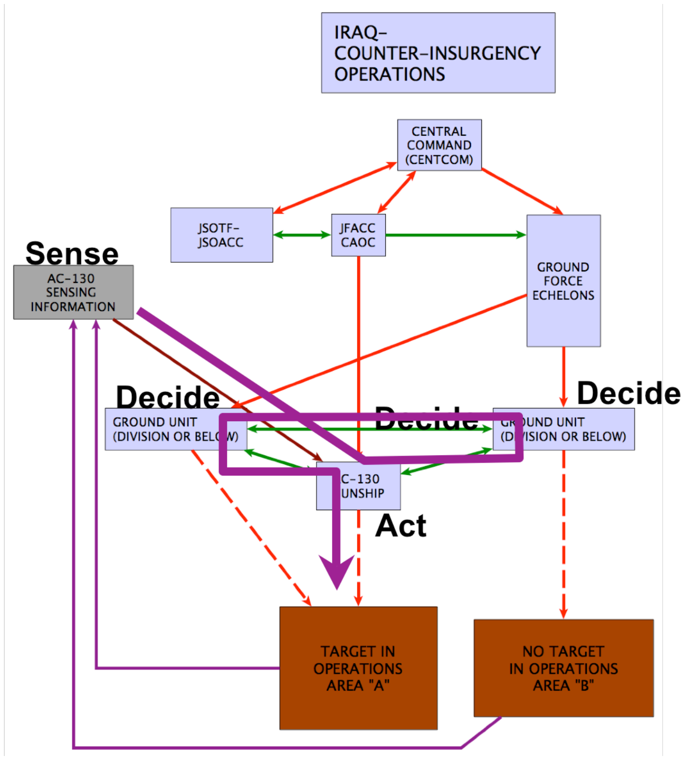

Figure 52: AC-130 air-ground operations with laterality

Air power doctrine says that control of air power at the strategic and operational level of war ensures efficient and flexible employment, whereas control at the tactical level is inflexible and inefficient (U. S. Air Force 2001). On the other hand, a simple thought experiment can show us how assigning (apportioning) air assets to ground units can be *efficient* and *flexible*. Whether in ground combat or air combat, a local commander generally has the best information on the situation and how best to employ the capabilities at hand. Transmission of this knowledge and information to higher levels of command takes time and effort that often exceeds the rate of change in operational and tactical situations. So assigning air assets to ground commanders can be efficient, there is no lost effort coordinating or negotiating with or between higher headquarters. A local commander can directly command a change in air asset priorities to different targets or even reassign the air asset temporarily to another ground asset. Two tactical level commanders could coordinate the exchange of an air asset between them in order to employ it against the most valuable mission. Indeed, two entities at the battlefield level are more likely to be able to synchronize and agree than a battlefield entity and an operational level entity (Seifert 2007). But at the operational level, issues are more complex and time scales of interest are longer; more information must be integrated to develop effective decisions. Allowing local commanders to control and reallocate assets in this case might reduce flexibility by impeding responsiveness to theater level priorities.

The point is that a *balance must be achieved* between optimizing tactical level outcomes and operational and strategic level outcomes.[240] Kometer articulated two solid recommendations for addressing the tension: his general formula for command and control and the concept of depth of command. One of these is a method, the other an enabling capability for achieving flexibility.[241] From an architectural perspective, his methods enable the commander to craft an architecture that has many alternatives for action in response to uncertain operational demands.

6.3.2 Lateral interactions—an enabler of flexibility

How do we achieve this balance? As we approach flexibility for enterprises, we can use information system flexibility to help understand the general nature of trade-offs in enterprises, which can be viewed as large information or resource processing systems (Galbraith 1974; Tushman and Nadler 1978). Architecture has been a dominant consideration in information systems (especially software) for a long time, especially as it relates to flexibility and life-cycle concerns (Moses 1971; Parnas 1972; Gifford and Spector 1987a). In particular, the tension between efficiency and flexibility has been an ongoing debate (Moses 1971). If the architecture is well conceived, it is possible to have a flexible software system without a significant performance penalty. This has been possible because of Moore's Law (inefficiencies in processing are mitigated by gains in hardware performance) and because of the ability to change software relatively easily as learning takes place (Arrow 1962a; Moses 2006b).[242] The relatively small cost penalty of flexibility in software can be seen as an analogy for organizations and enterprises. The

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[240] It is critical to remember that the indeterminacy of combat and war means that each level will have different "weights" in the overall outcomes and that these weights will change over time. An excellent example is Vietnam, where tactical success was high, but the overall outcome was a strategic failure.

[241] In an email communication on this subject, LCol Kometer confirmed this assessment.

[242] As a more flexible software system is created, it is generally less efficient than others. But as the processing power and memory capacity of computers increase and experience with the new system develops (learning), the loss of efficiency can be reduced (Moses 2006b). A slightly different way to view this is that Moore's law allows us to absorb inefficiencies in software—it provides excess resources at the level of technological performance. This is not the same as using different levels of abstraction to gain flexibility, but has the same enabler.

initial “purchase” of flexibility in the form of multiple interactions (connections) among people and organizations that enable more alternatives can create confusion. But this cost is gained back over time as learning occurs through exercises, training, trust building and other factors.[243]

In information systems, layered structures enable flexibility (Moses 2003).[244] In organizational practice, lateral connections within organizational layers also enable flexibility (Galbraith 1973; Chisholm 1989). The design issue for enterprises, then, is how to design a multi-level architecture for flexibility. This leads us to consider what types of interactions we need to design into enterprise architectures if we want to enable operational flexibility. Intuitively, lateral interactions and layered architectures are less efficient than a pure tree structure (Moses 2006b). Interactions are established that may only be used infrequently or that may be used at inappropriate times (especially in organizations); they may be redundant or may divert information or resources along a suboptimal path; they may create confusion over directives or by adding superfluous information. But as uncertainty in the environment increases, the ability to predict precisely which path information or resources should take or who in the organization is best suited to use a given piece of information decreases. It might also be the case that multiple people at the same level require the information and must interact with each other to accomplish useful work. This places a premium on having multiple alternatives along which to pass information or to coordinate action.[245]

Layered architectures are one way to provide these multiple alternatives.[246] These types of connections become even more important when we consider that information can arrive anywhere in an organization. Strategically important information can enter the system at the bottom of the hierarchy and tactically important information can arrive at

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[243] This phenomenon is captured by the famous “J-curve” effect whenever any change is made to a system or process, where, initially efficiency or effectiveness drops when a change is made, but results in overall improvement in performance with time.
[244] It can also be argued that it enables efficiency as well, at least in programming (Abelson et al. 1996).
[245] It also makes a stronger argument for commonality in certain aspects of technical systems in addition to interoperability among them.
[246] As discussed in Chapters 2 and 3, a layered architecture is defined as an architecture where nodes at a given level can have more than one parent, can change parents easily. A lateral architecture is where there are interactions among nodes at the same layer as well.

places in the hierarchy remote from the place where it is best used. Having multiple pathways to move this information and multiple alternatives to accomplish action improves flexibility and, in general, overall effectiveness. Lack of having these paths can also reduce effectiveness by preventing information from getting to where it is most needed; it is also a driving force for generation of the many *ad hoc* connections (Cohen 1993; Leveson et al. 2003).

6.3.3 Flexibility: Advantages

This section discusses advantages of flexibility; disadvantages are discussed in section 6.3.4.

Flexibility in combat operations with air and ground forces provides several advantages:

1. Air and ground forces can be employed in closer proximity to each other with either the same or lower risk levels;
2. The total force can be more responsive to changing battle requirements;
3. More force combinations are possible: air and ground force mission assignments can be traded-off and complementary capabilities can be leveraged;
4. Control modes can change: attention management of leadership can be improved if flexibility is gained by lowering decision-making burden;
5. Decision structure can be changed quickly in response to changing information, risk tolerance or mission focus (Kometer 2005).

A core benefit of flexibility is the increased likelihood that the enterprise will be able to respond effectively to a *wider range* of unforeseen events or performance demands.[247] In the military context, this is captured in a maxim of LGen. Horner during

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[247] This does not imply that *all* types of unforeseen events are easy to deal with, nor does it imply that all unforeseen contingencies will be able to be handled by the flexibility enabled in the system. What we are aiming for is a way to design flexibility explicitly and to avoid the inefficiencies and dangers when *ad hoc* flexibility must be relied upon.

operation Desert Storm: "the enemy gets a vote."[248] His point to his staff and to the analysts conducting the Air Power Survey following the war is that the air power system must be able to respond effectively to unforeseen events—the enemy is not going to just sit there and let us beat him up.[249]

Flexibility in a single service (the Air Force, for example) can provide a commander more options, confusing the enemy by providing multiple problems for him to solve or address. In a multi-service context, flexibility among services (Army, Air Force, Navy, Marine Corps) further increases the enemy's problem as well as providing our side more options, both offensively and defensively. Employed properly, this can improve efficiency as well: we can win the war faster and with less loss of life and other physical damage.

In an uncertain and dynamic operational context, flexibility enables efficient application of air power. As we have noted, this is the core argument of Air Force doctrine: air power's flexibility provides the force commander with a tool that can range over the depth and breadth of the battle space in response to the commander's changing priorities. Air power's flexibility makes overall force application more efficient because resources are less likely to be either idle or used on low priority or low pay-off tasks. But we should be cautious. Air power doctrine focuses on the operational level of war, with secondary emphasis given to tactical level support of ground operations.[250]

But again, flexibility has many advantages at the tactical level. Closer interaction between ground and air forces can quickly identify new force employment options. A flexible architecture can enable ground and air forces to operate in closer proximity to each other. A way that this type of operation can be enabled is by faster opening and

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[248] I do not know the origins of this truism, but it is pervasive in all types of defense writing, including in formal Air Force doctrine publications.
[249] Often this perspective is missing in commercial business. Many times a commercial business will alter its strategy without regard to either subsequent moves by customers or competitors that change the calculus of the original move. Such static thinking and analysis is giving way to more dynamic approaches, but there is much work to be done. The "environment" is not a passive, static, bystander—it "gets a vote." (Prof. Joseph Sussman highlighted this point).
[250] The explicit assumptions or air power theory is that strategic and operational level actions can win wars while minimizing physical destruction and inherent inefficiency of ground combat. The adjustment of our enemies in Post-MCO Iraq is an example of the invalidity of these assumptions.

closing of "off limits" areas between services. Both of these types of flexibility can reduce enemy sanctuary that is granted when longer planning times and larger margins of error are required to coordinate among friendly forces.

It is also important to note that these types of flexibility advantages are complemented, enhanced or enabled by technical system improvements. Information systems can lower the burden of information exchange and sharing on operators and staffs, thus lowering the cost of greater flexibility. It can also improve the operational capability of lower level units. A significant example is precision weaponry. Increased precision in weapons makes it possible to employ them in closer proximity to friendly forces and makes it possible to change targets quickly in response to changing operational schemes.[251]

Another benefit is the ability to address unforeseen contingencies. With flexibility, a commander gains options for addressing uncertainty. Depth of command aims to enable low-level decision-making, providing effective response against an adaptive enemy. Moving decisions to a level that best matches the problem can be faster and possibly more accurate than hierarchical decision-making. The ability to move decision-making locations up and down the hierarchy provides a commander with the ability to optimize the configuration of the enterprise in response to changing risk assessments or risk tolerances. In addition, while there will always be interactions and combinations that are discovered in the course of operations—"discovered flexibility"—by explicitly designing flexibility into an architecture we can increase overall effectiveness and avoid *some* of the trial and error involved with discovery, while simultaneously increasing higher level visibility to and awareness of system flexibility.

6.3.4 Flexibility: Disadvantages

The previous section discussed advantages of flexibility; this section discusses disadvantages to flexibility:

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[251] A good example is the development of the Precision Strike Suite-Special Operations Forces (PSS-SOF) targeting system, which enables three dimensional target mensuration by tactical forces in the field, lowering the time responsiveness of precision targeting from hours to minutes and moving it from an operational headquarters (the AOC) to tactical level ground units.

1. More coordination is required: more effort must be expended before conflict (extending to peacetime exercises and career paths) on trust building, exercises, training;
2. Loss of a traditional level of management control; acceptance of a degree of uncontrollability or potential error;
3. Potential confusion or loss of efficiency due to:
    a. More decision alternatives at more levels of command;
    b. Conflicting preferences or decisions based on the same information;
    c. Bad decisions;
    d. Too much information;
4. Increased arbitration of decision conflicts by higher echelons;
5. Losses of some specialty skills or skill proficiency as operators learn to do more things.

The reverse of the flexibility coin is that there is a potential loss of efficiency. Until recently, it was difficult for a central commander of air forces to manage the hundreds of aircraft flying missions. If a pilot's original mission was not achievable or if a pilot found himself 'unemployed,' he would use his radio to look for work. Missions found in this way may not have been 'optimal' or even desirable from the theater commander's perspective—from strategic level of the conflict. While a mission found this way might not have been 'efficient' in terms of strategic execution, it was certainly of value to the ground force that employed it and, if successful, could be viewed as both efficient and effective at the tactical level or from the perspective of the ground campaign.

Another cost of flexibility is that capabilities and technical systems must be purchased and maintained even though they are not used or are not used very often. For example, Air Force doctrine places low priority on close air support missions. Additionally, learning the procedures for and maintaining proficiency at close air support takes time and effort.[252] But performing these missions enhances flexibility at the tactical level, which can also enable flexibility at the operational level that can, in turn, provide strategic flexibility. In technical system architectures, flexibility has costs and benefits that can often be quantified. For example, the F-16 aircraft has evolved from single mission air-ground support to a multi-mission aircraft over the course of three decades of operation and development. Sometimes the maintenance of these flexibility options is costly, at least at first. But increasingly, flexibility is achieved on the information side of systems, where we have noted that adding new capabilities is often less expensive than a more physically intensive system change.

