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IDENTIFICATION AND EVALUATION OF ORGANIZATIONAL STRUCTURES AND MEASURES FOR ANALYSIS OF JOINT TASK FORCES

by

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Joint Task Forces (JTF) operate in a variety of missions and uncertain environments. The architectures of these organizations must be capable of adapting to changes in the mission, the environment, or the organization itself. Mathematical models that are useful in predicting operational performance are needed for research into the optimum design of a JTF architecture for a given mission. To develop these models, properties of a joint task force organization must be understood and measures must be identified that are both sensitive to changes (differences) in architectures and related to operational performance.

A literature review of civilian research in organizational structures and measures identified several candidates. To analyze the usefulness of these measures to identify differences in operational architectures, two known contrasting JTF organizations are developed using structures found in the literature. Each of the measures is applied to all structures in both architectures and analyzed to determine which measures show promise. Those that identify differences between operationally relevant architectures are deemed useful measures. Limited data from a related Naval Postgraduate School command and control experiment, in which architecture type is a factor, is used to fit a regression-type model that predicts JTF performance based on measures classified as useful.

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IDENTIFICATION AND EVALUATION OF ORGANIZATIONAL STRUCTURES AND MEASURES FOR ANALYSIS OF JOINT TASK FORCES

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Submitted in partial fulfillment
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ABSTRACT

Joint Task Forces (JTF) operate in a variety of missions and uncertain environments. The architectures of these organizations must be capable of adapting to changes in the mission, the environment, or the organization itself. Mathematical models that are useful in predicting operational performance are needed for research into the optimum design of a JTF architecture for a given mission. To develop these models, properties of a joint task force organization must be understood and measures must be identified that are both sensitive to changes (differences) in architectures and related to operational performance.

A literature review of civilian research in organizational structures and measures identified several candidates. To analyze the usefulness of these measures to identify differences in operational architectures, two known contrasting JTF organizations are developed using structures found in the literature. Each of the measures is applied to all structures in both architectures and analyzed to determine which measures show promise. Those that identify differences between operationally relevant architectures are deemed useful measures. Limited data from a related Naval Postgraduate School command and control experiment, in which architecture type is a factor, is used to fit a regression-type model that predicts JTF performance based on measures classified as useful.

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The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logic errors, they cannot be considered validated. Any application of these programs without additional verification is a the risk of the user.

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EXECUTIVE SUMMARY

Today's global political and military volatility ensures that United States Armed Forces will continue to be tasked with worldwide missions in a variety of unexpected environments. Dramatic changes within the United States have impacted the military. Force size reductions, base closures, and fiscal restraints resulted in smaller Armed Forces that are tasked with more assignments, with some of these potentially becoming long term responsibilities. In view of the ever growing demand for U.S. involvement and the ever tightening limitations, it is time to *assess* current and future capabilities, and to *develop* new doctrinal concepts and organizational architectures that will enable tomorrow's military to meet the future challenges.

Tomorrow's Joint Task Force (JTF) may have to respond with a totally different force structure, equipment, and architecture than today's JTF. The organizational architecture chosen by the Commander Joint Task Force (CJTF) needs to be effective for accomplishing the original mission, and for adapting to changes in the mission, the environment, or the organization itself. These changes are referred to as "drivers " of adaptation.

With the advent of innovative technology and the willingness to dramatically change doctrine and organizational concepts, *new* organizational architectural designs can be developed that facilitate mission accomplishment, even when confronted with unusual missions or other drivers of adaptation. Several agencies within the Department of

Defense, the Joint Chiefs of Staff, and the Service Communities are currently looking at several possible architectures for the future military.

Ultimately, it is desired to have models that are useful in predicting various aspects of operational organizational performance based on organizational architectures. To develop these models, measures are required that are both sensitive to changes in the architecture (or differences in architectures) and functionally related to measures of performance. Unfortunately, such a set of measures is not currently available. This paper is a step in that direction. The *definition* and *measurement* of organizational structures is established in order to form a framework for the subsequent study of organizational architectures, and data from a recent command and control experiment is used to demonstrate how predictive models can be developed.

An organizational architecture can be described as the superposition of several *structures* (e.g.; a command structure). An extensive review of recent organizational theory literature identified several structures used in analysis of commercial business organizations. Drawing upon these structures and the insight the author gained from over a dozen interviews with senior joint flag officers, **five** structures pertinent to a Joint Task Force were identified. These are Command, Authority, Formal Communications, Informal Communications, and National Intelligence.

Most current measures of military organizations tend to concentrate on extrinsic measures of performance rather than differences in architectural properties. One set of measures recently developed by researchers at Carnegie Mellon University shows promise as being useful in analyzing organizational structures, however. A subset of **six**

of these measures has been selected for this thesis and adjusted to include the various resources available to a JTF to conduct its mission. The six measures are: Carley's Organizational Costs, Krackhardt's Hierarchy, Mackenzie's Hierarchy, Krackhardt's Efficiency, E-I Index, and Krackhardt's Least Upper Bound.

Given several architectures, it is possible to calculate the value of each measure for each structure within each architecture. If these architectures were each used to perform the same operational tasks (same scenario), and performance data was collected for each of the aspects of performance, it would then be possible to fit one or more regression-type models to predict performance based on architecture (as characterized by the structure measures).

Unfortunately, no data is available from any experiment designed to analyze these relationships. There is, however, some limited organizational performance data (two organizations, one performance measure) available from a related Command and Control (C^2) experiment in which architecture type is a factor that can be used to demonstrate the concept. This C^2 experiment was designed and conducted at the Naval Postgraduate School in support of the ONR sponsored Adaptive Architectures for Command and Control research project. This limited data is used to fit a model that predicts performance based on Organizational Cost and Mackenzie's Hierarchy, two of the six measures shown by analysis to be potentially useful.

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I express my appreciation to Dr. William G. Kemple whose vision inspired and motivated me throughout this thesis, particularly during this time. His enthusiasm in teaching and his dedication to students made the learning process a pleasurable experience. In addition, I am indebted to the following people:

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- Dr. Zhiang Lin of The Hong Kong University of Science and Technology, for his paper and numerous e-mails, which provided many of the concepts in this thesis.

Most importantly, I express sincerest thanks to my wife, Kirsten, whose patience, support, and encouragement are greatly appreciated and can not be expressed in words. This thesis could not have been accomplished without her.

I. INTRODUCTION

A. BACKGROUND

Today's global political and military volatility ensures that United States Armed Forces will continue to be tasked with worldwide missions in a variety of unexpected environments. Dramatic changes within the United States have impacted the military. Force size reductions, base closures, and fiscal restraints resulted in smaller Armed Forces that are tasked with more assignments, with some of these potentially becoming long term responsibilities.

In view of the ever growing demand for U.S. involvement and the ever tightening limitations, it is time to *rethink* and *explore* the range of military operations in which forces will be employed. It is time to *assess* current and future capabilities, and to *develop* new doctrinal concepts and organizational architectures that will enable tomorrow's military to meet the future challenges.

During field research for this paper, the author visited nine military commands whose responsibilities range from developing Joint and Service Doctrine to conducting Joint Operations. These agencies are:

1. United States Atlantic Command (USACOM)
2. Joint Warfighting Center (JWC)
3. Joint Training, Analysis, and Simulation Center (JTASC)
4. First Marine Expeditionary Force (I MEF)
   (a USCENTCOM pre-designated JTF)

5. Commander of the U.S. Naval Forces Second Fleet (COMSECONDFLT) (a USACOM pre-designated JTF)

6. Commander of the U.S. Naval Forces Third Fleet (COMTHIRDFLT) (a USPACOM pre-designated JTF)

7. Naval Doctrine Command (NDC)

8. Marine Corps Combat Development Command (MCCDC)

9. Commander Amphibious Group Three (PHIBGRU3)

In addition, the author participated in the Expeditionary Warfare Conference in Norfolk, Virginia, which was attended by over 20 Navy and Marine Corps Flag Officers. The purpose of the conference was to resolve Navy–Marine Corps points of disagreement and to develop Naval and Joint doctrine regarding Naval Expeditionary Warfare.

Interviews and discussions with 13 Admirals and Generals from the above commands provide a unique opportunity to gain insight into the robust review of future command and control doctrine that is now taking place throughout the Department of Defense. To develop and study some of these proposed designs, the Joint Chiefs of Staff are sponsoring the Revolution in Military Affairs (RMA) series of experiments, wargames, and analyses. These RMA events occur around the country and are designed to gain insights into concepts for the future military. Many thoughts and concepts expressed by senior and junior officers involved in shaping doctrine for tomorrow, along with observations from RMA studies, are incorporated in this research.

B. PROBLEM STATEMENT

Joint Task Forces (JTF) are called upon frequently to respond to situations on a short notice basis. The Commander of the JTF (CJTF) must rapidly assemble members

of the Navy, Marine Corps, Army, Air Force, Coast Guard, and a host of other supporting agencies, into an organization that will deploy to uncertain environments. The organizational architecture chosen by the Commander needs to be effective for accomplishing the original mission, and for adapting to changes in the mission, the environment, or the organization itself. These changes are referred to as "drivers " of adaptation.

Current organizational architectures may, or may not, be effective, depending on the mission at hand. For example, the United States military today faces frequent other-than-war operations, and few senior officers are trained and experienced in large-scale, joint operations. Then Vice Admiral Gehman, Deputy Commander of the United States Atlantic Command, stated that in light of the above, the selection of a JTF Commander and an effective organization architecture was an 'ad hoc process.' This, plus the need to rapidly form a JTF in response to a crisis, results many times in a 'cookie-cutter' JTF architecture which is inappropriate for the mission. (Interview, VADM Gehman, 1995)

With the advent of innovative technology and the willingness to dramatically change doctrine and organizational concepts, *new* organizational architectural designs can be developed that facilitate mission accomplishment, even when confronted with unusual missions or other drivers of adaptation. As a first step, the *definition* and *measurement* of organizational architectural dimensions need to be studied in order to establish a framework for the subsequent study and design of effective organizational architectures.

A workshop, participated in by the author, to discuss command and control (C^2) measures for organizational architectures was held at George Mason University in March

1996. Many issues requiring further studies were identified. Two that relate to this project are: 1) the lack of concisely defined organizational dimensions available in the literature, and; 2) the scarcity of measures that can quantify dimensions in a way that can help detect organizational adaptation. (Workshop, 1996)

A military organization has intrinsic structures imbedded within the overarching shell of its architecture. Figure 1 illustrates some of these structures critical to the effective operation of the organization. Corporations will have similar structures, but the focus here is on the military organization.

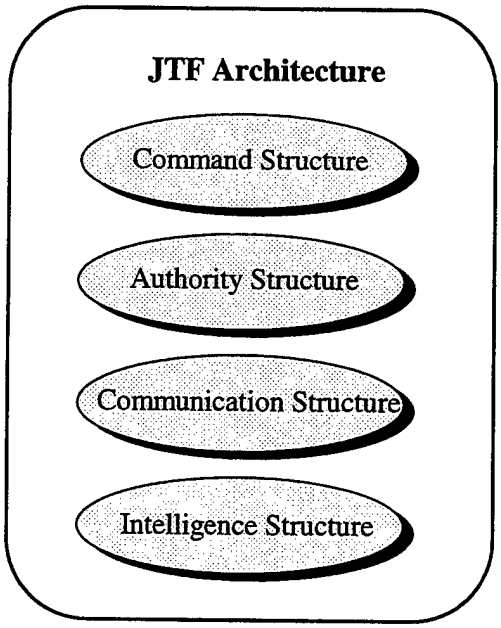


Figure 1. An Organizational Architecture with Four Intrinsic Structures.

The **goal** of this research is twofold. First, define the dimensions of organizational architectures, called **structures**. Secondly, evaluate the applicability of organizational **measures** found in the literature to each of these structures and the architectures as a whole.