Flexibility, the availability of more alternatives to achieve an objective, can also incur costs in the form of mistakes. A system or an organization that only does one thing can practice to minimize mistakes, continually refining and optimizing its performance (Arrow 1962a; Spear 2008). It can become extremely efficient and possibly come to dominate its competition. But, as options (alternatives) are introduced, inefficiency can arise and mistakes can be made. Not all alternatives (paths) are of equal value in a given situation, even though there may be multiple alternatives to achieve the same objective. Also, people coordinating via lateral connections in an organization could choose an ineffective (incorrect) alternative. Again, these effects can be mitigated with training, exercises and experience.

Another cost is that lower level organizations sometimes do not have enough information or expertise to balance the multidimensional considerations for which higher-level organizations are designed. Creating the ability to make decisions based on multiple criteria or to have more options at the enterprise level creates "overhead." Overhead arises in the form of both more systems to operate and more people with whom to interface. All of these lower efficiency not just by potential dilution of attention but by potential human error and influence. It takes time and effort to coordinate, collaborate

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[252] U.S. Army Center for Operational Leadership's oral history project contains an interview with a B-52 pilot that documents some of the costs and benefits of flexibility in Operation Enduring Freedom. B-52 crews learned how to do close air support, a mission that provided high flexibility when combined with the large payload capacity of the aircraft. (Government Printing Office: Transcript. Records of the Combat Arms Research Library; Online version of March 1 2005)

and negotiate the myriad activities that go into achieving enterprise flexibility through lateral interactions. In this sense, the general formula for command and control and depth of command are more "expensive" than a traditional planning and command and control method. Implied in the general formula is more plan iteration, more vertical and lateral interactions among peers and between seniors and subordinates.[253]

Other disadvantages of flexibility center on risk and control. This is one of Kometer's central themes and is central in Air Force doctrine as well. Designing flexibility into enterprise architecture entails risk of dilution of the high-level intent or mission objective of the enterprise.[254] Because we are dealing with fallible entities (people and systems designed by them), delegating decision authority means loss of a degree of control for senior leadership. Loosening control coupled with fallibility of people can increase the chance of unforeseen outcomes.[255] Flexibility in the form of numerous options or execution paths can also lead to overload of both individuals and organizations. Choosing among alternatives takes time. Having more alternatives in terms of system configurations, when coupled with differences in preference, perception and information access among people and organizations can cause disagreement over choice of alternatives, requiring arbitration by higher-level authorities. This has the added disadvantage (aside from the increased time to choose an option) of deflecting senior management attention from other matters.

By having many alternative configurations, some are likely to be longer sequences or more complex than others (we demonstrated this with a simple example in Chapter 4). This implies added coordination and collaboration effort in execution. Though these disadvantages seem significant, building trust can mitigate their impact

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[253] Refer to Chapter 2 for a detailed review of the general formula and depth of command.
[254] Designing flexibility into any architecture entails risk. This is the focus of financial options, portfolio analysis, real options analysis and strategic engineering research in engineering systems, to name a few areas where this issue is relevant. In most domains where flexibility has been researched, uncertainties are market-based, with stochasticity that can be estimated, if not measured. In engineering systems analysis focused on flexibility, the analysis is grounded in physical models that are used to explore a large number of alternative system configurations, but relatively small numbers of them when compared to the possible configurations of a combat operations enterprise (or any enterprise, for that matter).
[255] We do not intent to imply that the senior level is omniscient. Bad objectives can be chosen, poor policies (or even architectures) implemented. Our perspective is that the enterprise must be flexible (at all levels) so that it can adjust to change while still maintaining focus on the desired outcome (defined by the top level of leadership).

and, as we noted earlier, training and exercises can minimize the chances of choosing inefficient alternatives.[256] Of course, building trust is not costless either. It takes time and effort, all of which can detract from an individual's specialty skill set. In the aggregate, building of trust as a driver of future enterprise architectures in the DoD is largely a moot point. Legislative and policy directives have placed requirements on the Services for education, exercises, and training and in some cases system procurement, aimed to create trust relationships and interdependencies among the Services (Arrow 1962a; Goldwater-Nichols Department of Defense Reorganization Act of 1986" 1986). In addition, though there may be some loss of specialty skill levels, some of these specialty skills may be automated, an additional layer can be added to the system to compensate for any system level loss of capability, or a cadre of specialists can be retained.[257]

6.4 Operation Iraqi Freedom (Second Iraq War) Trade-off Analysis

6.4.1 Strategic-operational level

There were numerous constraints placed on Gen. Franks as he prepared his campaign plan for the Second Iraq War. Secretary of Defense Rumsfeld placed constraints on the level of forces that General Franks could use to execute his assigned mission; President Bush placed constraints on the visibility of any force posture changes. Rumsfeld's main concern appears to have been efficiency (Franks 2004a; Woodward 2004). The need to maintain strategic surprise also constrained both size as well as the process of moving and operating forces in the run-up to the war (Franks 2004a). Late in the preparations, the loss of over-flight rights from Turkey made the 4th Infantry Division unavailable to the plan, adding an additional resource constraint and impacting the overall campaign plan (loss of a second attack front). These constraints placed a premium on using flexibility to be effective with fewer resources, something emphasized by Gen. Franks to his component commanders (Franks 2004a).

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[256] Of course, the other way that military organizations reduce these costs is a strong reliance on hierarchical rank structures, which can be applied across service boundaries in many (not all) circumstances.

[257] The retention of single skilled, single mission strategic nuclear forces is an example.

This example highlights the difficulty in analysis of efficiency-flexibility-effectiveness trade-offs. The initial resource constraint from Secretary Rumsfeld, based on not wanting to repeat the resource-excess (waste) of Desert Storm, drove the development of the campaign plan toward leveraging flexibility to cope with limited resources. But Gen. Frank's operational plan, based on his experience and lessons learned also influenced the plan's evolution—his emphasis on strategic surprise, and thus less time to increase resources, was a key factor in the calculus as well as his emphasis on Joint Operations. Franks thought flexibility would enhance his effectiveness, regardless of any resource constraints.

6.4.2 Tactical level

Kometer uses an air-ground battlefield example to illustrate his depth of command concept and its benefits. I will review the example from the perspective of flexibility and how it can be developed at the tactical level of operations.[258] The following example is taken from (Kometer), pages 139-140.

During the first battle of Fallujah in April 2004 an AC-130 gunship was tasked to support a ground force of Marines. In these cases of close air support, a formally trained air controller directs and grants permission for the aircraft to engage the enemy, with the aircraft supporting the ground (supported) unit. In close air support, there are clear procedures and rules of engagement to be followed in order to ensure safety of friendly forces and non-combatants. In this case, the Marines came under attack the AC-130 gunship spotted a second, larger, group of insurgents preparing to attack. The aircraft informed the Marines of the larger group and requested permission from the ground controller to engage. The Marine controller could not see the assembling force, so did not think they had enough information to grant permission.[259]

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[258] I have defined flexibility as the number of paths (alternatives) from input (sensing) to output (action) in a system. When considering technical systems or alternative organizational arrangements, this is a fairly straightforward idea. When considering simultaneous, or real-time interactions (in either a military or non-military case), the implementation (or enactment) of a path is more difficult to explain. This example will attempt to make this clear.

[259] The reasons the ground controller could not give clearance are unclear, but was likely due to either the rules of engagement or the requirements of the formal procedure for ground control in an urban environment.

The ground controller called up his chain of command to get permission to engage the insurgents, while at the same time preparing the gunship to engage by conducting the standard pre-attack briefing. While the ground controller was conducting his attack briefing to the pilot and while waiting for permission to engage from higher headquarters, the ground force came under attack from the second insurgent group. This prompted the ground controller to grant immediate permission for the gunship to engage. In the course of the engagement, the insurgents split into two groups. The gunship, with multiple weapons and visibility on both groups, continued engaging both. The ground controller, technically in charge of the engagement, could only see one group of insurgents and attempted to direct all gunship fires to them, unaware of the split. A possible architectural solution to mitigate this confusion is to allow the ground controller and AC-130 gunship to collaborate and shift the location of control using a formal procedure, creating what I have defined as a *lateral* connection.

A second example comes from recent counter-insurgency operations in Iraq, also with AC-130 Gunships. In the 2nd Quarter Joint Forces Quarterly magazine, a professional publication of the National Defense University, Major Robert Seifert reviews the current employment of Gunships against the Iraqi insurgency (Seifert).

Seifert reviews the current employment architecture for AC-130s. They are assigned a mission, attached in direct support of a single ground unit. Sometimes the ground units do not have 'work' for the Gunships. They represent a flexible option for the ground commander should he need them. The "trouble" with this arrangement, as noted in my review of Kometer's thesis and air power doctrine, is that the AC-130 is filled with sensors and radios. It has the ability to see developing situations while it is in transit to its mission area, returning from a refueling stop, or simply by monitoring radio frequencies while on station. Seifert describes situations he participated in where the AC-130 was underutilized by the ground force to which it was assigned, but was able to see attacks on other ground forces (or pending attacks).

In one specific case, Seifert describes the architecture:

> "Having worked with the Marines there (Najaf) previously, it took less than a minute to get their JTAC on the radio and inform him of the gunship crew's

situational awareness and nearby location. The JTAC confirmed that he had troops in contact and asked for immediate assistance. Unfortunately, the aircraft commander had to notify him of his inability to assist due to assignment to another unit. The aircraft commander told the JTAC to make a request immediately to the Air Support Operations Center (ASOC) and told him that he would also call to try and get released from his Al Hayy tasking."

Seifert describes the classic inability to gain or gather adequate situational awareness at higher levels, when he recounts the story of his AC-130 being denied permission to assist the ground force under attack. A gunship 30 minutes away was re-tasked to support the Marines that his gunship was asking to help. His aircraft was directed to its original tasking. Seifert's punch line here is that his aircraft was eventually ordered home early due to lack of tasking and the last radio call heard from the Marines was for a medical evacuation. A different operational architecture might have been a bit more inefficient or lead to some increases in errors or arguments about priorities, but might have been able to prevent casualties in the ground force.

Architecturally, the basic rule at play here is: assign one aircraft to one ground unit, request headquarters' permission before deviating from this mission. Structurally, this results in a tree structure with immobile connections at the lowest levels. In addition, because of the unique capabilities and operational assignments of AC-130s, the hierarchical structure for changing their tasking is more difficult than for an A-10 or F-16 close air support aircraft.[260] We assess the flexibility in this structure as low. According to Seifert the request chain for re-tasking the AC-130 was: "…from the ASOC to the Combined Air Operations Center to the Special Operations Liaison Element to the Joint Special Operations Air Component and then the Air Force Special Operations Detachment." This represents a 5-step chain across at least two hierarchical levels of command. Figure 53 shows a simplified depiction of this arrangement.

[260] AC-130s are under the operational control of the Special Operations Component Commander (SOCC). Because of this, the Air Operations Center (AOC) must work through the SOCC to get permission to retask these aircraft.

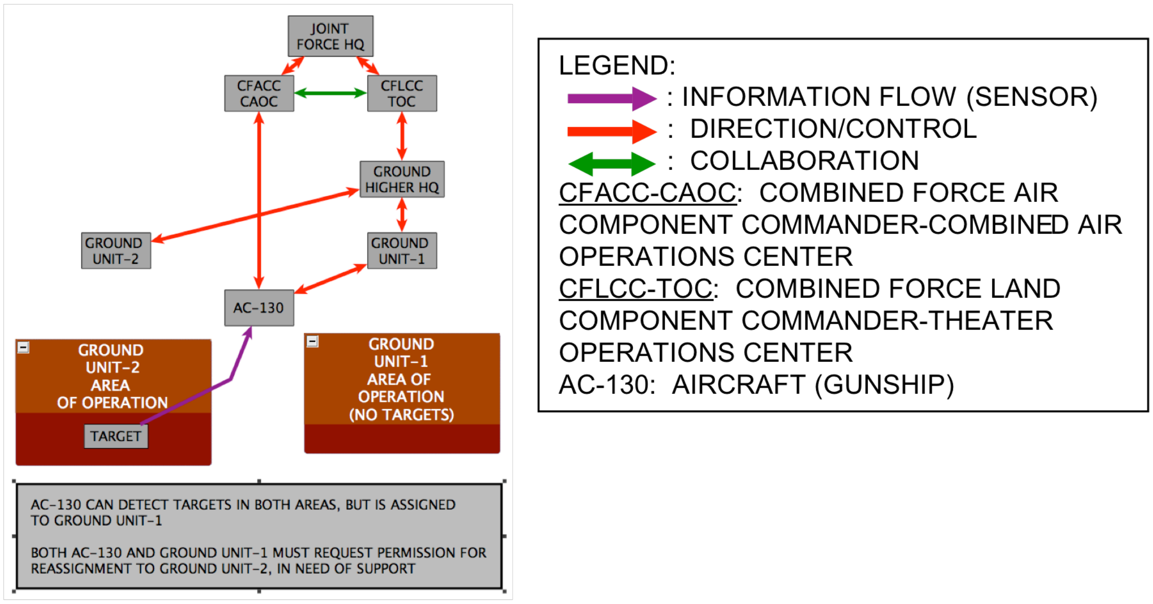

Figure 53: AC-130 air-ground operations in Iraq

Seifert's proposed solution is a command and control arrangement similar to one used in Vietnam during the 1960s. He calls this the "on-call" method. In this method, AC-130s are assigned a mission rather than assigned to a ground unit. They rove the battle space, serving as sensors for ground units and leveraging information passed from ground units. By roving, they are within responsive range of any needy ground unit without having to request higher-level permission. He combines this scheme with the use of sensor-equipped fighters controlled by higher-level controllers (ASOC). These loitering fighters can respond quickly to requests for sensor coverage, lowering response time for ground units even farther.

Architecturally, this is a distinctly different arrangement. The basic rule is: assign AC-130s a mission tasking to search for and engage insurgents in collaboration with ground forces in the assigned area of operations.[261] Structurally, this is a more lateral structure—AC-130s work with ground forces to figure out the best way to accomplish a particular mission, with ground forces collaborating on the sharing of the AC-130 air asset and higher headquarters monitoring and providing direction only when

[261] The military term for this idea is *Auftragstaktik*. It is German for "mission order", a method of command where a mission is given and the unit or person tasked is expected to find the most appropriate way to accomplish it. *Auftragstaktik* developed in the German Army in the 19th and early 20th Centuries.

necessary. There is also a distinct difference in the kind of decisions that are made at each level in this (Seifert's) proposal. The higher level headquarters can now make judgments about overall priorities and is not distracted by the minutiae of details involved in micro-scale coordination of aircraft and various arrival times. The tactical level commanders are more involved in the use and employment of all elements of combat power, instead of awaiting decisions from above, or finding ways to increase their safety margin by gaming the aircraft allocation system. Arguably, the proposed control scheme is more responsive to tactical level needs, with the potential for operational level headquarters to be more effective as well.

A diagram depicting what this architecture might look like is in Figure 54. In terms of the depth of command concept, this lowers decision authority to the level of the local ground commanders (battalion-level, probably) and the aircraft commander. Risk is managed (per Kometer's formula) by the procedures for air-ground coordination and by the low-yield (low explosive power) weapons of the gunship. Information access is robust, because of ROVER and other sensor systems on the AC-130 as well as an

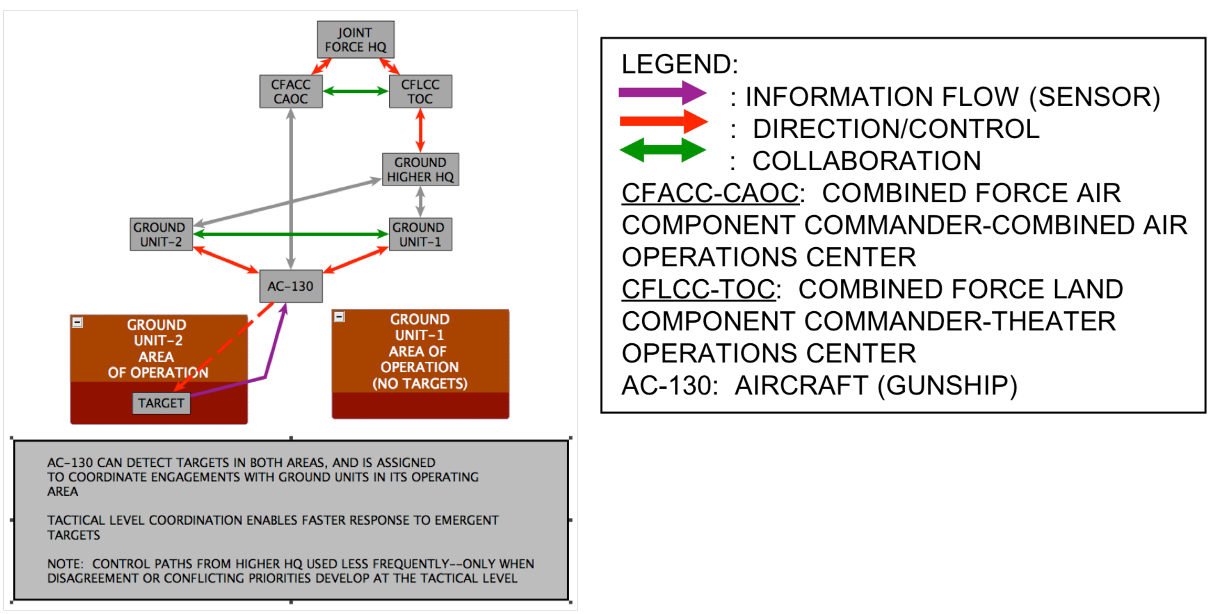

Figure 54: AC-130 air-ground operations supporting multiple ground units

extensive set of radios that enable the aircraft commander to monitor the battlespace for relevant information.[262]

6.4.3 Summary: Second Iraq War

The second Iraq War is an example of the use of flexibility to maintain (possibly increase) effectiveness with fewer resources. This required increased complexity in the interfaces between air and ground forces at the V Corps-4th ASOC level (Hollis 2003; Kirkpatrick 2004). Even further, the contrast between V Corps interaction with air power and the Marines' integration of air and ground power demonstrates another level of complexity that comes with flexibility (Roberts 2006).

Flexibility also enabled maintaining risk levels constant while increasing effectiveness—the most commonly cited example is the use of a kill box grid instead of a continuous line to maintain separation of air and ground targeting areas. Grid boxes are easier to activate/deactivate than moving a line across the wider battlefield. By creating more alternatives for separation of air and ground forces (lowering complexity), flexibility was increased.

In Iraq-II, the number of levels of the US military that had lateral connections was the largest of our four cases. This resulted in flexibility at the strategic, operational and tactical levels for the first time (with higher levels of flexibility at lower levels than earlier conflicts and higher strategic coherence than ever before).

6.5 Summary: Trade-offs to flexibility

This chapter examined complex military operations from Chapter 5 to highlight trade-offs among flexibility, effectiveness, complexity and efficiency. Our main argument is that enterprises operating in dynamic and uncertain environments should have flexibility as a high priority goal and that traditional "either-or" trade-offs between flexibility and other properties are less important in uncertain and dynamic environments and can be mitigated by careful architecture choices. We began by noting that a major challenge in enterprises is balancing many conflicting requirements at different hierarchical levels of operation, detailing some specific examples. We also noted that

[262] ROVER is a dedicated air-ground two-way video link that allows ground forces to see the aircraft's video and the aircraft to see the ground forces picture.

designing flexible architectures adds complexity, which can lower efficiency but also that learning and trust can mitigate these costs, especially in information-intensive systems.

In most organizational design frameworks, the architecture choice is usually viewed as “either-or” with respect to efficiency and flexibility. Architecture alternatives are cast as mechanistic (bureaucratic, hierarchical) vs. organic (market, collaborative, networked) and we must choose one or the other (Burns and Stalker 1961). In addition, the effect of hierarchical structure on these architecture choices is rarely considered. Consequently, because managers and senior leaders of organizations live in a dynamic and ever-changing environment, they are presented with conflicting practical guidance on the value and benefits of flexibility vs. efficiency. A third general option, discussed in Chapter 4, is the layered hierarchy, which is rarely explicitly considered outside of computer science but offers the potential to balance this dichotomy.[263]

Our definition of effectiveness is the ability to impose control on the operational situation (environment, competitors, customers, etc.) (Wylie 1989). In military operations, controlling the enemy is a goal of both the Army and the AF. While AF likes to emphasize breaking structures deep inside enemy territory the Army emphasizes controlling by physical occupation of space. We saw that in Operation Iraqi Freedom, the Air Force and Army worked more closely than ever before, each complementing the capabilities of the other. While the architecture was more complex and there were inevitable inefficiencies, the overall warfighting system dominated the Iraqi Army using one third the number of ground combat forces as were used for Operation Desert Storm in 1991.

We have defined operational flexibility as having alternative ways of delivering value on operationally relevant timelines, in response to changing requirements. We defined efficiency as being effective with fewer resources (planes, bombs, people, money) or by increasing output (maintaining ability to deliver value) with the same resources. Our analysis shows us two ways to use flexibility at the enterprise level:

[263] As we noted earlier, layered hierarchies can be found in numerous places such as law firms, the Catholic Church, Universities and in some aspects of the military (Moses 2006a).

1. Increase complexity of the opponent's problem using the same level of resources. This entails competing by creating or identifying new opportunities and/or making the opponent work harder (create confusion). We have named this externally focused complexity.
2. Maintain the same level of performance with fewer resources, competing efficiently by using structures that are more complex. We call this internally focused complexity.

Alternatively, a choice can be made to use a combination of excess resources and highly specialized and skilled (overwhelming) assets to dominate the competition.

The fighting force in Iraq-II used flexibility in the face of strategically driven resource constraints to achieve success. The long-term planning that restricted ground force size coupled with the last minute loss of the 4th Infantry Division caused Gen. Franks to force a tighter integration of his air and ground forces.[264] This resulted in lateral interactions at multiple levels of hierarchy between the Air Force and Army, resulting in more effective ground and air operations against the Iraqi Army.

Our main point in this chapter is that *lateral interactions* in a *layered architecture* can help *balance* the conflicting needs for *flexibility* in the face of uncertainty and the need to maintain *efficiency* for control and strategic focus. In military operations, air power doctrine says that control of air power at the strategic and operational level of war ensures efficient and flexible employment, whereas control at the tactical level is inflexible and inefficient (U. S. Air Force 2001). We saw that in some cases, centralized control of air power can provide operational level flexibility and efficient use of resources, but in other cases, where tactical level support must have primary consideration (counter insurgency operations) operational level efficiency must sometimes be sacrificed to gain more flexibility in order to enable or improve tactical level effectiveness. In military contexts, flexibility in a single service (the Air Force, for example) can provide a commander more options, confusing the enemy by providing multiple problems for him to solve or address. In a multi-service context, flexibility

[264] Recall also that, according to Franks, his operational philosophy was inherently Joint. This meant that he was predisposed to achieving effective integration among his service components (what is colloquially termed "Jointness"). This tells us that resource constraints were only one driving force for achieving flexibility (Franks 2004b). Based on the statements of Gen. Wallace, the V Corps commander, resource constraints became a compelling force for increased laterality with his air support organization (Kirkpatrick 2004).

among services (Army, Air Force, Navy, Marine Corps) further increases the enemy's problem as well as providing our side more options, both offensively and defensively, even though the efficiency of each particular service branch may need to be lowered in search of effectiveness at the enterprise level.

When considering architectural choices in an enterprise context, it is important to consider the multi-level nature of enterprise architectures and understand the flexibility-efficiency trade-offs that result.

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Chapter 7

New England Patriots: Balancing Efficiency, Effectiveness, Flexibility and Complexity at Multiple Levels of the Game

7.0 Introduction

In an era of salary capped football teams, the New England Patriots are an anomaly. National Football League rules are aimed at making all teams relatively equal and avoiding the dominating teams of past decades such as Shula's Miami Dolphins and Landry's Dallas Cowboys. But the New England Patriots and its head coach, Bill Belichick, have found a recipe for sustained success in this environment. In a two volume work, James Lavin, an avid Patriots fan with no inside knowledge of the team but armed with an economics Ph.D. in high performance work organizations, we have a comprehensive look at the team and its system (Lavin 2005a; Lavin 2005b). These books were written because Lavin observed that the Patriots seemed to understand business strategy and organizations particularly well and he wanted to explain their system to the practicing business community.

Our interest is in understanding one aspect of how the Patriots can be so successful in an environment explicitly designed to level the playing field: player flexibility, its cost and its impact at multiple levels of the game. My advisor, Joel Moses, has been interested in flexibility of the Patriots since my arrival at MIT. In our quest to understand flexibility in socio-technical systems, we decided to look closely at how the Patriots do it. There are certainly many ways to examine and interpret the Patriots success. Some might say they cheat, given the 2007 season's videotaping scandal.[265] Some might say they have simply identified a better strategy or that they work twice as hard as everyone else or that Coach Belichick is a better strategist, leader and team builder. Still others might observe that the talent of quarterback Tom Brady carries the day. All of this may be true or not. In many ways, each is an interpretation based on value judgments or narrow views of the Patriots system. Our interest is different. There are certain aspects of the Patriots approach to the game of football that can serve as explanatory analogs to flexibility in warfare and that can help illuminate fundamental

[265] This was a comment made to me by more than one person when I mentioned this study in conversation.

trade-off issues and consequences of flexibility in enterprise architecture. The integration of different specific position skills in football is analogous to integration of different military service capabilities in joint military operations.

There are two key points. First, recall that we are interested in operational architectures—systems and organizations in operation, executing complex missions and tasks on multiple time scales and at multiple levels of abstraction. Second, recall that a core conceptual construct is that flexibility pays benefits in excess of its costs in most situations once an initial investment is made in a flexible architecture, especially in cases where switching costs among built-in alternatives are low.[266] Certainly, in competitive situations where there is uncertainty about what might happen next, it is beneficial to have alternatives. Alternative courses of action are enhanced in value and made more efficient to have if the things that provide those alternatives are flexible themselves. Flexible parts or versatile people make it easier to shift from one course of action (configuration) to another—they make the overall system more flexible than it would be otherwise. This chapter aims to look closely at the role of multi-skilled players as a component of the Patriots' strategy in order to explain better the value of flexibility in an enterprise context (extending our analysis of military operations in this case).

7.1 Analog to military operations

There is a parallel between strategic, operational and tactical concerns in military operations and different aspects of football. In military operations, tactical concerns are

[266] This observation is made in Chapter 4, and is noted in a briefing titled "Strategic Engineering" by Prof. Oliver de Weck, dated Nov 7, 2006, available at http://strategic.mit.edu/content/view/38/86/. Switching costs are a discriminator between information intensive systems and matter-energy intensive systems when considering design of flexibility for operational purposes. In matter-energy intensive systems high switching costs in terms of time, money and effort to change a system's configuration are an important consideration in system design for uncertain environments. This creates a need to think strategically (longer term) about system design as fiscal, demand, environmental and other constraints tighten. As switching costs decrease, it becomes less necessary to consider long-term system design implications of changes to a system—many options can be designed into the system up front, making operational and tactical changes to system configuration more viable. In this way, switching costs may help us discriminate between strategic, operational and tactical flexibility in operational situations. In addition, system flexibility in operation is distinct from design flexibility; it is more challenging to design operational flexibility into matter-energy intensive systems than in information intensive systems. It is more difficult, in general, to add options to an automobile than it is to add options to software or to redirect a person. Also, once written, software can become inflexible from a design standpoint, so even though software may have more operational flexibility to begin with, changing that flexibility can become as difficult as changing a matter-energy intensive system.

those centered on short term, direct engagements with the enemy. In football, this equates to game play of each down. The operational level in military operations concerns the larger scale support, coordination and exploitation of many, often dispersed, tactical level activities over a longer time scales in order to achieve strategic goals. This level bridges tactics and strategy. In football, this equates to a game plan—the overall scheme for managing a game against a certain opponent. It considers issues related to exploiting game play successes to win the whole game. In military contexts, strategy concerns the determination of the overall approach to the conflict or competition, and usually considers the longest time scales. In football, strategic concerns are those related to how the team competes within the league—the overall approach to the game within the constraints of the rules determined by the league. These levels are summarized in Table 7

Military level	Football equivalent
Strategic	Season-to-season considerations; overall approach to the game, including hiring strategy: general managers and staff
Operational	Individual game plans; integrating individual plays within a game to exploit success and mitigate errors: coaches
Tactical	Individual plays within the game: players

Table 7: Levels of abstraction for National Football League teams

7.2 Flexibility in football

Football is a relatively tightly constrained and symmetric competition. Skills necessary on both sides are open and well known; the number of players allowed on the field and on the team roster is the same. In this case, as discussed in Chapter 5, a strategic choice can be made to compete on overwhelming skill and specialization in certain areas, or to compete by using plays that are more complex, using flexibility against the other team and its game plan. In football, flexibility in the offense can enable the quarterback to exploit weaknesses in and confuse the defense. Likewise, flexibility in the defense can confuse the opposing quarterback as well as exploit weaknesses in the offense. To build a model of flexibility in football, we need to state some observations up front:

1. Single position, exceptionally talented players command large salaries;
2. The NFL imposes salary caps on teams.

With these two observations, we can discuss the implications of multi-skilled (flexible) players on overall flexibility of the team and discuss the structure of this flexibility at the team level. Some positions naturally require highly skilled, single position, players. Quarterback, kicker, cornerback and sometimes safety are these types of positions. Players with multiple skills can fill other positions. Linebackers and defensive ends are examples of positions that the Patriots fill with multi-skilled players.