C. RESEARCH EFFORTS

The breadth and diversity of technology today and in the future, will facilitate the design and implementation of JTF organizational architectures capable of rapid and effective adaptation in response to various situational drivers. Recognizing the need for further study in this area, the Office of Naval Research (ONR) is sponsoring a multi-year research project to advance the knowledge regarding organizational flexibility. The ONR collaborative effort involves the Naval Postgraduate School, the University of Connecticut, ALPHATECH Inc. of Burlington, MA, and others. Five separate, but interrelated research tasks, are stated in the program:

1. Identify Components of Organizational Structures for Joint Operations
2. Map Missions onto C^2 Organizations
3. Reconfigure Structural and Coordination Strategies
4. Develop Testing Scenarios
5. Measure Development

This thesis supports efforts in the first and fifth task areas, *Identifying Components of Organizational Structures for Joint Operations* and *Measure Development* (developing measures that describe the organizational structures).

D. OVERVIEW OF SUBSEQUENT CHAPTERS

1. Chapter II. Literature Review

Chapter II presents an overview of quantitative techniques available in the literature that are used in corporate organizational analysis. To establish a common level of understanding, basic graph theory concepts are first reviewed to standardize the

terminology and to provide some examples that will be applicable in further discussion. Since each organizational architecture is composed of a stratified set of intrinsic structures, current studies and research on these structures are presented using the basics of graph theory. Finally, selective mathematical measures are discussed and demonstrated using several examples.

2. Chapter III. Development of Contrasting JTF Architectures

Among other things, the ONR project seeks to develop quantitative models of the relationships between architectures and performance for various missions that the JTF might face. This requires measures that are sensitive to differences in the architectures (differences in their structures). To help determine which measures usefully reflect the degree of similarity (or difference) between architectures, two JTF organizational architectures are developed. The first architecture, JTF A, is an operationally realistic organization that reflects today's technology and military policy. The second architecture, JTF B, incorporates advances in technology and joint doctrine that are currently under development or investigation by the Joint Chiefs of Staff (JCS), the Department of Defense, the Department of the Navy, and several commercial businesses. The architectures are deliberately different, and they are referred to as *contrasting architectures* throughout the remainder of this thesis. The contrasting JTF architectures are used for analytical comparison of the mathematical measures and the organizational structures discussed in Chapter II.

Intrinsic structures that are useful for characterizing a C^2 architecture were identified from the literature and joint officer interviews. These are developed and

discussed for the two JTF organizations. The differences between the architectures occur as differences between their intrinsic structures.

3. Chapter IV. Analysis of Organizational Structures and Measures

In this chapter, the contrasting architectures developed in Chapter III are used to help determine which of the measures from Chapter II show potential for identifying and characterizing differences between JTF architectures (or structures within them).

For the thesis, measures that tend to take on noticeably *different values* when applied to architectures that are *operationally different*, and *similar values* when applied to architectures that are *operationally similar*, are referred to as *useful measures*. In this chapter, six measures identified in the literature are applied to each of the five structures in each of the (known operationally different) JTF architectures. A difference scoring method is used to determine which of these measures, if any, are promising as *useful measures*.

As a demonstration of how these measures might be used to model the relationship between architectures and measures of performance, these candidate measures are then applied to experimental performance data obtained from a C^2 experiment conducted at the Naval Postgraduate School in March 1996. In this case, the modeling is accomplished by regression of the performance data on two command structures for each candidate measure.

II. LITERATURE REVIEW

A. LITERATURE REVIEW PROCESS

This Chapter presents the key findings of a literature search for possible organizational structures and measures to be used in the analysis of organizational architectures and their adaptation. To establish a common understanding of the terminology and computations used in this subject area, some fundamental information is presented to familiarize the reader. Following this familiarization, numerical examples of selected measures are demonstrated.

Section B covers the basics of *Graph Theory*. Since it is widely used to express and quantify the measures to be discussed, it is necessary that one has a rudimentary knowledge in this field. If the reader is already familiar with graph theory, Section B may be skipped.

Section C talks about recent research in defining *organizational structures*. **Section D** and **Section E** explain the organizational architectures that are commonly used in the literature for analysis of formal and informal organizations. **Section F** presents the *concepts* and *measures* currently available in the literature, drawing upon the elements learned in the previous sections. Finally, six measures are selected for analyses in Chapter IV.

B. GRAPH THEORY

1. General

Classical organizational charts of a business, with nodes and links between them, are used often to represent many aspects of that business, such as: the positions of leadership; the flow of communications, resources, and policy; and the height and breadth of the organization. This form of representation also lends itself to the use of the mathematical quantification of Graph Theory to define these architectural aspects. Therefore, a few basic Graph Theory definitions are required.

2. Basic Graph Theory Definitions

Frank Harary presented the initial groundwork on graph theory in 1969 in his *Graph Theory* book, from which many of the current definitions are derived. The definitions applicable for the study of organizational architectures are discussed by R.K. Ahuja, T.L. Magnanti, and J.B. Orlin in their *Network Flows,* and by Cormen, T.H., Leiserson C.E., Rivest, R.L., in their *Introduction to Algorithms*. These definitions, presented below, are: undirected graph, directed graph, incidence, adjacency, adjacency-matrix, connectivity and components, and a rooted tree.

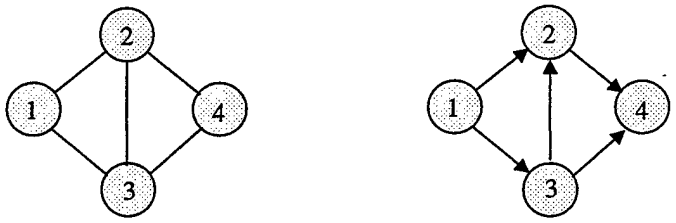
a. Undirected Graph

An *undirected graph* G consists of a set N of nodes and a set A of arcs, G=(N,A), in which the arcs are *unordered pairs* of distinct nodes. In this graph, there is, or is possible, two-way flow between nodes if connected by an arc. We refer to the undirected arc joining the node pair i and j as either (i,j) or (j,i). Figure 2.a gives an example. (Ahuja, R.K., *et al.*, 1993)

b. Directed Graph

A *directed graph* G consists of a set N of nodes and a set A of arcs whose elements are *ordered pairs* of distinct nodes. In this graph, there is only one-way flow between a node pair. The directed arc is referred to as (i,j) if flow is permitted from node i to node j, or as (j,i) if flow is permitted from j to i. Figure 2.b gives an example of a directed graph. (Ahuja, R.K., *et al.*, 1993)

Graph G=(N,A) N={1,2,3,4} A={(1,2), (1,3), (3,2), (2,4), (3,4) }



(a) Undirected Graph (b) Directed Graph

Figure 2. Undirected and Directed Graphs. (a) Undirected Graph with two-way flow permitted between each pair of nodes. (b) Directed Graph with flow permitted only in direction of arrows.

c. Incidence and Adjacency

If an **undirected graph**, G=(N,A), has an arc (i,j), it is said that arc (i,j) is *incident on* nodes i and j. This implies that the arc is symmetric and allows two-way flow. In addition, it is said that node i is *adjacent* to node j, and node j is *adjacent* to node i. (Cormen, T.H., *et al.*, 1990)

If a **directed graph**, G=(N,A), has an arc (i,j), it is said that arc (i,j) is *incident from* (leaves) node i and *incident to* (enters) node j. The arc (i,j) is not incident

from node *j* nor is it incident to node *i*. In addition, it is said that node *j* is *adjacent* to node *i*, but node *i* is not adjacent to node *j*. (Cormen, T.H., *et al.*, 1990)

d. Adjacency-Matrix Representation

Directed and undirected graphs can be represented by an adjacency-matrix that is an |N| x |N| matrix. In this matrix, the headings of the rows and columns are the node elements (N=1,2,3...n), and the value in the matrix position for node pair (*i,j*) indicates the existence of an arc between them. A "1" in the matrix place for node pair *i* and *j* indicates *there is* an arc (*i,j*) in the graph G=(N,A), and a "0" indicates *there is no* arc (*i,j*). For an undirected graph, this matrix is symmetric, and can be simply represented by an upper-right-triangular matrix. (Cormen, T.H., *et al.*, 1990) Figure 3 shows the adjacency-matrices for the two graphs that are discussed in paragraph II.A.2.b and shown in Figure 2.

	1	2	3	4
1	0	1	1	0
2		0	1	1
3			0	1
4				0

(a) Undirected Graph Adjacency-Matrix

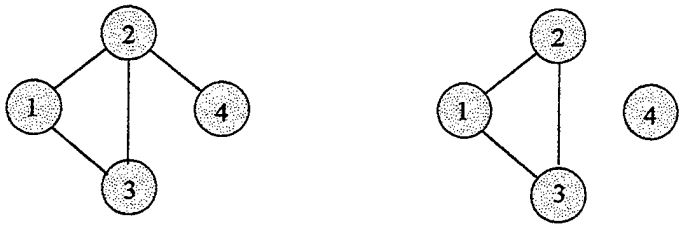
	1	2	3	4
1	0	1	1	0
2	0	0	0	1
3	0	1	0	1
4	0	0	0	0

(b) Directed Graph Adjacency-Matrix

Figure 3. Adjacency-Matrices for a Graph G=(N,A). (a) This matrix is symmetric since the arcs are undirected and flow goes both ways. Thus, only the upper-triangular portion is needed. (b) Though similar to the other matrix, this one is *not* symmetric since flow travels in one direction only. Note that *directed* arc (3,2) is represented with a "1" in the (3,2) position, and a "0" in the (2,3) position.

e. Connectivity and Components

Two **nodes**, *i* and *j*, anywhere in the graph are *connected* if the graph contains at least one path from *i* to *j*. A **graph** is *connected* if every pair of its nodes is connected, otherwise the graph is *disconnected.* For a directed graph, it is necessary to view the underlying graph without directed arrows when analyzing connectivity. The largest connected subgraphs of a disconnected graph are referred to as its *components.* The graph in Figure 4.a is connected and has of only one component, and the graph in Figure 4.b is disconnected and consists of two components. (Ahuja, R.K., *et al.*, 1993)



(a) Connected Graph (b) Disconnected Graph

Figure 4. Examples of Connected and Disconnected Graphs with Components.

f. Rooted Tree Graph

A tree graph is an undirected, connected, acyclic graph (it is impossible to start a path at a node *i*, and return to the same node *i* without backtracking). A rooted tree is a tree graph with one node that is distinguished from the others (the root node). Properties of a rooted tree graph, G, are:

1. G is connected with |A|=|N|-1, and such that if any arc is removed, a disconnected graph results.
2. any two nodes are connected by a unique path.
3. G is acyclic, such that if any arc is added, a cycle results in the graph.
4. G contains ancestors and descendants (defined later) on a unique path.

Figure 5 shows a rooted tree graph in which node 1 is the root node.

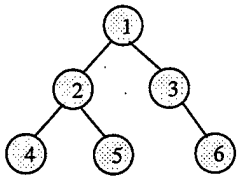


Figure 5. Example of a rooted tree graph

C. STRUCTURES OF AN ORGANIZATIONAL ARCHITECTURE

1. Initial Identification of Structures

A business will design its organization based on numerous factors. The final design is called the organizational *architecture*. For example, a business may choose an architecture in which a *single top decision maker* is responsible for analysis of *all* the inputs from those below. Another business may choose an architecture in which the *single top decision maker* is responsible for three inputs from three *middle level managers* who analyze inputs from below. In any case, the organizational architecture can be characterized as multiple complex systems, called **structures**, that are rigidly or loosely tethered together and enable the organization to function. Some structures identified by the ALPHATECH, Inc. Technical and Management Proposal are: *responsibility* structure (who should do what), *expertise* structure (who could do what), *information* structure (who knows what and when), *communications* structure (who can talk/send to whom), *command structure* (who reports to whom), *resource structure* (who owns what), and *goal structure* (who has what goal). (ALPHATECH, Inc., 1994)

The above list provides the starting point for research into identification of applicable structures for a Joint Task Force (JTF) organization. An organization that is

adaptable will display changes in some or all of the structures mentioned above in response to drivers of adaptation.

2. Sengupta's Organizational Structures

Recent research into organizational structures has been done by Professor Kishore Sengupta at the Naval Postgraduate School. Drawing upon the organizational theory literature of Daft, 1988, Katz and Garnter, 1988, and Mintzberg, 1993, and the research on command and control teams, Professor Sengupta defines a set of 'dimensions' that has direct applicability to this research (Sengupta, 1994). Dr. Sengupta's term *dimension* means the same as *structure* defined in Chapter I, and will be referred to as structure from here in. He generates four **categories** into which he assigns a total of nine **structures** of an organizational architecture. The four categories and nine structures (in the parentheses) listed below are discussed in the following sections:

1. Topology (hierarchy, authority and reporting).
2. Facilities and infrastructure (resource, information, and communication).
3. Distribution of activities (distribution of functions and capability, knowledge).
4. Others (goal, culture).

3. Topology

a. Hierarchy

Hierarchy addresses the number of levels and the span of control of the organization. Implicit in this are the coordination requirements entailed in the organization. Figure 6, on the next page, illustrates the level and span of control.

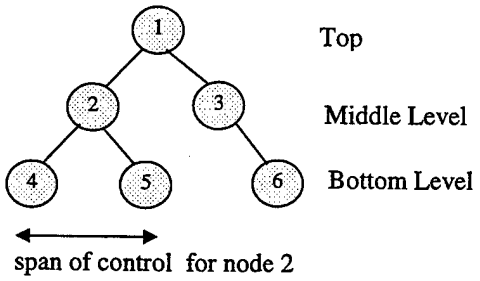


Figure 6. Organizational Hierarchy.

b. Authority and Reporting Structure

This is the 'operationalization' of the hierarchy dimension. It details the flow of authority and reporting in the organization, and as such, it implies a directive flow of leadership. Figure 7 shows the classical authority and reporting structure of a business in which there is only one boss directing two others below him. In turn, the middle managers have authority over their *descendants* (who report to them), and so forth.

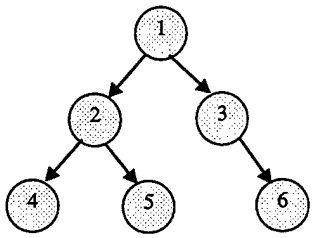


Figure 7. Example of an Authority Structure directed tree graph.

Operational Control (OPCON) and Tactical Control (TACON) of the forces and resources assigned to a JTF are two examples of military authority structures. Authority and reporting structures in a joint organization are not crisp and clear because of the competing loyalties placed on a commander and his resources. For example, a Carrier Battle Group Commander assigned to a JTF continues to have obligations and

requirements to a Navy Type Commander (NTC). These may conflict in some way with directions set by the CJTF. This aspect will be discussed further in Chapter III.

4. Facilities and Infrastructure

a. Resource Structure

This structure accounts for the ownership of resources accumulated by the organization. Examples of resources for a Joint Task Force are aircraft, helicopters, combatant ships, significant weapon systems (deep strike ground artillery and cruise missiles), and national level intelligence gathering assets. Again, as touched on above, the ownership of these resources may bring about conflict between joint force commanders. Does the Tomahawk missile belong to the Joint Maritime Component Commander for his discretional use, or does it belong to the Joint Air Force Component Commander for his coordination in deep strikes?

b. Information Structure

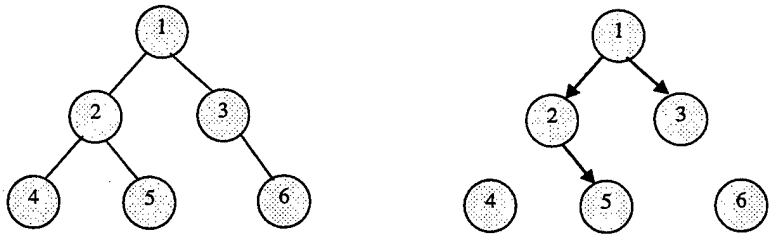
The information structure consists of *sources* of information and intelligence, and its *dissemination* to the proper nodes within the organization. This structure can range from a highly decentralized dimension where all nodes receive the same information, to a highly centralized dimension where the information is filtered and only partially disseminated to the other organization members. Two other factors in a JTF affect this element. First, the *access* to types of intelligence and information (compartmented Top Secret versus widely available Secret) limits which JTF agents receive or send the information. Secondly, the *hardware capability* to handle the level of

information further restricts the speed and volume of information which the JTF agents may receive or send.

c. Communication Structure

The extent to which each part of a hierarchy can communicate with the others is determined through policies established by both the joint force commanders and the respective service commanders, as well as imbedded equipment communication links. In a highly *decentralized* organization, the underlying graph is *dense*, in that each node communicates with almost every other node. A highly *centralized* communication structure graph is *sparse*, in that just a few nodes control the communications. A communication structure may be categorized further into either a **formal** structure defined by the organization top decision makers, or an **informal** structure defined by the nodal constituents of the organization. Extensive use of telephones and fax machines to gain or send information outside the formal channels is a prime example of an informal structure.

Figure 8 portrays two possible communication structures. For any business or JTF organization, the communication and information structures have



(a) Undirected Two-way Formal Communication Graph

(b) Directed One-way Formal Compartmented Information Graph

Figure 8. Two Possible Communications Structures of an Organization

immense impact on its performance since the ability to disseminate information and intelligence, as well as accuracy, is critical to task accomplishment or adaptability.

5. Distribution of Activities

a. Distribution of Functions and Capability Structure

This structure captures the manner in which the functions performed by organization are distributed across the hierarchy. Included in this is the specification of the distribution of unique functions as well as overall workload. In a JTF, the distribution of functions is mapped into the capability of the respective Functional and Service Component Commanders, and consists of the service command nodes and attached resources. For example, the **Joint Force Air** Component Commander (JFACC) directs the joint function of *air and deep strike warfare* using resources of the Air Force, Marines, Army, and Navy. The **Navy Service** Component Commander handles the functions associated only with the Navy, not with the Marines, Army, or Air Force. Again, Chapter III discusses this in more detail.

b. Knowledge and Expertise Structure

The level of knowledge and expertise in an organization is critical to efficient and correct analysis and decision making on the part of the organizational agents. The provision of functional redundancy in a JTF to minimize the impact of the loss of a major decision maker is paramount and dependent on the threat.

6. Other Structures

a. Goal structure

Specification of the goal to be accomplished by the organization consists of a global goal that can be decomposed into local goals for each element of the organization. For simplistic operations, this may be easy, but for complex undertakings involving multiple goals, it may lead to goal conflict. Overlap in the authority structure, where one organizational agent falls under the control of two different, competing bosses (ancestors), also introduces goal conflict.

b. Organizational Culture Structure

This includes the set of organizational norms, company values, general practices, and formal procedures that characterize an organization. Elements of norms, and company values can be stated in written media and practiced by personnel, but there are currently no organizational measures that can be expressed by graph theory. Again, procedures are codified and usually available to all agents, but a single quantifying measure using graph theory has yet to be developed.

D. STYLIZED ORGANIZATIONAL ARCHITECTURES

1. Background

Research in organizational theory over the last few years has resulted in the categorization of a few *commonly accepted organizational architectures.* These architectures figure predominantly in recent studies in the field of joint cognitive and structural basis for social and organizational behavior. Two prominent researchers in this area are Dr. Kathleen Carley of Carnegie Mellon University, and Dr. Zhiang Lin,

formerly of Carnegie Mellon University and now at the Hong Kong University of Science and Technology. Both have researched organizational structures and the effects of the architecture and personnel in performance of the organization.

In several simulation studies, Carley and Lin utilize **five common architectures** that provide a baseline of information and insight in contrasting designs. The organizational architectures used in their computer simulations are:

1. Team with Majority Voting
2. Team with a Manager
3. Hierarchy
4. Matrix-1
5. Matrix-2

These architectures are briefly presented below.

2. Five Common Stylized Organizational Architectures

a. Team with Majority Voting

The team with majority voting is a totally decentralized architecture in which organizational *decision* is made through a *majority vote* by all members. Figure 9 shows this design. (Lin, 1993) There is no application of this form in the operation of a JTF since it is a large organization in which a single individual, the Commander of the JTF, is designated to lead the forces.

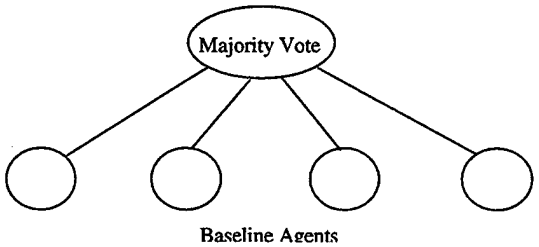


Figure 9. Team with Majority Voting Decision Making

b. Team with a Manager

This team incorporates a single top manager in a flat hierarchy in which each baseline analyst examines information and makes a *recommendation* to the manager. The manager makes the ultimate organizational *decision.* (Lin, 1993) Figure 10 illustrates this concept.

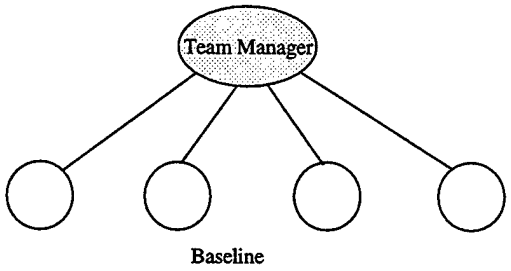


Figure 10. Team with Manager Decision Making.

c. Hierarchy

The Hierarchy stylized organizational architecture is a multileveled architecture in which each baseline agent examines information and makes a recommendation to his or her immediate supervisor, a middle level manager. In turn this manager makes a recommendation to the single top-level manager who then makes the ultimate organizational decision. (Lin, 1993) See Figure 11. This architecture closely

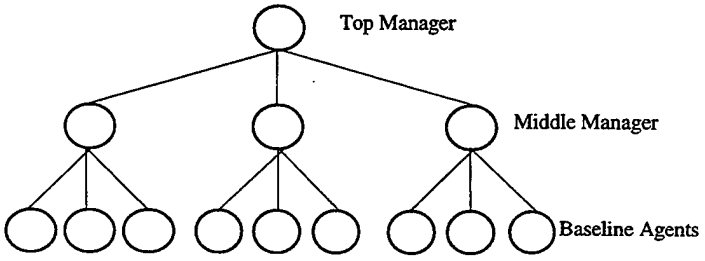


Figure 11. Hierarchy Architecture.

resembles a small-sized Joint Task Force with the three middle level managers representing the three functional components that are discussed in Sengupta's

Distribution of Activities structure. The middle managers could represent the Joint Maritime, Land, and Air Forces Component Commanders.

d. Matrix-1

This architecture is related to the hierarchy architecture. It is a multilevel structure with the addition that some of the baseline agents have connection with *two* managers, one *inside* their division linked to the immediate boss, and one *outside* their division linked to another middle level manager. (Lin, 1993) Figure 12 shows this relationship.

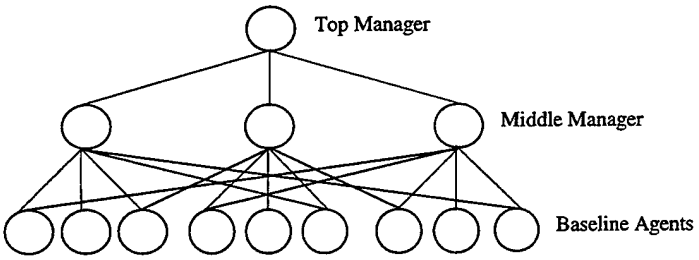


Figure 12. Matrix-1 Organizational Architecture. Each middle level manager oversees three baseline agents within a division. *Two* of the baseline agents in each division, communicate inside their division with their boss, and *outside* their division with *one* other middle manager.

e. Matrix-2

Matrix-2 is similar to Matrix-1, but each baseline analyst has communication to two middle level managers across divisions. This architecture, seen in Figure 13, is a more complex design than the previous ones.