An example of flexibility in offense is the option available to the quarterback to pass or throw. Having multiple receivers and a running back/fullback makes the problem complex for the defense. It gives the defense many possible problems to solve. On the other side, if defensive players are versatile (can switch roles quickly), the quarterback has a difficult problem to solve as well; he has difficulty choosing a play that can exploit weaknesses in the defense. These examples of flexibility, the benefits it creates and problems it causes are the equivalent of tactical level operations in a military context.

Football teams can achieve flexibility in at least two ways that we will consider. The first, most conventional, way is to swap out players for different plays. This has some drawbacks, such as giving the other side time to 'read' the play (if swapping on offense), interrupting the flow of the team's overall game strategy or not having the right mix of players on the field (if swapping on defense) (Lavin 2005b).[267] The second is to have multi-skilled players that can easily switch positions—altering the configuration of the team quickly and with relative ease.

In manufacturing situations, economists have seen that multi-skilled workers enabling flexible manufacturing and production, enhancing regional or industrial competitiveness as well as providing robustness to external change (Piore and Sabel 1984; Piore 1989). In a similar vein, Coach Bill Belichick and his Vice President of Player Personnel, Scott Pioli, select certain players specifically for their potential to

[267] Many of these insights were developed by personal observation of the Patriots football games by (mostly) Dr. Joel Moses and me. These insights are enriched and largely validated in the book by James Lavin, *Management Secrets of the New England Patriots: From Patsies to Triple Super Bowl Champs*.

become multi-skilled players that can support the Patriots' strategy of flexibility. As Lavin notes: "Belichick drafted strong safety Gus Scott...because "He's played both free and strong safety. He's also played some nickel back. I like him on all four downs."(n. 599)" (Lavin 2005b). This gives Belichick's coaches many more options for play sequencing and game strategy, the football equivalent to operational level of war.

7.3 Multi-skilled Players

Based on this discussion, there are two 'meta-strategies' in professional football. We will call these 'superstar' and 'multi-skilled'. The main approach—the one used by most teams, relies on a relatively small number of single-skilled superstar players. These are highly skilled, dedicated role, players. They command high salaries and are coveted by many teams and competing with this type of strategy creates a two-tiered team architecture. There are a few highly paid superstars and many players paid close to the league minimums. In this strategy, competitive advantage is gained by superlative skill, flawless execution and a well-crafted game strategy that leverages the high-priced talent, generally driven by coaches on the sidelines.

As we noted earlier, the Patriots take the 'multi-skilled' approach, choosing multi-skilled players for key positions. There are a few superstars, such as Tom Brady, many mid-level salary multi-skilled players and a lower-tier of single-skilled or entry-level multi-skilled players. The availability of multiple skills in a single player creates more options for coaches when building game strategies and more options in game execution when unforeseen events happen on the field. In this strategy, competitive advantage is gained from the ability to adjust to opposing strategies and by changing configurations to confuse the opposition, using a game strategy that relies on a mix of control from the sidelines and direction on the field. Using multi-skilled players combined with innovative play development and strategy, the Patriots have become a powerhouse football franchise.[268] Looking to the Patriots as an example for flexibility may help us gain more general insights to flexibility in enterprises.

7.3.1 Defensive flexibility and multi-skilled players

[268] Super Bowl Champions, 2003, 2005, 2006.

The Patriots differentiate themselves from other teams largely in the flexibility of the defense, especially in the linebacker position. This is where we will focus our analysis. The Patriots' defensive tactic is to present many alternative and rapidly changing configurations to the offense.[269] Because of the multiple positions that their linebackers can play, the Patriots' defense can shift configurations in response to the offensive setup before the ball snap. The aim is to try to confuse the opposing quarterback into making a mistake (Lavin 2005b; Lavin 2005a).

On the defense, the main source of flexibility comes from the outside linebackers. The Patriots' linebackers are specifically chosen for their balance of size and speed. Speed provides them with an ability to defend against the passing play and size enables them to move up and work on the defensive line. They can also drop back to the safety position if necessary. So there are three different positions that are filled by linebackers on the Patriots. This contrasts with most league linebackers (and the origins of the linebacker position), where the run and short pass are their main focus. Positions and the general mobility of players are shown in Figure 55.

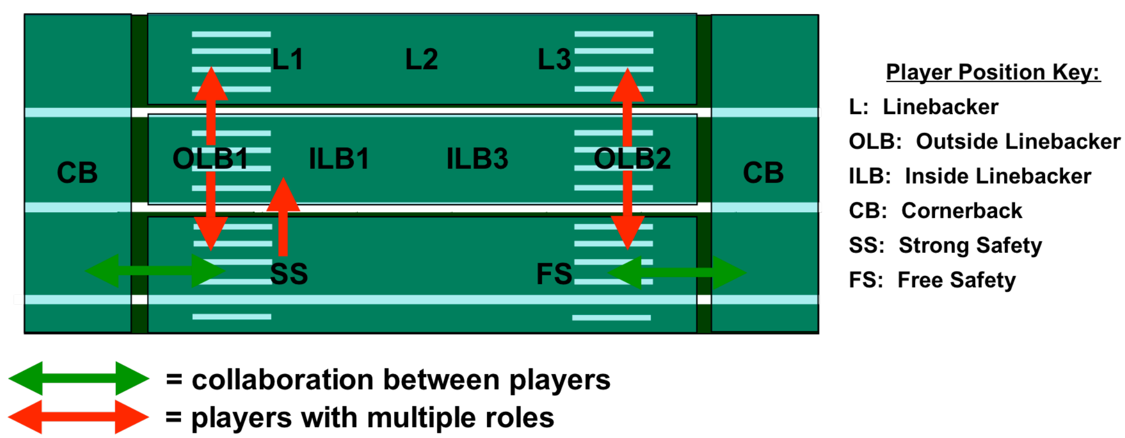

Figure 55: Position flexibility on Patriots' defense

A second source of flexibility on the Patriots is the Strong Safety, who can come up and play outside linebacker when necessary, filling two positions. This brings the total number of configurations possible for the New England Patriots' defense to 18. Flexibility by position is shown in the following table:

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[269] Christopher Price notes in *The Blueprint* how the Patriots' defense used many different defensive configurations to confuse Peyton Manning in the 2004 AFC Division playoff game (p. 238).

Position	L_1	L_2	L_3	OLB_1	ILB_1	ILB_2	OLB_2	FS_1	SS_1	CB_1	CB_2
# Positions playable	1	1	1	3	1	1	3	1	2	1	1

Table 8: Position flexibility by position on Patriots' defense

In fact, the total number of possible defensive configurations can be counted as much higher if we consider that different linemen serve different functions (and that they are trained in multiple functions), that cornerbacks can shift sides of the field and that inside linebackers can also shift positions.[270] Another source of strength and flexibility is the mutual support and collaboration between cornerbacks and safeties in the secondary. In addition, some offensive players can shift sides to play defense if necessary, providing flexibility at the level of the whole team and at game level, not just defense.

7.3.2 Analogy to military operations

This kind of flexibility is equivalent to tactical level flexibility in military operations. If different systems or units can serve multiple roles or functions, it is possible to respond with a more useful configuration in the face of enemy actions than would be possible if we simply had single role units. For example, there are three main missions for attack aircraft in the employment of combat air power: deep strike against enemy strategic targets, air interdiction against assets that are in direct support of an enemy's army, and close air support, usually against forces in contact with our ground forces. If an aircraft can fill more than one of these missions, the force is more flexible. Two specific examples are illustrative.

In Operation Desert Storm F-111F aircraft were used to attack Iraqi Republican Guard tanks. Designed to penetrate enemy air defenses and strike targets deep in enemy territory, the Air Force discovered that the F-111's Forward Looking Infrared Radar (FLIR) could pick out warm Republican Guard tanks against the cool desert sand after dark (Gordon and Trainor 1995). Over ten years later, during Operation Enduring Freedom in Afghanistan, B-52 bombers demonstrated similar flexibility in use. Designed

[270] A close analysis of Patriots player flexibility shows flexibility on offense and in other defensive positions as well. For example, Safeties will shift to play Cornerback in some situations (Reiss 2008b). I focus on the defense and linebackers because this is the most obvious source of additional flexibility and is it's the area of largest payoff for the Patriots.

for Cold War strategic strike missions and modified over the years for other bombing missions, they were loaded with the Joint Direct Attack Munition (JDAM), a GPS guided precision weapon. Flying from their base in Diego Garcia, they were used in the close air support role supporting ground forces in contact with the enemy. Both examples illustrate flexibility in operation of platforms originally designed for a single type of mission. This type of flexibility increases efficiency and effectiveness in two ways:[271]

1. Assets that might not otherwise be suited to the task at hand become productive in the air war and, as a complementary effect, the air component of the overall force is more effective;
2. Individual sorties are more efficient as well as effective, since fewer bombs are required to destroy a target and individual bombs are more likely to hit a target (more destroyed targets per sortie).

Having multi-skilled players (multi-functional systems) can provide competitive advantage by increasing confusion on the opposing side and increase ability to respond to uncertainties.

7.4 Flexibility at game level

The previous discussion focused on flexibility on defense, enabled by multi-skilled players, drawing a parallel to tactical missions in air combat. This section discusses in more detail how the Patriots leverage multi-skilled players on defense as well as how they provide flexibility at the game level.

7.4.1 Discussion of Defense configurations:

There are two main defensive layouts in the National Football League: 3-4-2-2 and 4-3-2-2. These numbers represent the physical layout of the players on the field in the order: linemen, linebackers, cornerbacks and safeties as shown in Figure 56. Viewing the layout this way enables us to see the structure of the defense and to visualize

[271] There is a key distinction between these examples and the examples of the Patriots. The Patriots' players have been specially chosen for versatility and trained for flexibility. These two military examples show flexibility driven by operational necessity *after the fact*, once the systems were fielded. This type of flexibility, driven by necessity, will always be a feature of complex systems and organizations, especially in combat. A prime motivation for this research is to understand the benefits of the type of flexibility demonstrated by these two examples so that decisions about flexibility can be made, *before the fact*. Many arguments over designing flexibility into systems center on cost effectiveness (efficiency) or inefficiency. As the information component of systems continues to increase and the performance attributes of *ensembles of systems* becomes of primary importance, it may become more operationally effective, and therefore cost effective, to design interoperability (flexibility) into these systems up front, rather than view flexibility as something that lowers overall performance of the system.

how the configuration can change as the players move between positions. These two layouts are illustrated in Figure 56.

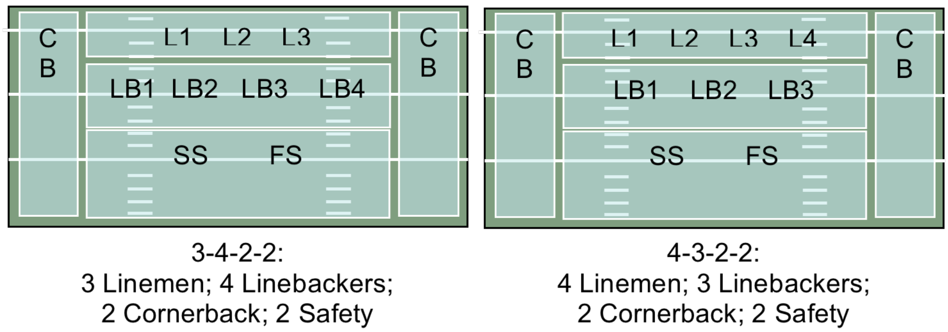

Figure 56: Defensive configurations

The 3-4-2-2 defense uses four linebackers and three linemen, while the 4-3-2-2 uses four linemen and 3 linebackers. The Patriots, by virtue of the ability of their linebackers to shift positions just before the snap of the ball can shift between these two configurations (and several others as well, for example a 3-3-2-3 or 3-2-2-4), making it difficult for the opposing quarterback to predict the weak points in the defense or to predict the timing or direction of blitzes (Price 2007) (Lavin 2005b).[272]

Using this approach, we can think about how the play is analogous to an air campaign. Knowledge of a lineup of players and their level of skill (intelligence) enables a team to craft an offensive game plan that exploits weaknesses in the defense. Similarly, for the defense, it is possible to look at the opposing offense and figure out whether a 3-4-2-2 or a 4-3-2-2 lineup is better. This is similar to developing a military campaign plan—allocating resources to missions with the objective of hitting the enemy at key places that give friendly forces an advantage.