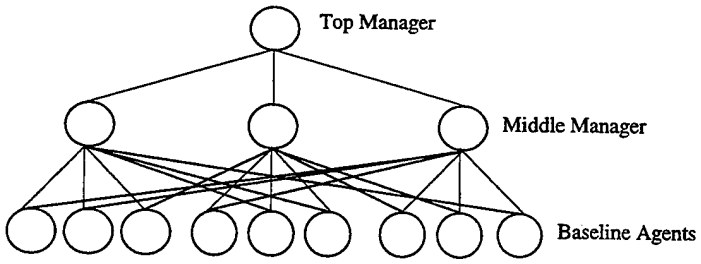


Figure 13. Matrix-2 Organizational Architecture. Each middle level manager oversees three baseline agents within a division. *All* of the baseline agents in each division, communicate *inside* their division with their immediate boss, and *outside* their division with *one* other middle manager.

3. Summary of Stylized Architectures

Two of the above stylized architectures used by Carley and Lin in their computer simulations closely approximate simple command structures of a JTF. **Team with a manager** represents futuristic command arrangements currently being researched by military doctrine commands through computer models, and through a series of Revolution in Military Affairs (RMA) conceptual wargames (e.g., the Nimble Vision wargame series sponsored by the JCS). **Hierarchy** architecture nearly replicates the form under which a small, *functional* JTF would organize. The relevance of conclusions drawn from Carley and Lin's simulations will be discussed later.

E. STYLIZED RESOURCE ACCESS FORMS

1. Information Access

Organizational architecture is only one critical factor in an organizational analysis. The second critical factor is the access to **resources** or **task information**. The *resource access* design defines which analyst in the organization has access to which incoming information and the resources to collect that information (Carley, et. al., 1995). As with

stylized architectures, research has defined four commonly accepted categories of resource access: 1) Segregated; 2) Overlapped; 3) Blocked, and; 4) Distributed. In the majority of research, only the baseline agents at the lowest level own resources and have access to the "raw" information provided by them as a result of tasks. These baseline agents are the analysts who pass on information to the next level of agents who then make decisions.

2. Stylized Resource Access Designs

The stylized resource access designs presented above are shown in Figure 14.

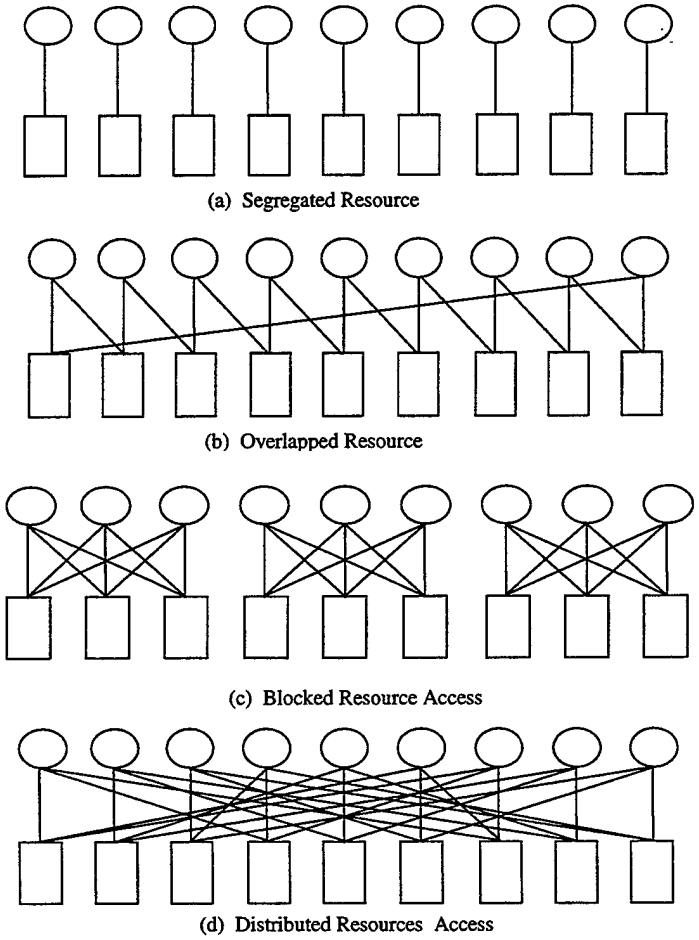


Figure 14. Four Stylized Resource Access Forms. The oval-shaped objects represent baseline analysts, the rectangular objects represent the resource or task pieces of information.

In the **Segregated** access form, each baseline analyst has access to one resource element, and must make a recommendation with that. In the **Overlapped** access form, each baseline analyst has access to two resource elements, one resource component being overlapped with another baseline analyst. Referring to the **Blocked** access form, it is seen that the three baseline analysts have access to three resource elements, all within the same division. Finally, in the **Distributed** access form, each baseline analyst has access to three resource elements, but across different divisions. (Lin, 1993)

In the above examples, the rectangular boxes are the resources or tasks. Since this paper discusses military organizations, the boxes will be referred to as **resources** that represent categories of assets available to a commander (e.g.; ships, aircraft, and ground elements). These resources are given local tasks (Sengupta's subgoals) to carry out in support of the overall organizational goal, and in turn, they report information during the conduct of these tasks.

F. GRAPH THEORECTICAL DESCRIPTIONS OF ORGANIZATIONS

1. Information

This section discusses the following items in sequence: (1) Dr. David Krackhardt's concept of hierarchical deviance in contrasting various organizational architectures; (2) Listing of additional measures by Carley, Lin, and K.D. Mackenzie; (3) The coupling of organizational architectures and stylized resource access forms by Carley and Lin, and; (4) Lin's study of the interrelationships of various measures.

2. Krackhardt's Concept of Hierarchical Deviance

Dr. Krackhardt of Carnegie Mellon University, developed four measures to analyze the degree of hierarchy of an organization. In his work, he measures the organizational ***deviance*** of a given architecture from a standard model. This concept is important enough to present *first* in order to establish an understanding of the computational significance.

Krackhardt's technical paper, *Graph Theoretical Dimensions of Informal Organization*, expanded on an earlier 1981 model by H.A. Simon, which argues that there is a universal function of hierarchy in "virtually all complex systems" (Krackhardt, 1994). In order to analyze whether the hierarchical architecture has implications in the operation of an organization, Krackhardt develops measures of informal structure. He clearly states that although there may be a hierarchical architecture in an organization, some factors "may not necessarily enhance the organization's efficiency or ability to survive" (Krackhardt, 1994).

Using graph theory, Krackhardt designs the **archetypical formal hierarchy**, that is, the original model against which all others are patterned or compared. His archetypical formal hierarchy then provides a basis in subsequent research to measure the deviance of other organizational architectures. Krackhardt selected the *rooted tree graph* as the archetypical architecture. Recall the requirements of a rooted tree graph above: Graph G=(N,A) must 1) be connected; 2) have any two nodes connected by a unique path; 3) be acyclic; and 4) contain ancestors and descendants. These are the conditions Krackhardt applies to a directed graph, from which to detect any 'violations.' If a

violation occurs, then the graph is not a tree graph. Measuring the number of violations determines the distance from the archetypical structure. (Krackhardt, 1994) The four measures of degree of structure, or dimensions as Krackhardt terms them, are:

1. Connectedness
2. Group Hierarchy
3. Graph Efficiency
4. Least Upper Boundedness (LUB)

These will be discussed in detail below.

3. Additional Organizational Measures

Dr. Lin's research, *A Theoretical Evaluation of Measures of Organizational Design: Interrelationship and Performance Predictability* (Lin, 1993), looks at additional measures of an organization and analyzes the interrelationship among them. In his research, he reviewed numerous sources of organizational theory for additional measures that are applicable to organizational structures. The additional measures Lin eventually selected and examined are:

1. Organizational Cost, developed by Carley in 1991.
2. Task Process Efficiency, developed by Mackenzie in 1978.
3. Hierarchy Degree, also developed by Mackenzie.
4. External-Internal Index, developed by Krackhardt and Stern in 1988.
5. Communications Level Measure, developed by Lin in 1993.
6. Anti-Blocking Level, also developed by Lin in 1993.

A more detailed discussion of these is conducted in Section 5.

4. Combining Organizational Architecture and Stylized Resource Access

Research dealing with the influence of specific architectures on organizational performance is useful for gaining basic insights into building efficient and effective ones.

Likewise, the study of a few representative resource access forms provides operational insights regarding their effect on organizational performance.

Research that looks at combinations of the two, *organizational architectures* with *resource access forms*, yields further significant insights into organizational performance. Carley and Lin examine the performance of organizations with various combinations of the architecture-resource designs subject to various fixed operational variables, such as experience of agents. (Carley and Lin, February 1993, Carley and Lin, 1995) The principle of combining architecture-resource access styles, put forward by Carley and Lin, is a major element in another study by Lin, and is discussed below since it is also a significant factor in this paper's analysis of structures.

5. Interrelationships Among Current Measures

Lin's evaluation of the interrelationship of organizational measures (Lin 1993) is a comprehensive undertaking that: (1) consolidates the ten measures discussed on pages 27 and 28 (Krackhardt's original four measures plus Lin's additional six); (2) selects five of these and adjusts them to account for the resource access forms; (3) combines the ten consolidated measures with the five adjusted ones to obtain a set of 15 measures; (4) generates 36 combinations of the organizational architectures and resource access forms discussed in pages 20 through 26, and; (5) runs computer simulations to analyze performance of these combinations under various levels of training.

Lin then uses cluster analysis on the Pearson correlation of these 15 measures to identify seven categories at the 0.75 level. These final seven measures are:

1. Carley's Organizational Cost
2. Krackhardt's Efficiency

3. Mackenzie's Hierarchy
4. Krackhardt's Hierarchy adjusted for resource access
5. Krackhardt's LUB adjusted for resource access
6. Krackhardt and Stern's External-Internal Index adjusted for resource access.
7. Anti-Blocking Level.

The last measure, Anti-Blocking Level, is henceforth omitted since requirements to set the maximum average number of divisions accessed by each analyst and the maximum possible number of access links to task from each analyst are not applicable or realistic for a JTF organization. Examples of the remaining six measures are taken from Lin's study and described below for an understanding of their properties.

a. Carley's Organizational Cost

The Organizational Cost measure developed by Carley in 1991 looks at the number of pieces of information being processed, and defines this as the 'cost' of processing (Lin 1993). The measure sums the information processing cost and the communication costs.

$$O_C = I_C + C_C \qquad (1)$$

O_C is the organizational cost, I_C is the information processing cost, or the total number of pieces of information being processed within the given organizational architecture, and C_C is the communication cost, the total number of links established in the organization. For example, the Matrix-1 architecture with an Overlapped-1 resource scheme in Figure 15 has 13 agents in the organization. Each of the bottom nine baseline analysts has access to two pieces of information through the resources links. Three baseline agents (the center ones in each group of three, report their two pieces of information to one middle level manager, while the remaining six baseline agents report

their two pieces of information to two middle level managers. Each middle level

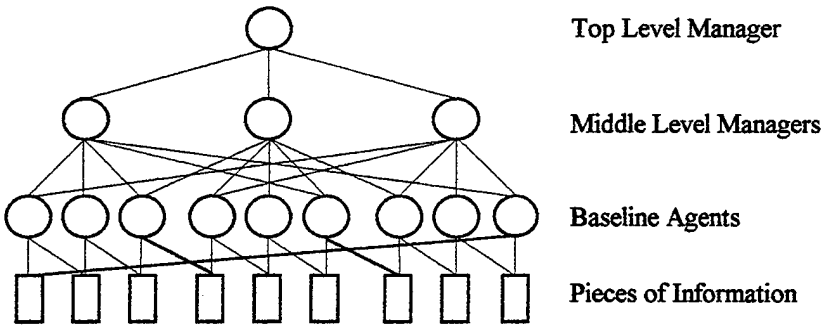


Figure 15. Matrix-1 Architecture with an Overlapped-1 Resource Access Form.

manager receives five pieces of information to process and then reports one piece of information to the top level manager. The top manager receives three pieces of information and makes the one final decision. In this case the *Informational Cost* is:

$$I_C = 6*(2+2) + 3*(2+1) + 3*(5+1) + 1*(3+1) = 55$$

$$\{\text{baseline}\} + \{\text{middle}\} + \{\text{top}\}$$

Six baseline analysts have 2 communication links to middle managers, three baseline analysts have 1 communication link to middle managers, and each middle manager has 1 communication link to the top manager. Thus the *Communication Cost* is:

$C_C = 6*2 + 3*1 + 3 = 18$ {baseline to middle}+ {middle to top }.