But generally it is difficult to account for all variations that an offense or defense can create, or to predict what an enemy might do during an attack. So locking a game plan into a 3-4-2-2- or 4-3-2-2 defense may not be successful. Most teams address this issue by shifting their defensive configurations in between plays. The Patriots, with their multi-skilled players are able to increase the space of possible configurations beyond the

[272] Price (p. 116) in particular notes that realizing they could diffuse the blitz function throughout the defense (to the Linebackers) was a key factor in the Belichick-Pioli drive to begin acquiring multi-skilled linebackers.

two fundamental alignments and are able to switch among these alternatives quickly. For example, if the defense must swap out players between plays to shift from one configuration to another some difficulties arise:

1. The offense has time to recognize the defensive configuration and change their play;
2. The offense can play a no-huddle strategy, eliminating the ability to swap players;
3. The defensive coaches must predict the most likely approach an offense is going to take on the next play in order to swap out the "right" players.

With the multi-skilled player approach of the Patriots, these difficulties are mitigated. A shift in the defensive configuration can happen in real time—the linebackers can shift their position up until the last moment before the ball snaps. This gives the offense less time to react, confuses the quarterback about his most viable course of action as he tries to start the play. While the offense always retains the initiative (e.g., they choose when to start the play), flexibility gives the defense some initiative, always an advantage in competition.

There are three potential paths (alternatives) for an outside linebacker to occupy a position. Taking a geographical (spatial) view, we can see how the positions are laid out on the field and how players move between positions, increasing the possible combinations for

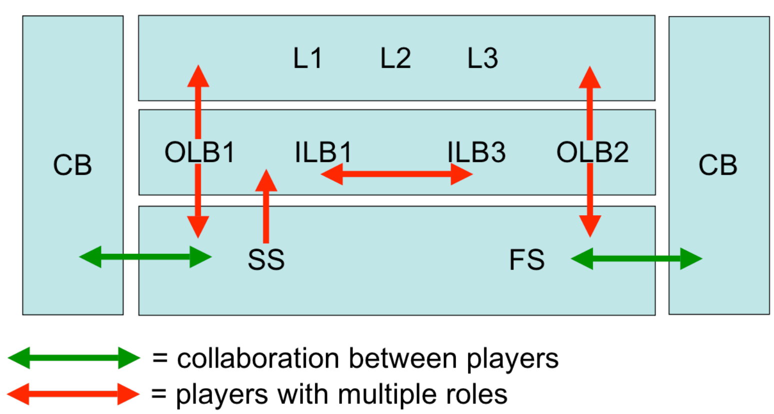

Figure 57: Defensive flexibility in action on Patriots' defense

defense in Figure 57:

Since decisions to shift the defense can happen in real time, leveraging the multi-skilled nature of the linebackers requires the coaches to give up a degree of play calling control to them. This analogous to Kometer's depth of command concept where, in order to respond effectively to unforeseen developments, decision-authority is delegated to lower echelons. This is particularly relevant to air-ground operations, where a lot of real-time adjustment must take place. On the Patriots, linebackers can coordinate and collaborate directly with each other and change the configuration of the defense. With depth of command, the air and ground forces can collaborate directly and change their configuration in response to emerging combat situations.

We can also see an analogy to time-critical/sensitive targeting operations, where aircraft are sent aloft (into the game) without a specific target assignment. When a time-sensitive target is identified (key defensive decision needs to be made from the sidelines), the AOC transmits the information to the aircraft (the coaches signal the defense to change configuration without player substitution).

7.4.2 Analogy to warfare

Football is not combat. It can be considered analogous to certain types of combat or warfare; by comparing certain aspects of the two, we hope to gain some insights to the implications of flexibility in complex operational contexts. In both activities, there are two sides and, in analogy to high-end warfare, they are commanded by a single person with a support staff to coordinate different aspects of the operation. Each side tries to out-maneuver, out-strategize and overwhelm the opponent. Strategically, player scouts interact with the general management staff with information about potential new players. Operationally, during practices and game plan development, coaches collaborate to build an integrated plan. In each case, either the general manager (Belichick), or the team coordinator (offensive, defensive) make final decisions. At the tactical level, we have seen how defensive flexibility can complicate the offense's problem. On the football field, the offense tries to break holes in the defense and sustain them long enough to move forward. On the offense, linemen and fullbacks break holes in the defensive line for the running back. They are like the Army. Wide receivers (WR) and tight ends (TE) also serve this function—they block, but they range farther into defensive territory than linemen and fullbacks (FB). So they are more like close air support in the AF when they fill this role.

WRs and TEs also can range deep in defensive territory, looking for holes in the defensive structure to catch the ball. These holes are often fleeting, because defensive players run to fill them when receivers arrive. There is a difference between football and the Air Force in this example. The receivers are not trying to *create* holes in the opposing structure, but rather to *find and exploit* them. Similar to the Air Force, the holes in the defense are filled rather quickly relative to a running play. Receivers are more like aircraft in another way: persistence. Many times, they will be tasked to block (like close air support, as noted above) but then will move on into a passing pattern. They block, behaving like artillery or close air support, but then move on, acting like attack aircraft.

7.5 Advantage and disadvantages of flexibility in football

7.5.1 Advantages

What becomes clear from an analysis of the Patriots' strategy of recruiting and training multi-skilled players is that it creates advantage at multiple levels of the game. We have seen that at the tactical level, which we classify as play-to-play and within individual plays during a game, the ability to change defensive configurations in real or near-real time adds complexity that the opposing quarterback must process while trying to execute his play.[273]

At the operational level, the level of the game plan and execution on a given day, multi-skilled players provide the ability to change the overall game plan by substituting players for different positions as the game unfolds and as the opposing game strategy and opposing team's strengths and weaknesses become known. Also, the ability to change players in response to injuries during a game and over the course of a season is operational level flexibility in the form of robustness to failure. This type of robustness might not be possible if the team had less bench depth from multi-skilled players. We

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[273] It is also worth noting that similar flexibility exists on offense, but in a different form. On offense, many different plays can be executed from the same configuration, so it is difficult for the opposing team to predict the upcoming play. Lavin notes (quoting Tom Brady), that offensive flexibility has a different character than defense, mainly because on offense there is a need to have what I will call "scripted flexibility" during passing plays due to the relatively short time the quarterback has to assess the developing situation and make a decision.

could take the calculation made in Table 8 and apply it to assessments of bench depth as well. NFL teams build rosters with multiple players at each position to support their overall competitive strategy, known physical vulnerabilities (potential for injury in a starting player) and other considerations. Because of the ability to shift players among different positions, multi-skilled players increase bench depth more than can be seen by simple inspection of the team's roster—it is a way to increase roster size "virtually".[274]

NFL rules on team size and player salaries are explicit constraints aimed at leveling team competitiveness. This is different than in warfare, where the objective is to exert control over the enemy, usually with force. Even though there is no league that levies constraints on resources in military competition, countries are nonetheless constrained in the resources they can devote to their militaries. Constraints such as the amount a country is willing to spend on defense, technological capabilities to design and field systems, and political considerations on use of force exert a similar effect to team size and salary caps of the NFL—competition occurs at multiple levels and along different dimensions of performance. Once constraints are established, the competitive problem becomes how to combine (design the structure of) the forces that are provided in order to gain competitive advantage.

In the industrial age, competitive advantage was generally dependent upon size of a country's military force and its ability to master the logistics of moving and supporting that force. In the information age, the source of competitive advantage is shifting to the ability to form of novel and innovative arrangements of forces—architectures.[275] Desert Storm was characterized by the use of overwhelming U.S. and coalition force against the Iraqi Army. In Operation Iraqi Freedom, force size was much more constrained. This, in combination with other factors, drove U.S. commanders to design their operations architecture differently than in Desert Storm—to use different organizational relationships and structures to gain advantage over the Iraqi army. This relationship

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[274] There is a parallel here with cross-service training and interoperability. It implies that sterile counting of force structure (size) might not convey crucial information that senior leadership needs for strategic decision-making.

[275] It can be argued that the attacks of 9-11 are an example of the use of novel arrangements of systems to create devastating effects.

between constraints and the ultimate designed structure is analogous to system design where cost, schedule and performance must be balanced by making choices among competing arrangements of components, subsystems and systems.

At the strategic level, the ability to maximize team level performance against a wide variety of opposing strategies from year to year derives in part from having multi-skilled players. Most other NFL teams choose to compete with a sizable number of "marquee" players, those who command very high salaries and starting bonuses. The market for multi-skilled players has not been as "hot" as the market for superstars.[276] Although the Patriots have marquee players (e.g., Tom Brady), they can hire multi-skilled players cheaper on average. Looking for multi-skilled players has two impacts:

1. The Patriots have more opportunities for finding the right fit for their upcoming season because they consider a larger portion of the NFL talent pool;
2. They look in segments of the talent market where there has been less competition from other teams.

The Patriots' emphasis on a "bundle of skills" in a player allows them to manage the team as a portfolio of skills against the NFL market (Lavin 2005b).

These points emphasize, though Lavin does not, that flexibility through a multi-skilled player acquisition strategy creates a cascading effect across multiple levels of the enterprise. It provides management and coaching staff more game strategy options within the constraints of the league rules regarding salary caps—options that are not available to teams with more traditional "single-skill/superstar" strategies.[277]

7.5.2 Disadvantages

An examination of disadvantages is also revealing. First, players have to work harder. Learning more than one position takes more time and physical and intellectual

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[276] Though the Patriots' success may be altering the market as some teams try to imitate this strategy and as some of Belichick's assistant coaches move on to head coaching jobs in the NFL (Price 2007 p. 260-3).
[277] The tradeoff between salary cap limitations and team size is complex and beyond the scope of this analysis. The maximum playing roster size is 53; the salary cap rules are complex enough that teams can "game" the system by deferring some bonuses or shifting some incentive pays in ways that keep the salary computation below the cap, but still allow significant compensation to some players. Adjustments to rosters must always be made to comply with these constraints by the time the season starts. Conceivably a multi-dimensional optimization model could be crafted that compared this trade-off with the additional variables of single- vs. multi-skilled players.

effort than honing skill at a single position (Lavin 2005a; Price 2007). Also, multi-skilled players are generally not as strong in their position as a traditional single skilled player—so there are skill level deficiencies that must be compensated for by teamwork on the field and by management attention to training routines.[278,279] To capitalize on the flexibility of their players, management must also work harder. Teaching, training, keeping track of progress of players in multiple or new positions requires time and effort. Developing plays and strategies that capitalize on multi-skilled talent also requires deeper and more detailed planning. It is a simple matter of numbers—there are more things to track.

A second disadvantage comes in the area of errors. As we noted above, to capitalize on the benefits of multi-skilled players and the investment in training that must be made with them, coaches must give up a degree of control over game play. This is likely to result in mistakes, possibly more errors than if more plays were called from the sidelines. The likelihood of these mistakes can be mitigated or lowered by training, learning, and team building (trust) and must be balanced with the probability of ineffective plays coming in from the sidelines because of time delays and inaccurate or incomplete assessments of the situation on the field.

This last disadvantage and the means to mitigate it have a direct analog in military operations and specifically in Kometer's depth of command. If an investment is made in a flexible skill set, in order to reap the benefits of this investment, the skills (options) must be leveraged in appropriate situations. Since it is impossible to forecast all possible situations and script responses *in detail*, if the multi-skilled talent set is to respond effectively to the opposition, decisions must be decentralized in some cases.[280]

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[278] Lavin repeatedly notes the tough and challenging nature of Patriots' practices and of the intellectual preparation for the season and for each game, citing multiple sources, from players to coaches.

[279] This trade-off may be more general. In integral vs. modular technical systems, a similar trade-off exists. If a system is built from modules with the goal of making many different system configurations (product models) by substituting modules, you do not get the best results unless each module is over-designed so that it can match any combination of other modules. Generally, an integral system can be designed to suit its requirements better than a modular one, but it is usually hard to modify. (This observation was made by Dr. Dan Whitney).

[280] There is an important distinction here between football and military operations. The game in football is well understood, the skill sets well defined and the rules transparent to all participants. The challenge is in choosing and applying the right mix of skills. My observation in this paper is that advantage can be gained

7.6 New England Patriots: Multi-skilled strategy drives salary structure

The New England Patriots have used flexibility to achieve a higher payoff with a lower payroll per player skill compared with much of the rest of the NFL. Though saving money is not an explicit goal, good stewardship and maximization of value per dollar spent is a goal. The Patriots' value function, based on sports reporting, is different than other teams. By concentrating on "skill bundles" and primarily on player value in the context of the team instead of skill level at a single position (and the value of that position in isolation from the team) the average quality of the Patriots as a team is probably higher than league average—higher than the salary cap would allow otherwise (Lavin 2005b). So we have a paradox: team level (global) performance per dollar is enhanced by the acquiring 'inefficient', though talented, players (local).[281]

This section continues our focus on structure, but from a different perspective. The salary strategy of the Patriots creates a three-tiered structure (based on salary) where many other teams, relying on superstar players, have a two-tier structure (some teams have only a single tier of salaries). In an environment where salary resources are capped and a team focuses on hiring superstar, "marquee" talent, there is little room left to pay the "non-marquee" players. In this situation, there are a handful of extremely highly paid players with most of the team getting paid relatively lower salaries.[282] It is logical to argue that if a team relies less on superstar talent and more on multi-skilled players that the prevailing market does not value as highly it can pay more players more generous salaries. Though there are a multitude of factors that go into team cohesiveness, a more "level" salary structure is likely to improve this intangible aspect of advantage. The Patriots salary structure is empirical support for the stated and observed practice of Belichick and Pioli to choose moderately valued players.

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through the intelligent insertion of flexibility to the team. In military operations, the skill set is much more varied and sometimes the appropriate skill or mix of skills for a given situation is unknown. The recent need for counter-insurgency operations and the associated skill sets in Iraq is an example. The natural uncertainty of military operations and the apparent increasing uncertainty as we move into the 21st Century only serves to highlight the need for flexibility in the Department of Defense. My thanks go to Dr. Dan Whitney for pointing out the need highlight this distinction.

[282] It is important to note that the minimum starting salary for a rookie NFL player was $285,000 in 2007.