This results in an *Organizational Cost* : $O_C = I_C + C_C = 55 + 18 = 73$.

b. Krackhardt's Graph Efficiency

Krackhardt defines the *condition* of graph efficiency: in the underlying, undirected graph of each component, there are exactly N-1 links, where N is the number of nodes in the component. For a *rooted tree graph*, the underlying graph is connected and has exactly N-1 links. Fewer than that, and the directed graph would contain at least

two components. More than N-1 links, and the directed graph would have cycles between nodes. Krackhardt's computation of this is:

$$\text{Graph Efficiency} = 1 - \left[\frac{V}{\text{MaxV}}\right] \qquad (2)$$

V is the number of links *in excess* of N-1 summed over all components (if there is more than one), and MaxV is the *maximum possible* number of links in excess of N-1. For a single component graph, MaxV= N(N-1)/2 – (N-1) . Krackardt stresses that graph inefficiency should not be confused with social or economic efficiency, and that there are cases where graph inefficiency is beneficial to an organization. For example, if an organization has *exactly N-1 links*, the deletion of just one link *breaks* the communication between two nodes, and creates two components. It is desired to have *more than N-1 links* to achieve network *redundancy*, which may allow the successful bypassing of the deleted link and continued operation. On the opposite end, a business that is extremely dense with a high degree of redundancy can be overburdened with extensive networking. People in a highly redundant organization are required to spend a higher percentage of time interacting with others than people in an organization with little redundancy.

Lin chooses to use Krackhardt's *original* version and does not adjust it for resources. Thus, any resource access combined with the baseline analysts will have *no* affect on the computation. For the Matrix-1 Overlapped-1 architecture example seen in Figure 16 on the next page, N= 1 + 3 + 9 = 13 total agents.

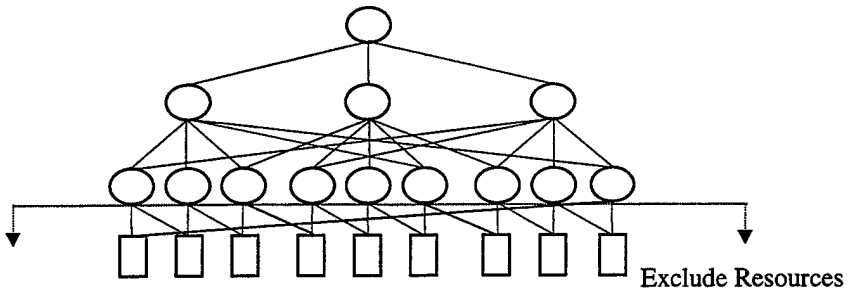


Figure 16. Example of Krackhardt's Efficiency Measure For a Matrix-1 Overlapped-1 Architecture Not Adjusted for Resources.

For this example, MaxV= (13*12)/2 – (13-1) = 66. The number of links in excess of N-1 is V= 6, calculated by summing all the links between managers (excluding links to and from resources) and subtracting N-1 links: 18-12 = 6. Efficiency is then 1-6/66 = 0.91.

c. Mackenzie's Hierarchy

K.D. Mackenzie's 1978 study, *Organizational Structures*, approaches the organization with a look at the overlapping relationship links, called *uncle-nephew* and *cousin* behaviors, and the redundant links, called *untimely* behaviors. The *uncle-nephew* behavior is from a baseline analyst to a middle level manager outside the baseline's division, and the *cousin* behavior is from one agent to another agent at the same level.

Mackenzie's measure is $H = 1 - \left[\frac{U_T+C+U}{T+U_T} \right]$. (3)

H is the degree of Mackenzie's Hierarchy.
U_T is the number of *Untimely* or redundant links in the architecture that includes redundant resource links *into* baseline agents, plus redundant information links *out of* each baseline agent, plus redundant information links *into* and *out* of each middle manager.
C is the number of *cousin* links among managers.
U is the number of *uncle-nephew* links among managers.
T is the total number of *Timely* links, the **minimum** necessary to *receive* and *report* information for a given architecture.

For illustration, Figure 17 repeats the architecture and resource access form of Figure 15. This organization has 6 uncle-nephew links and no cousin links between any agents, thus U = 6 and C = 0. U_T consists of 1 redundant resource link into each baseline analyst (1*9 = 9), 1 redundant information link from each baseline analyst (1*9=9), 2 redundant information links into each middle manager (2*3=6), and zero redundant information links out of each middle manager (0*3=0). Thus, the total redundant links U_T = 9+9+6+0=24. For this architecture, T consists of 1 link into and 1 link out of each baseline agent (2*9=18), plus 3 links into and 1 link out of each middle level agent ((3+1)*3= 12), plus 3 links into and 1 decision out of the top level ((3+1)*1=4). For this example, T = 18+12+4 = 34.

For this example, $H = 1 - \left[\frac{U_T+C+U}{T+U_T} \right] = 1 - \left[\frac{24+0+6}{34+24} \right] = 48.3\%$.

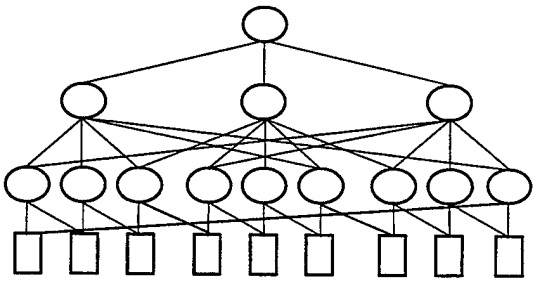


Figure 17. Matrix-1 Overlapped-1 Organization.

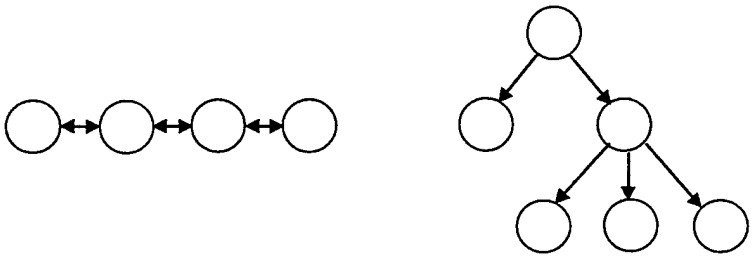
d. Krackhardt's Hierarchy Adjusted for Resource Access

Krackhardt's original measure looks at the "reach" through the chain of command. It measures how far down a high-level agent can reach. Also, this carries with it directivity, indicating the subordinates cannot reach back up the tree. If a directed graph is a rooted tree graph with flow in the downward direction only, then a directed arc

(i,j) will not have a directed symmetrical arc *(j,i)* in the opposite direction. Once again, *V* is the number of violations to the hierarchy. *V* is the number of *unordered pairs* of nodes that are *symmetrically* linked. That is, for two nodes *i* and *j*, if there is a directed arc *(i,j)* and a directed arc *(j,i)*, there is a violation. (Krackhardt, 1994) MaxV is the number of unordered pairs of nodes in the directed graph, with MaxV = N*(N-1)/2. The degree of hierarchy is defined as:

$$\text{Graph Hierarchy} = 1 - \left[\frac{V}{MaxV}\right] \qquad (4)$$

In Figure 18.a , V= 6 unordered pairs and MaxV= 6, thus Hierarchy = 1-[6/6] = 0. In Figure 18.b , V=0 and MaxV= 15, resulting in a Hierarchy = 1-[0/15] = 1.0.



(a) Hierarchy = 0 (b) Hierarchy = 1.0

Figure 18. Krackardt Hierarchy Values for Two Organizational Directed Graphs.

Lin adjusts Krackhardt's Hierarchy measure to account for the resource access links. A comparison of the two methods shows that Lin's adjusted 'reachability' definition is slightly different from Krackhardt's original one. Through analysis of examples in Lin's work (Lin, 1993) and through communications the author had with him (email, Lin, 1996), a new meaning of hierarchical reachability is defined. The adjusted

reachability definition is: the ability of a node to meet or interact with another node *through one's own initiative without having to go through ("seek permission of") an intermediary node*. For example, in Figure 19, the dotted lines represent the reachability of each node. It is seen that node 1 is permitted to reach nodes 2, 3, and 4 through its

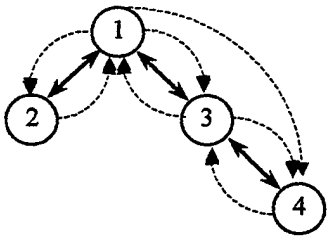


Figure 19. Reachability for a Simple Hierarchical Graph.

own initiative; nodes 2 and 3 can reach node 1 on their own initiative; node 3 can reach node 4 on its own, and; node 4 can reach node 3 on its own. Of these, the number of violations, V, are the reciprocal reaches: $1 \leftrightarrow 2$, $1 \leftrightarrow 3$, and $3 \leftrightarrow 4$. This definition is the context that will be used throughout this paper.

For example, Figure 20 shows a hierarchical architecture with a blocked resource access form. This organization has N = 13 agents, and 12 reciprocal links. MaxV = 13(13-1)/2 = 78. The adjusted degree of Hierarchy is $H = 1-\left[\frac{12}{78}\right] = 84.6\%$.

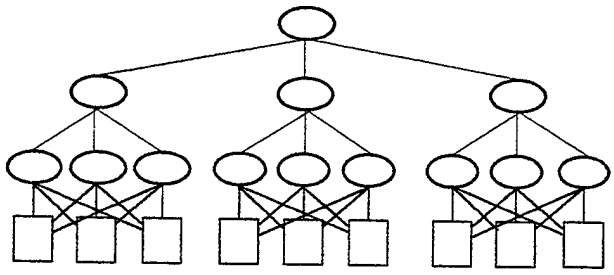


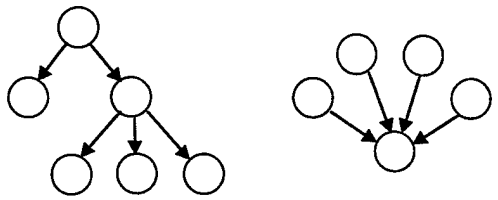
Figure 20. Hierarchical Architecture with Blocked Resource Access.

e. Least Upper Boundedness Adjusted for Resource Access

Upper Boundedness implies that a pair of nodes, *i* and *j*, have a common third node *k*, to whom they can appeal. Normally this node *k* is higher in the organization than either *i* or *j*, and there may exist other nodes *l,m,...* that also are higher upper bounds for *i* and *j*. In graph theory, node *k* is a Least Upper Bound (LUB) for two nodes, *i* and *j*, if there is a directed path from *k* to *i* and a directed path from *k* to *j*, and these paths are shorter than the paths from other upper bounding nodes. In an organization, this refers to the immediate ancestor of nodes *i* or *j*, or the closest boss who has authority over both nodes. (Krackhardt, 1994) The degree of LUB is defined as:

$$\text{LUB} = 1 - \left[\frac{V}{\text{MaxV}}\right] \qquad (5)$$

In this case V is the number of node pairs that have *no* LUB in each component summed across all components, and MaxV is the maximum number of pairs of nodes possible without a LUB. In a connected graph, there must be at least N-1 links, and it will have at a minimum, N-1 pairs of nodes with a LUB. The maximum possible violations for a directed graph are MaxV= (N-1)(N-2)/2. Figure 21 shows degrees of LUB for two different architectures. In Figure 21.a, N=6, MaxV= 5(4)/2 = 10, and V = 0 (every pair has a LUB), so LUB= 1.0. In Figure 21.b, N=5, MaxV= 4(3)/2 = 6, and V= 6 from (N-1) choose 2, or 4 choose 2 = 6 pairs, with a LUB = 1- 6/6 = 0.



(a) LUB = 1.0 (b) LUB = 0

Figure 21. Least Upper Boundedness for two Architectures.

LUB can be adjusted to include resource access forms. However, in this paper, each combination of stylized architecture-resource access forms is a *connected architecture with a single top manager*, and thus every pair of nodes has a LUB. For each architecture-resource combination, LUB= 1.0.

A hierarchical architecture tree graph with a high LUB condition preserves the unity-of-command principle. (Krackhardt, 1994) The existence of a LUB for a node pair provides the opportunity to resolve conflict between the nodes. If there are many pairs without a LUB, as in Figure 21.b, then conflict may exist in the organization trying to resolve a situation. In this case, the bottom node is taking orders from four bosses.

In almost all simple and complex Joint Task Forces, as in most military organizations, the architecture is hierarchical with a LUB = 1.0. There may be infrequent situations, though, where a middle level command is tasked both by the JTF Commander and by another commander external to the JTF entity. One possible joint scenario reflecting this situation occurs when an agent in the JTF Command (e.g., a Marine Expeditionary Unit) is assigned one mission from the JTF ('conduct an amphibious operation in Area ZULU') and another mission from a theater Service Component Commander (SCC) ('use necessary personnel and conduct an embassy evacuation in neighboring nation'). The MEU commander in this case, seen in Figure 22, is working for two immediate superiors.

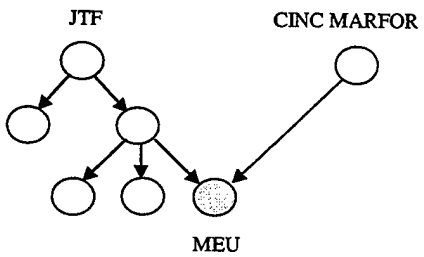


Figure 22. Conflicting Command Arrangements in which LUB does not equal 1.0.

This situation occurs frequently in *coalition* operations where a command from Nation ABC works for the Coalition Task Force Commander, but continues to fall under the authority of the ABC National Military Commander.

Lin adjusts Krackhardt's original version of LUB in that *V* is the number of points that have no least upper bound in a vertical dyadic, summed across all components, and *MaxV* is the maximum number of pairs of points that possibly may have no LUB, summed across all components. In this case Max V = $(N_a\text{-}1)*(N_a\text{-}2)/2 + N_i*N_b$, where N_a is the number of agents, N_i is the number of pieces of information coming from resources, and N_b is the number of baseline agents.

Figure 23 is a Matirx-1 Overlapped-1 architecture with 13 agents (N_a=13), 9 baseline agents (N_b = 9), and 9 pieces of information (N_i =9). The number of dyadics

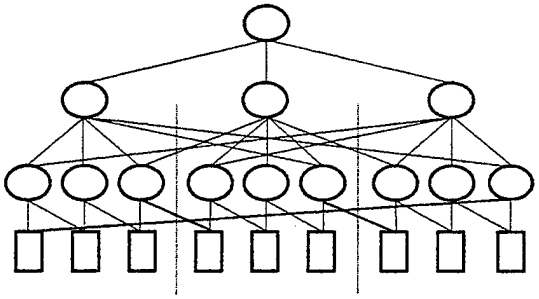


Figure 23. Matrix-1 Overlapped-1 Organization.

that *have* a LUB is 12 + 6 + 2(9) = 36. *MaxV* = (12)*(11)/2 + 9*9 = 147. *V* is determined by subtracting the 36 pairs with a LUB from the maximum possible, resulting in *V* = 147 - 36 = 111. Lin's LUB adjusted for resources is;

$$\text{LUB adj} = 1\text{-}\left[\frac{111}{147}\right] = 0.245.$$

f. External-Internal Index Adjusted for Resource Access

The External-Internal Index (E-I Index) developed in 1988 by Krackhardt and Stern, measures the degree of external and internal divisional linking in an organization. The Index is $E\text{-}I = \left[\frac{EL\text{-}IL}{EL+IL}\right]$. (6)

EL is the number of external links that cross divisions, and IL is the number of internal links that are within the division. It can be seen that if an organization has extensive inter-divisional information linking, a *positive* E-I index results. If an organization has mostly intra-divisional information linking, then a *negative* E-I index results. (Lin, 1993)

Figure 24 shows the Matrix-1 Overlapped-1 organization. There are 27 internal links: 1 each from the top manager to three middle managers (1*3) = 3; 1 from

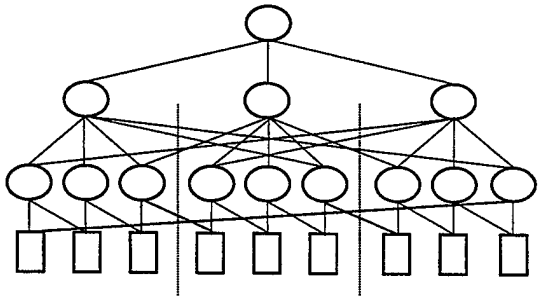


Figure 24. Matrix-1 Overlapped-1 Organization with Divisions Shown.

each of the three middle managers to each of its three divisional baseline analysts ((1*3) * 3 = 9); and 1 or 2 from each baseline agent to the divisional resources (2+2+1 in each div)*3 divisions = 15. The total IL = 3+9+15 = 27. There are 9 external links: 2 each from the three middle managers across divisions to baseline agents (2*3 = 6); and 1 from

one baseline agent in each division across to another resource (1*3=3). The total EL = 6+3 = 9. The E-I Index = $\left[\frac{9-27}{9+27}\right]$ = -0.50

G. SUMMARY

Chapter II is an extensive presentation of several concepts and measures that are used in this research project. A summary of these ideas will show the framework taken forward for analysis.

First, the **structures** that implicitly constitute an organization were reviewed. The structures selected to be analyzed in this work are:

(1) Command.
(2) Authority.
(3) Formal Communications.
(4) Informal Communications.
(5) Intelligence.

Secondly, **organizational architecture** styles and **resource access** forms commonly used in research were presented. The applicability of these to represent a JTF were briefly discussed. These organizational architectural styles and resource access forms are:

Organizational Architectures	Resource Access Forms
(1) Team with Majority Voting.	(1) Segregated.
(2) Team with a Manager.	(2) Overlapped.
(3) Hierarchy.	(3) Blocked.
(4) Matrix-1.	(4) Distributed.
(5) Matrix-2.	

Thirdly, Krackhardt's concept of **hierarchical deviance** was presented. This measure of a specific organization's deviance from the standard rooted tree organization is an important concept used in many of the subsequent measures.

Fourthly, the few **measures** available in the literature, were reviewed for applicability to a JTF. Measures chosen to be used in this paper were discussed and computational examples of each were provided. These final six were selected from similar work done by Dr. Lin. The *final six* are:

(1) Carley's Organizational Cost (Oc).
(2) Krackhardt's Efficiency (K-Effy).
(3) Mackenzie's Hierarchy adjusted for resource access (M-Hier-adj).
(4) Krackhardt's Hierarchy adjusted for resource access (K-Hier-adj).
(5) Krackhardt's Least Upper-Boundedness adjusted for resource access (LUB-adj).
(6) Krackhardt's and Stern's External-Internal Index adjusted for resource access (E-I adj).

In the following chapters, two contrasting Joint Task Forces are designed and then the six measures are applied to each to determine which of these measures may be *useful* for identifying operationally different architectures and quantifying the differences. The measures which perform best in this analysis are used along with data from a Command and Control experiment to demonstrate how measures identified as *useful* can be used in predicting task-oriented organizational performance.

III. JOINT TASK FORCES

> *In dealing with the explosion in information systems, we have tended to focus on improving their current capabilities. Generally, we have tried to improve performance elements within current organizational structures...In the future, the requirements of the battlespace may make traditional hierarchical command and control arrangements obsolescent.*
>
> Joint Warfighting Center Doctrine Division
> *Warfighting Vision 2010*

A. PURPOSE

The purpose of this chapter is to develop two practicable operationally different architectures that will be used in studying the six organizational measures selected in the last chapter. These *known* ***contrasting*** JTF architectures provide a **basis** in analyzing the measures for: 1) their *usefulness* in identifying differences in operationally relevant organizational architectures; and, 2) the examining of fundamental relationships between architectures and organizational performance.

It is difficult, however, to define a current "standard" JTF organizational architecture. There are several issues that preclude designing a standardized architecture considered by doctrine as appropriate for a given mission. Actions are being taken to correct this. This includes establishing and enforcing joint doctrine, standardizing joint training for candidate CJTFs, and learning from experience. These three actions are discussed in the next section to illustrate the challenges a commander faces in designing any JTF architecture, let alone a "standard" one. These are challenges that the flag

officers interviewed for this research encountered during their joint force assignments. Following this discussion, the design and the rationale for the composition of two known contrasting JTF architectures are presented.

B. FACTORS OF INFLUENCE IN ORGANIZING A JTF

When a commander is issued a tasking order to organize a JTF in response to a crisis situation, that commander assumes responsibility for *analyzing* the mission, identifying the *required* resources to complete the mission, and constructing from the *available* resources the best joint organizational architecture to successfully complete the mission. In many instances, the time from receipt of the tasking order to deployment in the crisis area is only a few weeks, forcing the CJTF to quickly put together his organization. Many factors influence the design of the JTF. Of the several factors, three significant ones are briefly discussed below: 1) Doctrine; 2) Training; and, 3) Experience. Abbreviations and definitions of terms are in Appendix A.

1. Doctrine

A pre-designated JTF Commander and staff must have a working knowledge of Joint Doctrine. The Joint Chiefs of Staff (JCS) has a series of Joint Publications (Joint Pubs) that state doctrine and policy for joint operations. Joint Pub 0-2, *Unified Action Armed Forces (UNAAF)*, the Joint Pub 3-0 *Doctrine for Joint Operations* series (with over 42 publications), and Joint Pub 5-00.2, *JTF Planning*, are just some of the publications needed by a CJTF. Together, these documents provide the fundamental concepts and principles of joint command organizations, the military guidance for the establishment and exercise of authority, and the planning of joint operations by a JTF.

The joint publications are the overarching guidance for joint operations, and as a result, they refrain from detailed directions. In addition to these publications, each service in turn generates *their doctrine manuals* that attempt to translate joint doctrine into service-specific doctrine. As such, on many occasions each service brings to the JTF a warfare or other functional capability designed around service-specific doctrine interpreted from joint doctrine.

2. Training

The Joint Training, Analysis, and Simulation Center (JTASC) in Suffolk, Virginia, was established by the CJCS to provide *one vehicle of standard joint training* for the commands of potential joint force commanders (JFC). This phased training includes weeks of in-house academic instruction on the fundamentals of the joint publications, followed by up to two weeks of an interactive, computer-simulated joint operation scenario. This scenario phase is unique – the designated JFC and his staff set up their headquarters in the JTASC facility for the period, and 'command' the JTF 24 hours a day. Actual at-sea and in-the-field commands, and other training facilities may participate in real time as component commanders of the JTF through interactive, distributed linkage.

This is an excellent opportunity for major commands to obtain joint training, but the drawback is the time requirement for a designated CJTF trainee and his staff to be in JTASC. This phased training can cover several months during which the staff members travel between their resident headquarters and JTASC until the cycle is complete. Currently, about three scenarios per year are run, but the Joint Staff is developing plans to

conduct six per year to establish a pool of JTASC trained commanders. (Interview with VADM Gehman, 1995)

In addition, each unified command conducts training and exercises for its pre-designated JTF commanders. These ideally complement the JTASC training, but each unified commander tailors the *organization architecture* and *training* to respective theater concerns (Ivancovich and Wigge, 1996, and Interviews with VADM Gehman and I MEF Staff, 1995). One Lieutenant General with extensive experience in joint operations speaks for many others when he characterizes the mid 1990's training level of JTF commanders:

> ...some of the Unified CINCs are taking it (training) up in their own area and are starting to produce sort of standardized approaches to JTF's, but every CINC has his own approach, and in some cases the CINC doesn't have an approach. He just tasks the Joint Force to have his approach... There are so many disparate ways of doing this business that there isn't a standardized way of approaching it. Therefore there is not a standardized way of training for it, at all.
>
> (ALPHATECH, Inc. Interviews 1995)
>
> (Note: personal anonymity was assured as a precondition for the interviews)

3. Experience

Operational field experience in a JTF command is perhaps the best method to obtain a working knowledge on how to develop an organizational architecture best suited for the mission and adaptability. Observations of a *successful* JTF mission may highlight certain concepts beneficial in constructing the organizational architecture. Observations of an *adverse* experience are just as important, if not more, than a *successful* one.