A look at the 2007 salary data for the Patriots is shown in Figure 58.[283] Using a

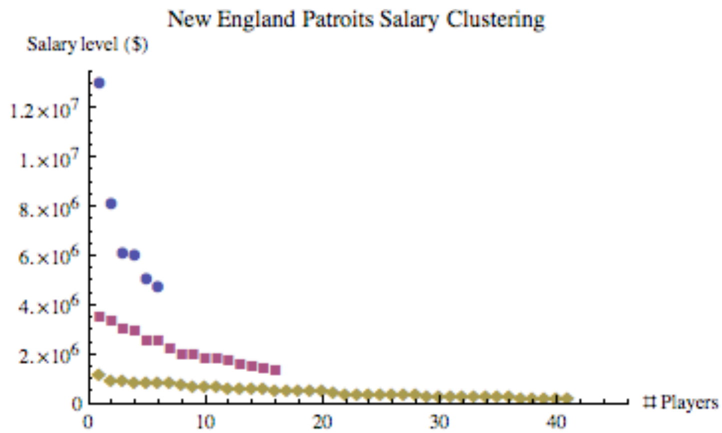

Figure 58: Patriots' salary structure

clustering algorithm embedded in Mathematica™, the tiered salary structure is shown along with a table of the salaries by player:

PATRIOTS 2007 SALARIES				
Rank		Player	Salary ($)	Cluster Avg Salary ($)
1	LB	Adalius Thomas	**$13,006,720**	**$7,147,033**
2	DL	Ty Warren	**$8,080,640**	
3	WR/TE	Wes Welker	**$6,106,720**	
4	QB	Tom Brady	**$6,005,160**	
5	WR/TE	Kelley Washington	**$5,006,720**	
6	RB	Laurence Maroney	**$4,676,240**	
7	OL	Matt Light	**$3,505,160**	**$2,198,127**
8	??	Kyle Brady	**$3,306,720**	
9	WR/TE	Randy Moss	**$3,001,560**	
10	RB	Sammy Morris	**$2,956,720**	
11	LB	Mike Vrabel	**$2,550,840**	
12	RB	Kevin Faulk	**$2,506,720**	
13	DB	Fernando Bryant	**$2,253,360**	
14	WR/TE	Chad Jackson	**$2,014,420**	

[283] Salary data for 2007 was retrieved from the Fox Sports News website, http://msn.foxsports.com/nfl/teamSalary?categoryId=67054. Note that the salaries listed here are single year figures that include bonuses and other annually paid performance related compensation, not comprehensive package totals, which for some players is much larger.

15	DL	Jarvis Green	**$2,005,640**	
16	OL	Stephen Neal	**$1,806,720**	
17	OL	Oliver Ross	**$1,804,800**	
18	LB	Tedy Bruschi	**$1,706,120**	
19	DB	Brandon Meriweather	**$1,540,000**	
20	DB	Rodney Harrison	**$1,530,252**	
21	DB	Jason Webster	**$1,381,320**	
22	DB	Lewis Sanders	**$1,299,680**	
23	??	Chad Scott	**$1,236,720**	**$559,305**
24	OL	Dan Koppen	**$1,006,720**	
25	LB	Junior Seau	**$1,000,840**	
26	OL	Billy Yates	**$866,720**	
27	LB	Larry Izzo	**$865,160**	
28	WR/TE	Marcus Pollard	**$863,360**	
29	??	Troy Brown	**$860,000**	
30	RB	Heath Evans	**$845,840**	
31	??	Mel Mitchell	**$731,720**	
32	OL	Lonie Paxton	**$725,640**	
33	DL	Richard Seymour	**$706,720**	
34	WR/TE	Sam Aiken	**$678,360**	
35	DB	Tank Williams	**$635,000**	
36	OL	Russ Hochstein	**$626,720**	
37	WR/TE	Jabar Gaffney	**$626,700**	
38	DL	Vince Wilfork	**$605,160**	
39	K	Chris Hanson	**$595,000**	
40	LB	Victor Hobson	**$595,000**	
41	DB	Benjamin Watson	**$566,120**	
42	OL	Gene Mruczkowski	**$535,000**	
43	OL	Logan Mankins	**$505,640**	
44	LB	Eric Alexander	**$441,720**	
45	DB	James Sanders	**$441,720**	
46	QB	Matt Cassel	**$440,640**	
47	DL	Mike Wright	**$440,640**	
48	DB	Ellis Hobbs	**$440,160**	
49	OL	Nick Kaczur	**$440,160**	
50	??	Marcellus Rivers	**$420,000**	
51	WR/TE	David Thomas	**$366,720**	
52	LB	Pierre Woods	**$366,120**	

53	OL	Wesley Britt	**$365,640**	
54	K	Stephen Gostkowski	**$365,640**	
55	DL	Le Kevin Smith	**$365,640**	
56	??	Willie Andrews	**$365,160**	
57	OL	Ryan O'Callaghan	**$364,680**	
58	QB	Matt Gutierrez	**$295,000**	
59	DL	Steve Fifita	**$285,000**	
60	DL	Santonio Thomas	**$285,000**	
61	DB	Mike Richardson	**$276,000**	
62	??	Oscar Lua	**$253,000**	
63	RB	Kyle Eckel	**$234,706**	

Table 9: 2007 Patriots salaries ranked and by cluster

Clustering functions can give different results depending on the particular settings of the algorithm. In order to avoid this dependency, the Mathematica™ FindClusters algorithm was run with a range of possible settings. The clustering of three groups of salaries for the New England Patriots was the most consistently generated clustering arrangement. It was also with the most reasonable settings on the algorithm (simplest distance calculation function). In addition, the clustering algorithm was applied to the 2007 salaries of the rest of the NFL. Of these teams, only two rosters generated salary structures similar to the Patriots: the Miami Dolphins and the Houston Texans. These teams have structures with 3.48 and 3.9 levels, respectively, indicating a similar strategy to the Patriots.

7.7 Is flexibility worth it?

This is the grand question. As controversial as the Patriots are, and as narrow and brief a look at them as we have taken, it appears, in the context of the National Football League rules, that multi-skilled players enable creation of a dense set of interdependent advantages that outweigh their seeming disadvantages. There are myriad factors that contribute to the success of the Patriots:

- Strategic ‘genius’ of Bill Belichick;

- Belichick and staff's coaching style and team-building skills;
- The competence of his staff;
- The work ethic and work environment created by the combination of Belichick, his staff, the players they recruit and the team's owners;
- Mutual trust between players and coaches, especially between backup players and their position coaches
- The intangible aspects of the team that create a commitment to it on the part of the players, even though they do not earn a salary level that some of them might earn elsewhere in the league.[284]

The list can go on. But overall, it appears that the strategic choice of creating options through flexibility is _a_ central feature of the Patriots' advantage, the cost is something that all participants are willing to bear and that flexibility is observable in the structure of the team along at least two dimensions (salary and defensive game play). The payoff, according to many of the citations in Lavin's account of the Patriots is, simply, winning football games.[285]

As 2008's Super Bowl results show, it is clear that flexibility is not a silver bullet.[286] Flexibility alone cannot guarantee a win. It is only one part of an integrated, strategically chosen, systematic, and *multi-level* approach toward the game of football. The main constraint is the League salary cap.[287] In the face of a rule designed to prevent the emergence of 'dynasty' teams like the Dolphins, Cowboys and Steelers of the '70s or the '49ers and Cowboys of the '80s and '90s, Belichick has crafted a strategy, reflected in the structure of the team, which created sustained advantage. Multi-skilled talent and flexible structures appear to be a key ingredient of this success.

7.7.1 Efficiency considerations

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[284] It is difficult for most entry-level players (rookies) to earn large starting salaries, except some of those chosen near the top of the first round of the draft. But once a player establishes a reputation and demonstrates longevity in the league, NFL rules give them bargaining power. Also, NFL salary structures are complex, making comparisons difficult. The observed phenomenon on the Patriots is that players who could demand (and receive) higher salaries elsewhere often choose to stay at New England.

[285] Again, this metric is very clean, clear and unambiguous. This is in stark contrast to warfare, where success metrics can be highly subjective.

[286] The 2009 season is another example. However, it is not an indictment of flexibility; in their early season loss to Miami, the Patriots' defense was *not flexible enough*, as inferred by the following quote from Rodney Harrison: "they caught us by surprise. We tried to make adjustments. We still didn't stop it. We tried to make more adjustments, and we still didn't stop it." (Reiss 2008a)

[287] Free agency, the order of draft picks and balanced scheduling are also factors the League uses to level team capabilities and generate even competition.

We have reviewed the advantages, disadvantages, and structural implications of a multi-skilled approach. But is it efficient? During a football game, (tactical level) both sides have the same level of physical resources (11 players on the field, a maximum allowable team roster). In addition, the NFL rules constrain team salary levels, so that all teams are equal in terms of the maximum amount of money they are allowed to spend on skills (playing talent). The Patriots use this salary constraint to advantage by hiring players that are flexible—in effect increasing team-level efficiency under this resource constraint (having more skills per player or per dollar salary). During game play, the Patriots' defense uses this flexibility to confuse the opposing offense with many different possible configurations (complexity).

On the face, multi-skilled players are inefficient—they are less effective at their position than single-skilled, "marquee" players. But in a game strategy like the Patriots, they are highly efficient---there are more skills per dollar salary, they are effective against a wider array of opposing strategies and the team overall is more successful over time (at least, the Patriots are). Adding a multi-skilled player, as noted earlier, increases the depth of the team's roster without increasing its size. From a skill maximization perspective, this is efficient—more possible output (number of available skills) for the same input (size of the team).

A secondary issue regarding flexibility is the additional coaching and training burden required to leverage the talent of multi-skilled players. At the level of the total team organization this seems inefficient. The management and coordination required to leverage multi-skilled players is larger than for other strategies. The Patriots' coaches must work harder than other teams for the same or fewer salary dollars.

This burden flows to the players as well. The increased number of play configurations possible with multi-skilled players creates additional interdependencies within the overall team that must be managed and understood in depth, in addition to the larger number of plays that are likely to be developed. For example, multi-skilled players must have a better understanding of the roles and responsibilities of other nearby positions, enabling them to understand what the other player might do in a new situation (Lavin 2005b).

There are two obvious benefits of the multi-skilled approach. First, it makes multi-skilled player teams more robust to the loss of a player. Second, the increased understanding by players of interdependencies among positions makes the team more robust to innovative strategies of other teams.

7.8 The 2008 Super Bowl and 2008-2009 Season

The basis for our analysis of the Patriots as an exemplar of the virtues of flexibility may be called into question, given their 2008 loss in the Super Bowl to the New York Giants and their failure to make the NFL Playoffs this year. We must remember, flexibility is not a silver bullet—it is not assurance of success. It is a tool to be used by management (in this case Belichick and his coaching staff) as a way to gain advantage in the highly competitive environment of the NFL. The factors of chance still play a role in the game. That said, the 2008 Super Bowl was not decided until the final seconds of the game—the Patriots almost won.[288] This past season, despite the strategy to increase bench depth by having multi-skilled players, there were many injuries. Beyond a certain point, even the benefits of being flexible cannot overcome resource constraints. It is also notable that, in the most important position on the team—quarterback, the backup worked exceptionally well. While this is not an example of flexibility via multi-skilled players that we have emphasized, it is an indication of an overall philosophy of ensuring that all players are ready to step in when needed. In addition, it is also possible that teams have learned how to adjust to the Patriots' overall strategy, thus lowering the potential advantage of it. While this thesis requires more detailed investigation, the recent departure of Scoot Pioli, along with other Belichick protégés that have diffused throughout the NFL is indication that the multi-skilled player philosophy, and knowledge of how to counter it are not unique advantages anymore.

7.9 Summary analysis

There appears to be a fundamental strategic choice in the game of football, a competition characterized by largely symmetric resources in terms of quantity (roster size and salary levels) and with well-defined game rules. Winning with a team composed of a

[288] It is also important to note the many times where the Patriots won very late in the game in both the 2007-2008 season as well as others.

few single skilled, highly paid players that afford little flexibility toward unforeseen strategies and events, or winning with a team composed of a mixture of medium-salary multi-skilled players and a few exceptionally skilled and highly paid superstars. Though arguments can be made in favor of either approach, the success of the New England Patriots using the second is compelling. In an environment when the differences in skill level are marginal, and most game strategies based on leveraging these highly skilled players, the increased flexibility of a multi-skilled approach provides a competitive edge. It enables a higher likelihood of having a season-long ability to counter a wider variety of game strategies with the same team size and salary constraints as the 'superstar' strategy.

This chapter has examined the architecture and the tradeoffs to flexibility we explored in Chapters 5 and 6 in an unrelated but analogous example, the New England Patriots football team. While the analogy to combat and multiple levels of warfare are not perfect, the main purpose here is to examine the generalizability of the ideas in Chapters 5 and 6. We found that, using a different abstraction than in Chapters 5 and 6, at the level of game play (tactical level), flexibility in players can be leveraged to gain advantage in a symmetrically constructed competitive situation.

In this case, we focused mainly on flexibility in space and time. For the Patriots, defensive linebackers can move across different depths (levels) in the field to confuse and respond to the offense. Flexibility in the form of multi-skilled players in combination with strong teamwork and empowered action on the field provides temporal flexibility—being able to shift function in the defense quickly. Though we did not address this aspect of military operations in depth, having multi-role aircraft can provide a similar kind of flexibility. An aircraft with appropriately flexible systems and crew can provide up close attack/defense, or can range successively deeper into the enemy's battlespace. Moving the location of decisions deeper in the command hierarchy (depth of command), coupled with better teamwork (lateral connections) can create spatial and temporal advantage similar to the one we explored with the Patriots.

The trade-off analysis is also similar to military campaigns. The Patriots have chosen to compete within the constraints of the National Football League's salary cap and roster size by using multi-skilled players. We find that this choice permeates to almost every aspect of the team and provides benefits in the form of enterprise level competitive advantage.[289] We also find that computing the cost of this advantage is difficult. There are indications that the Patriots team and management work much harder than other teams.[290] The teamwork necessary to leverage flexibility of multi-skilled players is high and mandates a lot of training, practice and study on the part of players—indeed it requires a different team culture (Lavin 2005b). Is this a sign of increased efficiency, or increased effectiveness? It depends on our analytical perspective.

A take-away from this chapter and from Chapters 5 and 6 is that flexible architectures cannot be examined using traditional frameworks that only consider output metrics in isolation from system level properties, the operational environment and the chosen competitive strategy. Evaluation of the trade-offs is contingent on these factors and inclusion of them into the analysis provides insights to the costs and benefits of flexibility that are obscured by a traditional focus on efficiencies and outputs (rather than effectiveness and outcomes).[291]

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[289] Players who could earn more money on the larger NFL market remain with the Patriots because of the work environment as well as to participate in the main enterprise level advantage (winning football games) (Lavin 2005a; Lavin 2005b).

[290] We do *not* mean to imply that other NFL teams do not work hard.

[291] This is a theme that is also seen in recent writing on evolving Internet architectures, though in our view, the idea is not stated as explicitly as we state it here (Clark et al. 2003).

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Chapter 8

Summary, Conclusions, Future Work

8.0 Introduction

This research has been exploratory. We have considered an architectural model of flexibility in operational contexts. It is easy, when focused so intently on a problem for so long to imagine that every other problem one sees is amenable to the newfound "hammer" that was developed in the process of research; that we have a "silver bullet", an ultimate (and easy) solution to all problems (Brooks 1987). We are under no illusions in this regard. We don't think this framework is a universally applicable or all encompassing answer to enterprise architecture and to the operational design of enterprises. We do, however, think it has relevance beyond the comparatively narrow scope in which we have applied it. We think that the framework, model and insights gleaned in this study can be applied more generally to non-military operational contexts as well as to large-scale commercial or public sector development projects and defense acquisition programs.

8.1 Summary and review

This thesis has addressed an emerging and increasingly pressing problem: design and operation of enterprises for operational environments that demand flexibility. Military operations have always been multi-organizational and there has always been a requirement for flexibility, even if throughout most of history flexibility took a back seat to massed forces.[292] In the past, the number of communication channels, sources of information and control paths (or modes) in operations were relatively limited. Our emerging problem is that these factors are all increasing, raising the complexity and number of organizational interactions in a military operation while at the same time the number of organizations that can influence or have a say in the operation is expanding beyond purely military and political ones. We have taken a conceptual approach from computer science to address the analytical challenge of understanding of enterprises and

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[292] The Roman phalanx was an effective, but not flexible, form. The Romans eventually created the legion, which supplemented the phalanx with cavalry and light infantry in order to gain flexibility. They continued using the phalanx as a tactic and as an organizational component of the legion.

their properties. Specifically, we build our framework on the idea of layered hierarchical architectures. This idea is grounded in the use of layers of abstraction to manage complexity in complex information processing systems. We view enterprises as operating at multiple layers of hierarchy, where layers are defined by the nature of information and decisions made at a particular level of hierarchy—the abstraction at which activity occurs. Higher levels of abstraction usually deal with more complex issues on longer time scales than lower levels; higher levels often contain personnel who are more senior in rank than lower levels as well (though this is not always the case). Many approaches to enterprise architecture take the time tested multiple-view approach, one derivative of the field of civil architecture, and used with great power in information systems design (Kruchten 1995; Zachman 1999; Board 2000). This method looks at an enterprise through differently dimensioned lenses, aiming to make it amenable to systems engineering design methods—making the enterprise an engineering object.[293] Multiple views help us understand detailed design and gain a comprehensive understanding of a complex system. They do not tell us what to design. We lack an understanding of how enterprise architecture relates to desired system level properties (such as flexibility).

We have taken a different approach. Our focus is on design of *architectures* as a distinct activity, separate from detailed system or organization design, as is often done in computer science (Amdahl and Blaauw 2000). Specifically, consideration of the operational need for certain system properties, such as *flexibility*, in the design of an enterprise architecture can help us with design, operation and management of these complex systems. In Chapter 4, we reviewed architecture concepts across different technical domains. We found that descriptions of architectures, by necessity, take on a more abstract meaning as systems become more complex. We also found that there is a distinct difference in the way that architectures are conceived for mechanical systems compared to information systems. Information system design is characterized by a more frequent use of abstraction, with architecture acting as guidance for specific system design decisions and for longer range decisions that drive the evolution of an existing

[293] This is consistent with the approach taken in IEEE STD 1471-2000, IEEE Recommended Practice for Architectural Description of Software-Intensive Systems.

system. The ability to use architecture as a guide for design of specific implementations of systems implies that we can design them to have specific properties. Architectures need not be simply by-products of a design process that delivers systems with specified functionality or worse, the *ad hoc*, "emergent" result of unguided, undirected decisions made on a contingent basis without an overarching set of guidelines.

We chose to examine this layered hierarchical approach by extending previous ESD research on combat air operations (Kometer 2005). Kometer took a process approach to the implementation of policy. We extended his work by examining a simplified version of his process through a hierarchical lens, viewing the overall system as an input-output device. Our purpose was two-fold:

1. to test the architecture analysis framework;
2. to examine closely the relationship of architecture to enterprise level flexibility.

We reviewed Kometer's work and noted that, while providing highly practical guidance for planning and operating, it lacked an overall framework in which to design or evaluate enterprises architecturally, specifically with respect to flexibility. Our review of four military campaigns using an architecture framework has highlighted the hierarchical structure of combat operations, and provided us insight into the relationship between structures and system level properties.

8.2 Results and Contributions

What have we learned? Architectural analysis of four military campaigns from 1991 to 2003 has shown us that hierarchical architectures with lateral interactions at multiple levels are more flexible than traditional tree-structured hierarchies. In all of the campaigns, in order to gain the flexibility necessary to accomplish missions, lateral interactions at the tactical level either developed *ad hoc* or were created by command direction after the start of the conflict. We also noted that without lateral connections at higher levels in the hierarchy, lower level interactions could contribute to loss of coherence.

We also noted that layer violations (e.g., micro-management of tactical issues from the strategic level) could result in unintended outcomes such as confusion and poor or unexpected responses from the system. This is not new and unique; the costs of certain types of top-down intervention are well documented through both research and experience. What we have learned is that there are natural reasons for this effect, which originate in differences in the level of abstraction at which different layers of an enterprise operate. Because enterprises exhibit all of the characteristics of complex systems, such as non-linearity, unpredictability and resistance to classical forms of control, it is natural that we should see these types of problems with layer violations. Our approach accepts enterprises as complex systems that exhibit these characteristics and views them as amenable to design if we take an architectural perspective. Our research shows us that there are logical explanations for and interpretations of these consequences, which is a different view than explanations that rely on emergence and surprise. We offer a framework that can increase appreciation for the costs and benefits of crossing many organizational layers in complex operations.[294]

To achieve strategic alignment, we find that lateral interactions *at higher layers of the enterprise are important to enabling strategic coherence*. In a manner similar to Alfred P. Sloan's organization of General Motors, the addition of lateral connections among leaders of the enterprise (not just their staffs), improved enterprise level flexibility, particularly in Operation Iraqi Freedom.[295] We also noted that where lateral interactions at higher layers failed, did not exist, or were by-passed, either operational problems developed or flexibility was inhibited as either the internal or external environment changed. Examples are pervasive. Operation Desert Storm, the first "Joint" military operation, lacked inter-service connections at multiple layers, but particularly at the senior leadership level. This disconnected layer in the architecture inhibited

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[294] It is important to note that not all operational instances of "layer violation" are negative. There are important instances where violation of layers in an operational situation is necessary to manage risk levels or shorten timelines.

[295] There is a related issue here, which is the dynamic among key leaders in the enterprise and how this dynamic affects the overall architecture of the enterprise and its evolution. This dynamic is evident in the reports and accounts of Operation Desert Storm and Kosovo but is in the background, not yet addressed analytically. An examination of this subject and its implications for the Air Force as an institution can be found in Warden's *The Rise of the Fighter Generals: The Problem of Air Force Leadership, 1945–1982* (Worden 1998).

operational choices (flexibility) and affected the evolution of the overall operational architecture of the campaign (Atkinson 1993; Roberts 2006).[296] In Afghanistan, the lack of fundamental alignment (interactions) among the senior leadership and their staffs late in the major operations part of that campaign contributed to operational difficulties encountered during Operation Anaconda in March 2002 (Davis 2004; Kometer 2005).

We conclude that, in uncertain and/or fast moving operations, *lateral interactions at all layers* are a necessary ingredient for operational and tactical flexibility while maintaining overall strategic coherence (alignment).

8.2.1 A new perspective on enterprise architecture

Our framework provides a valuable new way of looking at the very challenging problem of enterprise architecture. Many studies look at micro-scale interactions for precise causal relationships that impact specific system outputs. These approaches rapidly succumb to overwhelming complexity in description, analytical intractability and conflicting recommendations for action. We have taken a holistic view that examines fundamental properties of a system (in our case, flexibility) and their relation to architecture. We have seen that an architectural framework that explicitly considers lateral and vertical aspects of interactions and their impact on performance provides a valuable analytical tool for understanding enterprise flexibility. It also provides a useful supplement to traditional tools available to senior leadership when considering enterprise-level management challenges. While it is too early to implement a computer-driven simulation model to support design decisions, with further development, higher fidelity data and more operational case studies our framework may support development of a tool such as this for future enterprises. A simulation tool, if developed might consider the following aspects of enterprise architecture:

1. Length of action sequences, accounting for hierarchical differences;
2. Variation in location of inputs and how they impact (1) as well as the number of potential action sequences (paths);

[296] There is an argument to be made that these relationships (or lack thereof) were the real driving forces of the overall enterprise architecture. Delving into this issue is beyond the scope of this research and is left for future work.

3. Different levels of lateral vs. random shortcut interactions as a way to explore more comprehensively the potential benefits of explicit design over *ad hoc* actions;
4. Information passage probabilities—how the architecture impacts the flow of information across distance parts of the enterprise, given a hierarchical structure and assumptions about difficulty of crossing both lateral and vertical boundaries.

8.2.2 A principled approach to "Jointness"

Since passage of the Goldwater-Nichols Act in 1986, the Department of Defense has been moving slowly toward higher degrees of inter-service cooperation, something colloquially termed "jointness." Though much ink has been spilled, a lot of effort expended and many claims of success heard, there are still many challenges to achieving truly joint operations and interoperable systems. The difficulties of achieving flexible air-ground operations we discussed in Chapter 5 are only one example. We have exposed one aspect of joint operations that may have some significance—lateral connections at multiple hierarchical levels. Though some connections at high levels have been created in response to lessons learned (the Air Component Coordinating Element of Operation Iraqi Freedom), the architectural aspects of these connections have not been fully explored or appreciated. Our architectural perspective provides a framework within which we can view numerous issues of relevance to jointness.

8.2.3 Connection between strategy and structure

The connection between strategy and structure is well known, as is its importance to competitiveness particularly in manufacturing contexts (Chandler 1990; Ulrich 1995). In defense settings, this idea seems underappreciated.[297] Our research specifically addresses this issue by examining the overall strategic and operational approach of the

[297] There have been many recent criticisms of strategic thinking (or lack thereof) in the US military and national security establishment (Bacevich 2008; Watts 2008). Our cases have shown that most military officers aim at the personnel level and may be more prone to letting the organizational structure organically evolve (Mandeles et al. 1996).

U.S. to various cases then examining the structure of the enterprise that executes the operation as an implementation of the strategy.

8.3 Future work

We have attempted to take a new approach to emerging system-level problems that have proven routinely challenging, often intractable and that usually demonstrate surprising or counter-intuitive behavior and outcomes. Enterprises are a new form of organizing; taking an architecture design perspective to them is also new. There are two areas of future work for this thesis. First is to continue to develop and refine the framework and the enterprise architectural concepts of laterality and flexibility, with the goal of moving toward more concrete metrics that capture structure, flexibility and other properties. Second is to explore the generalizability of the framework by studying architectures of other complex systems and enterprises in other operational contexts.

8.3.1 Framework development

The foundational thinking for the architectural framework used in this thesis—the idea of layered hierarchical architectures is a new approach outside of computer science. Though military operations have been viewed and conducted at multiple levels of abstraction for decades, explicit design of multiple organizations operating at multiple layers *with the goal of attaining desired system level outcomes* has not been a general practice.[298] We conducted a first order test of the approach on a limited set of military operations and found support for the theory that lateral interactions at multiple hierarchical layers enable overall enterprise flexibility while retaining the ability to maintain strategic alignment. More case study analysis is necessary to test the limits of this framework.

8.3.2 Apply the framework with other methods

8.3.2.1 Design Structure Matrix

Other systems analysis methods and approaches might be enhanced or extended by this framework. Design Structure Matrix (DSM) methods have been used to examine

[298] This idea of a general architecture, or theory, is the subject of RADM J. C. Wylie's *Military Strategy: A General Theory of Power Control* (Wylie 1989), discussed in Chapters 2 and 4. Crafting architectures at the enterprise level is one method of moving toward true "Jointness" in military operations.

the efficiency of product development processes and management. The major application focus of this method as been on efficiency—identifying iterative feedback loops with the objective of reducing or controlling them to improving design process performance. Some recent applications of the DSM approach identified management issues for efficiency of team interactions at two different levels (Yassine et al. 2003; Sosa et al. 2004). Sosa, et al. do not address organizational performance issues in their analysis, nor do they address more than a two level architecture.[299] Applying the DSM method to more complex systems and enterprises, integrating it with our hierarchical perspective, and examining *flexibility* would be an interesting and valuable contribution to the product development literature on fast-moving industries (Iansiti 1995; Galunic and Eisenhardt 2001; MacCormack et al. 2001). Merging DSM methods with our hierarchical framework may also yield benefits to complex and innovative new product development projects such as the Boeing 787, where the business model involves technical design and development, finance and product services as aspects of the value delivery proposition.

Related to DSM approaches, the work transformation matrix framework takes a dynamical systems perspective on product development and examines system convergence or divergence characteristics from development team interactions (Yassine et al. 2003; Huberman and Wilkinson 2005). Again, these approaches usually aim to understand how development processes can be made more efficient or to identify critical interactions for management attention, not to design the enterprise *ex ante* to have specific property that enables delivery of a desired outcome. Taking these approaches and applying them to larger scale systems and to enterprises with an eye toward flexibility may add a useful tool for the emerging class of large-scale projects and program enterprises.