Studying the difficulties and problems encountered by an unsuccessful JTF mission can provide valuable insights regarding the structural properties of that organization.

Bear in mind, an 'inadequate' architecture started out as the 'best design.' Once issued a tasking mission, the highly capable JTF staff puts tremendous thought into the architectural design. This requires a colossal effort to bring together in one command the required branches of service with assets and logistics needed for the mission.

C. TWO CRITICAL DESIGN ISSUES IN A JTF ORGANIZATION

A CJTF will design an operational JTF organizational architecture based on knowledge of joint doctrine, interpretation of joint doctrine, level of joint training, level of joint experience, and available resources. In the process of pulling different service commands together into the cohesive unit of a JTF, two critical issues that always must be dealt with are authority (control) and organizational command.

1. Operational versus Tactical Control

A CJTF ideally would desire to have Operational Control (OPCON) over all the forces assigned to the JTF. This would enable the commander to freely build the JTF architecture the commander and JTF staff feel is proper. In addition, it would enable the commander to freely direct all forces assigned to the JTF as deemed necessary. This *unity of command* principle ensures that all forces are cohesively working for one commander, and thus conflicts would be minimized or eliminated.

In reality, this is not the case. In Joint Operations, and in Coalition Operations, some of the service component commanders, the subordinate commanders, and the force resources operate under dual allegiance. The Carrier Battle Group (CVBG) commander

might be assigned to the Joint Maritime Component Commander (JFMCC), but also may have responsibilities and actions linked back to the Naval Forces Commander (NAVFOR), or even to the distant Navy Type Commander (NTC). In this situation, the CVBG may be either under OPCON to the CJTF, or OPCON to the NAVFOR and Tactical Control (TACON) to the CJTF. Conflicts of authority and direction frequently result from these *cross-division links* of authority. The CVBG also may have dual reporting requirement, reporting to the CJTF and to the NAVFOR, again housing potential sources of friction in the JTF organization.

Even when a CJTF has OPCON over all commands, conflicts about OPCON and TACON still become apparent. For example, one highly debated issue is the function and limits of the Joint Targeting Coordination Board (JTCB), Joint Force Air Component Commander (JFACC), and associated subordinate commands. In theory, the JTCB speaks for the CJTF in coordinating which adversarial targets will be struck. Sometimes the board extends beyond that to selecting courses of action and which resources will be used – Air Force, Navy, and Marine Corps aircraft, cruise missile, or deep strike Army conventional munitions. A Joint Force Land Component Commander (JFLCC) might disagree with the JTCB or JFACC on targets of priority and the employment of its resources. The JFLCC may want to employ deep strike assets now on a target rather than as directed by the JTCB or the JFACC.

Add to these above conflicts the control of the joint air resources. The Air Force doctrine emphasizes that the JFACC has the ability to *integrate* and *control* air assets to accomplish theater objectives as directed by the CJTF:

> Unity of effort through centralized control of theater air assets is the most effective way to employ airpower. The current Joint Force Air Component Commander (JFACC) concept provides a Joint Force Commander the means to exploit the capabilities of airpower in a theater air campaign.
>
> (US Air Force JFACC Primer, 1992)

In addition to all Air Force sorties, these resources include Marine Corps long range interdiction sorties, Marine Corps sorties in excess of MAGTF support, Naval air assets in excess of maritime air operations requirements, Tomahawk cruise missiles, and Army deep strike munitions.

Joint Pub 3-0 attempts to be flexible in this area of concern by stating that the CJTF shall direct the scope and authority a JFACC within the JTF, but it does cite that the "JFACC normally has TACON of the sorties made available" (Joint Pub 3-0, 1995).

In summary, the critical issue regarding the OPCON/TACON of commands and resources will not have a clear and acceptable solution in the near future. This generates much discussion as well as friction within a JTF organization. The commanders in the 2010 architecture will need to surmount this problem as well.

2. Organizational Command

A JTF is organized as the mission and the CJTF dictate, but current doctrine *requires* at a minimum the inclusion of the **service component commanders** (NAVFOR, MARFOR, ARFOR, AFFOR). **Functional commanders** (JFMCC, JFLCC, JFACC) are stood up as the CJTF directs. A CJTF may establish a functional commander if the operations require close direction of similar capabilities and functions of forces from two or more services, and it is essential to mission success (Joint Pub 3-0, 1995).

There have been operations where the functions that would have been assigned to a functional commander were assigned to the service component commander. The U.S. Somalia Operations are prime examples of this (Allard, 1995).

What is the best JTF Command structure? There are dozens of joint publications available that offer views, as well as 10 years of recent history in which over 23 Joint Task Forces have been established. Maureen Wigge of the Center for Naval Analyses, along with John Ivancovich, conducted a review of this issue in their study *Options for Organizing a Joint Task Force.* Wigge points out that in the U.S. Pacific Command and in the U.S. Atlantic Command, an operational command will most likely be designated the CJTF, such as Commander Second Fleet. Whereas in the U.S. European Command, the CJTFs have traditionally been one of the CINC's service component commanders. In addition, alignment of the subordinate commands has varied within the JTF architecture in that some had functional commanders while others retained the service commanders to conduct the equivalent functions. (Ivancovich, et. al., 1996)

3. No Solution

The critical issues of authority and command structure are not to be taken lightly, and indeed, senior officers on every service or joint staff focus tremendous energy on these issues. The point to be made is that there is no easy solution to the organization of a JTF to achieve maximum mission success. It is necessary then, to see if the measures discussed in Chapter II can be useful in identifying and quantifying differences in operationally different architectures. Such insights are required for designing the effective, but different, organizational architecture for the year 2010.

D. DEVELOPMENT OF TWO CONTRASTING JTF'S

To analyze the usefulness of the measures presented in Chapter II, two contrasting organizational architectures are developed. The first one represents a JTF that could be designed today, and is labeled **JTF ALPHA** (JTF A). The second one represents a possible JTF in the year 2010, and is labeled **JTF BRAVO** (JTF B). Each structure for JTF A and B is illustrated in graph theory format and is precisely defined by a Node Adjacency Matrix. These illustrations and matrices are located in Appendices B and C. Figures 25 and 26 in this chapter show the command structures for JTF A and JTF B as examples of two styles of organizational architectures.

1. JTF Forces

To facilitate in the development of each JTF, a hypothetical crisis situation is generated that requires the rapid deployment of a Corps size Joint Task Force, about 25,000 troops and sailors. **JTF A** and **JTF B** are both composed of the following forces:

1. A Carrier Battle Group (CVBG) with an air wing embarked, and 10 cruisers and destroyers. Six ships carry land attack cruise missiles.

2. One Amphibious Ready Group (ARG) of six amphibious assault and support ships.

3. Two Marine Expeditionary Units combined into one Special Purpose Marine Air Ground Task Force (SPMAGTF), to be embarked in the ARG.

4. The 10^{th} Mountain Light Infantry Division, and the 82^{nd} Airborne Division to be pre-positioned the neighboring host nation

5. Two Air Force wings also stationed in a host nation. Each wing has fighter aircraft, and one wing has bombers equipped with air launched cruise missiles (e.g., ALCM).

Each of the JTFs includes the same five organizational structures presented in Chapter II (Command, Authority, Formal Communications, Informal Communications, and National Intelligence). The specific designs of JTF A and JTF B are operationally different, however. JTF A is developed using practicable concepts, current doctrine, and currently available equipment and systems. JTF B is developed using concepts, doctrine, equipment and systems under consideration now for the forces of the future. The rationale behind the design of each structure for both JTFs is presented in the following two sections.

2. JTF A: Today's Joint Task Force

There are many options to design this JTF as discussed in the previous sections. The author presents *one practicable organization* based on his experience on a joint staff, and on the interviews and discussions with the nine military agencies introduced in Chapter I. This is by no means the only possible organizational architecture, nor is it claimed to be optimum. It is presented as one of two operationally different organizations for analysis in this paper.

This design evolves around the functional commanders, that is, the mission requires specific functional operations involving cross service support. A JFMCC, JFLCC, and a JFACC are established by the CJTF to meet this goal. Service component commanders, the NAVFOR, MARFOR, ARFOR, and AFFOR are established, but they provide logistical and administrative support and possess no operational warfare capabilities. The rationale used in designing JTF A structures is presented in the following sections.

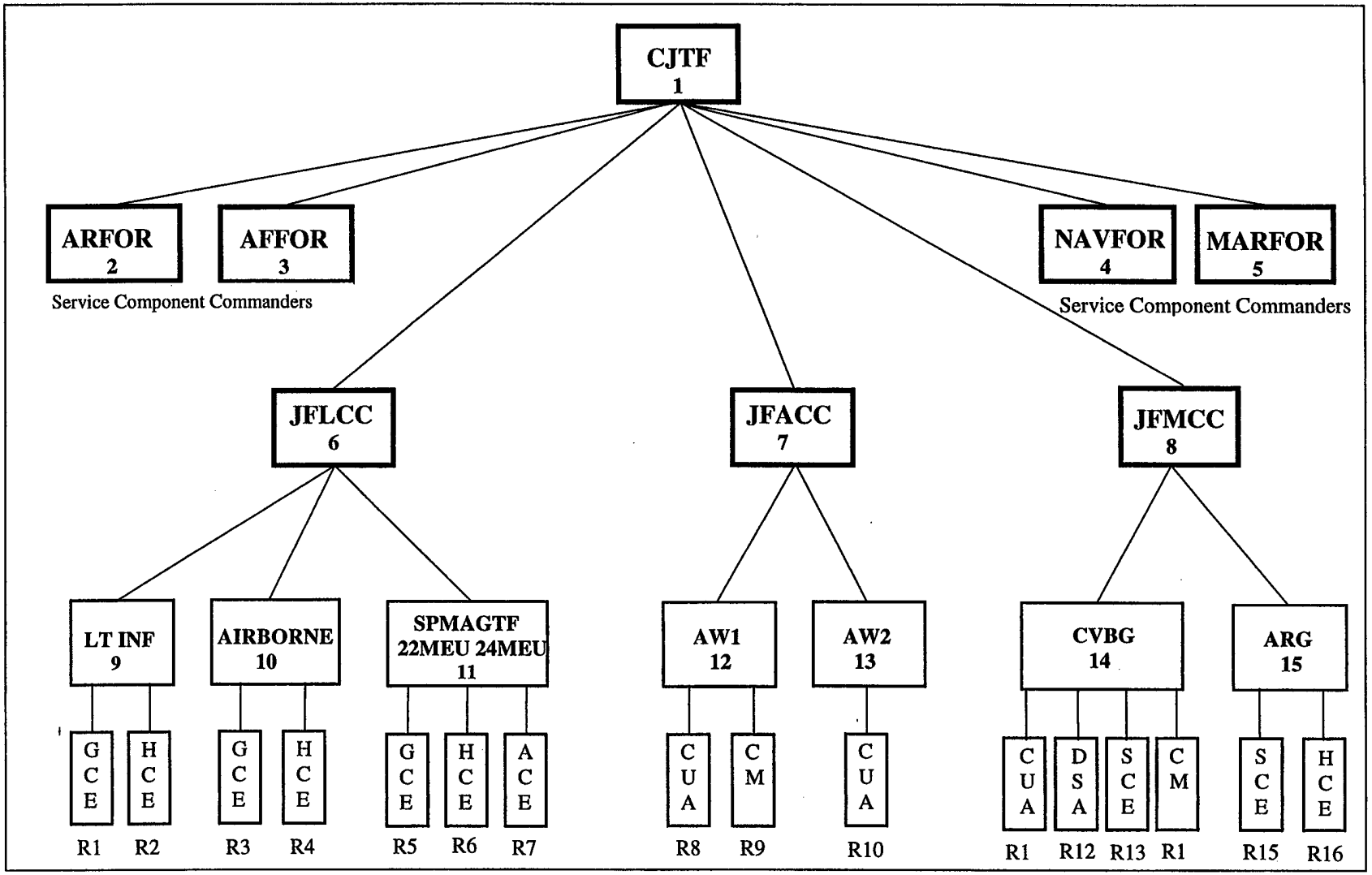


Figure 25. Command Structure of JTF A. The letter R indicates JTF resources.