Examining the hierarchical structure of social networks in the context of enterprise architecture is another area that might benefit from the ideas in this thesis. There is some evidence in our research and in some emerging areas of social science that suggests certain classes of social interactions may be key to understanding how large enterprises operate and evolve. Understanding how these interactions influence the

[299] Development teams and systems integration teams.

flexibility properties of the overall enterprise may provide insights for enterprise transformation and change practice and research efforts.[300]

8.3.2.2 Multi-Disciplinary Optimization (MDO)

Paths are a measure of flexibility, but the number of connections between nodes is a measure of complexity. A hierarchical tree is relatively simple and usually grows exponentially as problems get larger, but has a low level of complexity compared to the number of its nodes. Fully connected networks are complex, have short paths between nodes and have a high average degree. The average number of edges per node (average degree) can be used as a measure of complexity and paths per node a measure of flexibility. It may be possible to formulate the enterprise architecture problem using these simple metrics and explore the trade-off or optimization metric that could support an MDO design-oriented research approach to enterprise architecture.

8.3.2.3 Real Options, Operational Options

As we have defined flexibility, it is a measure of the capacity of an enterprise to adjust to changing requirements for its performance. In general, high switching costs in many mechanical systems argue against high flexibility in these systems. In these types of systems, cost of flexibility in the context of known or projected uncertainties define the key design challenge. This is the motivating force for application of options analysis to physical systems (real options). Designing enterprise architecture to be flexible is a form of option creation. Enterprise flexibility that can be called upon when necessary represents an option for the senior leadership of an enterprise. For example, in the New England Patriots, training players in multiple positions represents an option that is evaluated on an ongoing basis and exercised when needed (i.e., an injury to another player).

The key challenge in real options analysis is valuing the option—creating a metric that can quantify both the cost of flexibility and a metric that can quantify the risk (usually very difficult, especially in operational combat situations). Understanding how

[300] Applying this framework to some of the Inter-War years military innovation efforts, such as the development of carrier aviation or development of War Plan Orange might prove very instructive.

our framework can be mapped to real options analysis so that it can support enterprise architecting would be another valuable extension of this work.

8.3.3 Developing enterprise design guidelines

Our analysis has given us some initial clues as to some important issues for design of enterprise architecture. We can start with an examination of how different layers of an enterprise interact with each other. In developing computer systems, the articulation of the abstraction is an important part of the design process. In designing enterprises, it might be helpful to articulate the abstraction. For example, while military operations typically operate at three hierarchical levels (strategic, operational, tactical), they also are typically divided by operational medium (air, land, naval). Other abstractions, such as functional ones (logistics, strike, maneuver) are not used, but it might be helpful to explore these types of breakdowns.

Based on our findings, another design (and management) guideline is to pay particular attention to interactions instead of individual actions. It may be more important for senior management to know who is interacting with whom than it is to examining the tangible work product of a process (Note: we do *not* imply that work products from processes are not important or critical to enterprise performance).

8.3.4 Generalizability to other systems and operations

8.3.4.1 Other military operations

A more robust and detailed examination of military operational architectures should be undertaken to explore the premises of this framework more fully and with richer, higher fidelity, data. Deeper investigations of Operations Anaconda and Tora Bora in Afghanistan from an architectural perspective may shed more insight to consequences of architecture for performance of the overall system beyond the first order observation (in hindsight) of the need for cross-organizational communication. If operational commanders had been able to view how well the organizations involved in these operations were connected (and which ones were not) operational difficulties may have been avoided or potential trouble spots identified for closer monitoring.

It is important to reiterate that the lateral interactions we have focused on will not obviate the need for attention to detail, leadership and plain good sense and initiative. We do not imply that our approach makes enterprise design and management easy. Our point is that inadequate attention is paid to interactions within hierarchical layers. Correction of inadequacies in formal structures and processes are often left to chance and existing formal mechanisms are assumed dysfunctional or, as was the case in Operation Anaconda, they are assumed to be of such lesser importance as to be explicitly excised from the structure.

Post-Major Combat Operations (MCO) architectures in Iraq, in particular the architecture of Surge operations implemented by Gen. Petraeus in 2007 would also be particularly informative for the generalizability of layered architectures to different operational contexts and to the applicability of our analytical framework. Based on open source press reporting, part of the success of the Surge has been the development of lateral connections at lower tactical layers in the architecture as well as connections at multiple levels in the larger enterprise architecture of the Multi-National Force and Iraqi government organizations. At the Battalion level and below, ground forces made connections to local governing officials and leaders and maintain operational bases in local areas. This is in contrast to pre-Surge operations, where the general rule was to conduct operations into areas of insurgent strongholds from forward operating bases, then return to these bases. The Petraeus method, dubbed "seize-hold-build" has proven successful. An architectural perspective may help explain why and provide better insights for future operations.

8.3.4.2 Defense acquisition programs

The military acquisition system has proven remarkably resistant to change. McNamara's systems analysis approach, institutionalized in the Planning Programming and Budgeting Systems (PPBS) casts a long shadow.[301] This has created serious challenges as the complexity of defense systems has increased, the need for integration across service branches has grown and operational demands have become more diverse.

[301] Planning, Programming, Budgeting and Execution (PPBE) is the new term, but the mechanics and process are about the same, with the analytical approach essentially unchanged.

Major defense programs are now managed as enterprises (Murman 2002; Stanke 2006). They exhibit all of the hallmarks of complex systems—resistance to control, unexpected events and unpredictability. Yet we continue to manage these organizations to traditional cost-schedule-risk performance metrics, they continually fail to meet them, and we are continually surprised when this happens. Application of existing architectural frameworks has not appreciably improved this picture.

Some defense programs have shown remarkable flexibility, but often must routinely battle for survival in the face of mainstream acquisition processes. The Navy's submarine sonar program has transformed a multi-billion dollar legacy integrated system into a commercially based, open-architecture system using a business model that captures state of the practice technology and fields it quickly and inexpensively. A key factor in this success has been the technical architecture, which includes separation of hardware and software dependencies (a layering of the architecture) with a concurrent restructuring of the program organization. We have little understanding of how this program actually functions or how it is actually structured. Examination of the architecture of the multiple organizations that are responsible for the system (a) might provide explanatory power for the program's advocates (b) may be able to shed light on the scalability of these types of business models to larger, more complex, defense programs and (c) help understand the limits or our framework and model.

8.3.4.3 Commercial program development enterprises

Large commercial product development enterprises, such as Boeing's 787, may benefit from architectural analysis. The reported difficulties in design and management of this new and innovative system and the intricate complexity of its supplier network warrant study. Understanding the architecture of this project could be beneficial not only to Boeing but to national competitiveness.

Beyond product development, an examination of how a complex technical system such as the 787 is integrated into a larger business model could be instructive. For example, are their interactions among the service delivery segment and the marketing segment and the finance segment at multiple levels? How do these interactions affect system level performance? At what level does integration or laterality become irrelevant? These enterprise level questions can be examined using this framework.

8.3.4.4 Disaster response, enterprise resilience

The lack of coordination, collaboration and information flow in the federal, state and local response to Hurricane Katrina in 2005 offers another promising area for testing this framework and for further development of the model. Disaster relief, disaster response and crisis response are all examples of hierarchical systems that are generally not addressed as such. They are also different than other enterprise systems we have discussed. In these enterprises, the output is not a physical system, but it is delivered services and flow of commodities (Burkle and Hayden 2001; Beunza and Stark 2003). Sheffi notes that collaboration is important when attempting to develop enterprise resilience against disruptions (Sheffi 2005). Examination of the relationship between resilience and responsiveness to hierarchical aspects of enterprises is another way to test the limitations and generalizability of our findings.

8.3.4.5 Architecture of large government institutions

The architecture of the US Military and Defense Department is usually only addressed at a descriptive level. Discussions of the long-term evolution of the Department occur within defense circles, with inferences drawn about driving forces and consequences for national security and military effectiveness. An architectural perspective may be able to yield insight to both successes and failures of change efforts and may eventually yield to design methods. A motivation for this kind of an analysis is the impact of the Goldwater-Nichols Act of 1986 on the DoD and military services. Despite the Act's goal of fixing persistent operational difficulties revealed in the late 1970s and early 1980s, the DoD is still fundamentally non-Joint.[302] Indeed, in the background of much of this research is the fundamental orientation of the military services toward each other as competitors, a dynamic that directly impacts operational

[302] "Joint" is a term used widely in the Department of Defense to convey that a system, operation, or organization is focused on integrating the military services, without the excessive parochialism and divisiveness that have historically marked U. S. military operations. The two major events cited as prompting Goldwater-Nichols are the failed hostage rescue attempt in Iran (1979) and the Operation Urgent Fury (Grenada) in 1983.

architectures in practice. Initial observations and accounts of Major Combat Operations in Iraqi Freedom are that service parochialism was much less of a problem, though there is anecdotal evidence of resurgence of inter-service rivalry since then.[303]

8.3.4.6 Health Care Delivery

There has also been a surge of effort to reform the national health care system as its costs grow seemingly without bound, inefficiency in certain operations becomes obvious and inflexibility in others causes difficulties. Many efforts have focused on process improvement, few on architecture. By applying an architecture framework, a new perspective can be brought to bear on this pressing problem and potentially yield large improvement (Moses 2009).

8.3.4.7 Rise of Cross-Disciplinary Studies in Universities

The proliferation of cross-disciplinary research on University campuses may be an emergent response to the need for flexibility and may represent a "new level" of abstraction in the architecture of universities. MIT's Engineering Systems Division (ESD) may be a pro-actively designed response or recognition of the need for increased flexibility in both teaching and research on today's pressing problems. An analysis of ESD and other similar programs in the context of the architecture of a University using an architecture framework may be instructive.

8.4 Observation of recent events

The Air Force is undergoing a round of institutional difficulties. In the wake of some high profile operational failures and programmatic difficulties in responding to warfighting demands, the Secretary of Defense fired both the Secretary and the Chief of Staff of the Air Force. Some think it is significant that he replaced the Chief of Staff with a career pilot from the transport and logistics community, not the fighter community. A recent opinion editorial in the New York Times calls for disbanding the Air Force (Kane 2009). The Lexington Institute recently reported that the senior leadership of the Air Force expressed serious concern over recent programmatic decisions that impacted the F-

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[303] The author has heard numerous accounts of inter-service parochialism, in addition to many widely-publicized successes of inter-service cooperation ("Jointness"). The most public of these disagreements has been over the control and management of Unmanned Air Vehicles (UAVs) in theater, which has been widely reported in the defense press.

22, C-17 and other major Air Force systems (Thompson 2009). While these may be short-term issues driven by transient political agendas, if they reflect substantial problems it may be worth considering how to address them.

An hierarchical view of the Air Force architecture might provide some insights to solving some of these difficult issues. We noted in Chapter 2 that Air Force doctrine emphasizes the strategic level of war at the expense of operational and tactical levels. A more even emphasis across the levels of war hierarchy in Air Force thinking may help address some of the misalignments between the Air Force and the rest of the Department of Defense (whether these misalignments are real or perceived).

As a simple thought experiment, we have observed that the Air Force deemphasizes as less critical the operational and tactical levels of war. The claim of air power theory is that strategic targeting can bring down the enemy system, if it is done properly (Warden 1995; Douhet and Ferrari 1998). However, despite the Air Force's best efforts, the operational and tactical levels of war remain important.[304] It also stands to reason that, in terms of impact, strategic targets are high, but in numbers are low. The inverse holds true for tactical targets—they are numerous and, with rare exceptions, have a low impact at the system level. A detailed analysis that examines re-balancing in this way may enable new solutions to be developed and possibly address some of the current criticisms of the Air Force.

8.5 Fully embracing the "Information Age"

To reiterate, our research has been highly exploratory. We think that we have embarked on a fruitful path and developed a powerful framework. While many approaches to complex enterprises embrace their complexity and attempt to unravel and understand it from either a sociological or a mechanical perspective, we have applied concepts from information systems and mathematics to the problem. Since a large part of enterprise activity is information processing, itself closely coupled to mathematics, we think this approach is natural.

[304] Some protest that the Air Force has never been able to implement a campaign that allows a test of the theory. This claim remains highly debatable. A good review of this position is provided by (Cooper 2001).

Our approach has exposed a richer description and understanding of some well-known enterprise pathologies and highlighted a more formal way to view Joint military operational design and to formally design properties that have typically been considered as only achievable via informal action. We offer a way to make design of large-scale enterprises (specifically military and government ones) a serious design activity.

Our research approaches enterprise architecture from an information perspective. The 20th century focus of organizations on efficiency and specialization of processes and tasks have become "infrastructure." By this we mean that the ability to design and manage an organization has become routine; excellence is the norm.[305] Smooth running well designed processes and teams and individuals who are competent at specialized tasks are the price of entry to any competition. Past measures of effectiveness were performance parameters of individual products and systems, efficiency of processes and quality and quantity of output. Today, the interfaces with outside services, suppliers, customers and other stakeholders are the critical determinants of success. Today value is derived from the overall architecture of the system and its ability to cover a wider array of demands—its flexibility. The same is true in national defense. Our systems, processes, training, education and people are superb. Excellence is expected, demanded and delivered daily. The keys to our sustained advantage and future security now lie in how well we are able to architect these precious assets—how well we can design strategic and operational architectures. Understanding how to do this is not a trivial undertaking (Watts 2008).

Today, relationships and inter-relationships are key—a core idea in information systems architecting. We have addressed this issue directly by applying an information system concept to large information processing systems: enterprises. Combinations of systems and organizations are the source of competitive advantage. Technical systems that can be configured to meet increasingly dynamic and uncertain demand have long-term value. Enterprise-level relationships are increasingly necessary for survival, let

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[305] An interesting conceptual extension would be to apply Christensen's disruptive technology theory to this problem.

alone success. These trends places a premium on architecture design, specifically architecture designs that enable flexibility.

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