a. Command Structure

A typical hierarchical formation is presented. The CJTF may be located at the unified commander's headquarters, in the host nation, or embarked in a Navy command and control ship (NCCS). This location is transparent for analysis. The CJTF has four service component commanders (SCC) and three functional component commanders (FCC) working directly for him. They report to him on all matters. Each FCC has subordinate commands aligned through the land, air, and maritime functions. These subordinate commands report to their FCC.

b. Authority Structure

This structure is perhaps the most difficult to design. When presented to several junior and senior officers for input on the structure, the number of different responses equaled the number of requests. To incorporate areas of contention discussed above, TACON of excess SPMAGTF and CVBG aircraft is given to the JFACC. The Joint Targeting Coordination Board resides within the JFACC to facilitate coordination of deep strikes and air assets, thus the CVBG TLAM cruise missiles are assigned TACON to the JFACC.

c. Formal Communications

With satellite availability, communications with just about everyone is possible. The formal communications structure identifies those lines of *authorized official* communications. This is a result of all the commanders' policies regarding which of their subordinate commands can freely and officially communicate with external command elements. For example, the CJTF has authorized the three FCCs to

communicate with each other as well as with the SCCs, and the JFMCC authorized the CVBG to communicate with the JFACC regarding air operations.

d. Informal Communications

This represents the informal discussions that take place, and in many cases result in actions occurring. The STU III secure telephone network is the best example of this process, and proved invaluable in passing reports and information during Desert Storm. Information can be quickly gained via these channels. This structure is based on a STU III secure telephone circuit. There may be others worth developing for future studies.

e. National Intelligence

Situation intelligence, or the lack of it, has a significant impact on military operations. Throughout Desert Storm, several levels of political and military leadership anxiously awaited reports provided by national intelligence sources. Many of these reports contained damage assessments of the latest cruise missile and air strikes. Intelligence reports such as these, are critical inputs to the leaders for decision-making purposes and for planning follow-on actions. In JTF A, this highly classified national intelligence is only distributed from the CJTF to the JFMCC, JFLCC, and JFACC through sensitive security channels. Subordinate commands receive delayed sanitized reports from their respective commanders since the communications infrastructure to securely collect, store, disseminate, and access sensitive information at the field level is not yet fully developed.

3. JTF B: Joint Task Force of 2010

It is the year 2010 and the visionary concepts developed by General Shalikashvili and his staff in 1996 have taken shape. The advances in technology and information collection, processing, and dissemination resulted in dynamic changes in military organization and operations. JTF B employs an organization with a unique architecture that is not feasible today – a **flattened architecture**. This future JTF is envisioned with nearly unlimited communications capability, superior sensors, and rapid target identification and strike processing. As an example of this architecture, Figure 26 shows the Command Structure of JTF B in which all of the middle commands of JTF A have been omitted. In JTF B, the CJTF has authority and communications directly to the baseline commanders, and if required, even to the unit resource in the field.

This flattened architecture initiative was *enthusiastically* brought up by *every* flag officer interviewed, and by the majority of their staff. The Department of Defense Revolution in Military Affairs wargame and exercise series is conducting initial analysis into the flattened architecture and what ramifications it brings with it with respect to command and control, intelligence gathering, and information dissemination. (Interviews with VADM Gehman, 1995, RADM Saffel, 1995, I MEF Staff, 1995, and COL Felker, 1995). Flattened hierarchy is also gaining strong support in the commercial business community as the organizational architecture needed to effectively operate with rapidity and economy (Lecture by McKracken, 1996).

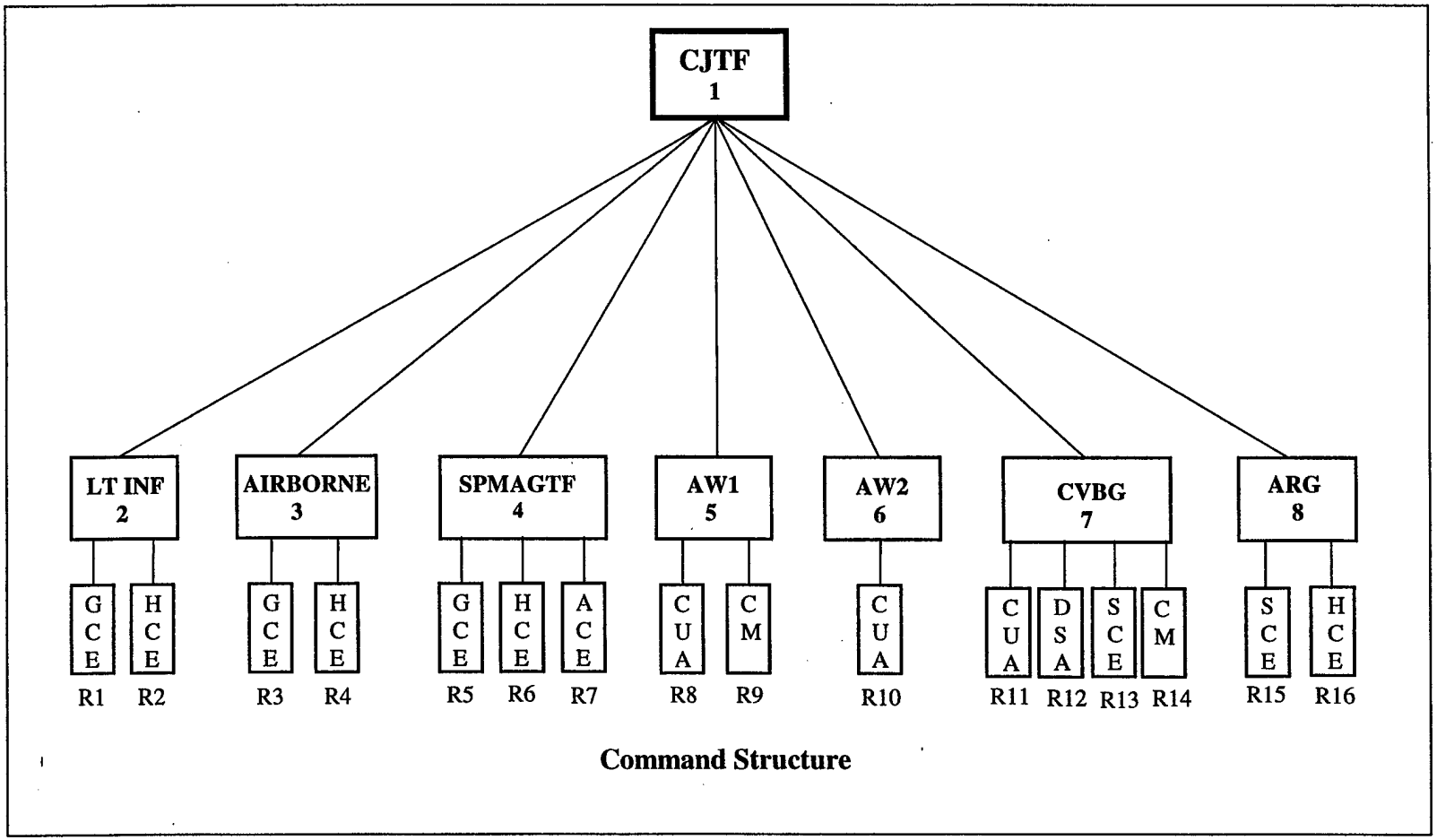


Figure 26. Command Structure of Joint Task Force BRAVO. The CJTF command node encompasses the responsibilities of the JFLCC, JFACC, JFMCC, NAVFOR, MARFOR, ARFOR, and the ARFOR Commanders. The operational commands own resources designated by the letter R.

In the multiple discussions and consultations the author held to develop this architecture for analysis, numerous unique fundamental command and control issues surfaced which made it challenging to design at least one possible 2010 organization. Many of these issues were also brought out by senior officers in a series of 30 interviews with joint commanders and staff officers conducted by ALPHATECH Inc. and Naval Postgraduate School faculty (ALPHATECH Inc. Report, 1995). These point out that the flattened architecture concept is not yet easily nor clearly defined and much doctrinal work lies ahead. The JTF B command structure is illustrated in Figure 26 for one example of a structure, with the complete set of structural illustrations and node adjacency matrices included in Appendix C.

a. Command Structure

The *absence* of the functional and service component commanders is immediately apparent. Given technological advancements, unlimited communications bandwith, and visionary equipment, the functions of these component commanders have been absorbed by either the CJTF or the subordinate commands, thereby eliminating the need for a middle management layer.

b. Authority Structure

The significant change in the authority structure is the direct authority link from the CJTF to the baseline commanders. The CJTF has OPCON of all the commands and resources, thus eliminating the need for TACON of forces between subordinate commands.

c. Formal Communications Structure

Policies set by commanders regarding official formal communications are the same as in JTF A. In the flattened architecture, there are fewer lines of communication.

d. Informal Communications Structure

The same issues covered in the JTF A informal communications structure apply to JTF B, and again there are fewer links.

e. National Intelligence Structure

The National Intelligence Structure in JTF B is radically different than in JTF A in that the lower-level commanders now have access to the same national intelligence information as the CJTF and at approximately the same time. The introduction of tactical computer networks with multi-level security and greater bandwidth permits near real time transfer of intelligence and information from the CJTF (or from national intelligence assets) to the field commanders, as well as transfer between the field subordinate commanders. National intelligence is immediately and simultaneously pushed from the national intelligence sources to the CJTF and the field commanders without sanitization.

E. CHAPTER SUMMARY

To conduct analysis of the six organizational measures, two known different operationally relevant JTF architectures, JTF A and JTF B, were developed with the elements of conflict discussed in this chapter. JTF A is a practicable architecture reflecting current doctrine and technology. JTF B is an architecture embodying a

proposed doctrine for 2010 concurrent with envisioned technological advancements in C^4I. These architectures provide a basis for analysis of the measures that can be useful in identifying the properties of JTF organizations.

The difficulties a CJTF faces in creating these organizations were discussed. Doctrine, training, and experience are three significant factors that influence the design of an organizational architecture. These factors, along with others, currently preclude a standardized approach to selecting an organizational architecture that is optimum for a mission.

IV. ANALYSIS OF ORGANIZATIONAL MEASURES

A. INFORMATION

In Chapter II, six final measures were selected as *useful* candidates in detecting differences between organizational architectures. In Chapter III, two contrasting, operationally different and practicable JTF organizations, JTF A and B, were developed to assist in the analysis of these six measures. In this chapter, analysis is conducted to identify which of the six show the most potential as *useful* measures when applied to the five structures.

The process to identify the potentially *useful* measures is as follows:

1. To begin, a priori beliefs for each measure when applied to the authority and formal communications structures of JTF A and B are discussed.
2. Values are calculated for each of the six measures applied to the five structures in each JTF. This results in 30 values for JTF A and 30 values for JTF B. These values are then graphically presented for visual examination.
3. A difference scoring method is introduced to provide a quantitative analysis for identifying potentially useful measures.
4. Comparisons between the a priori beliefs and the measure results are discussed to provide insight into each measure when applied to the all structures of JTFs A and B.

5. Finally, a simple illustration is presented to demonstrate the use of the candidate measures in modeling the relationship between organizational architectures and performance.

B. A PRIORI MEASURE BELIEFS

A brief summary of what each measure is attempting to capture, and an *a priori* belief of that measure when applied to structures of JTF A and JTF B is presented in this section. The *authority* and *formal communications* structures will be used for this discussion. Recall that JTF A and JTF B are two distinctly, operationally different architectures. **JTF A** is a 3-tiered, 15-node organization with 16 resources, and **JTF B** is a 2-tiered, 8-node organization with the same 16 resources. These resources are assigned tasks and in turn provide pieces of information to the 7 baseline subordinate commands, who then make a decision and pass on this new piece of information to the next higher command.

1. Carley's Organizational Costs

Carley's Organizational Costs (Oc) combines the total number of pieces of information processed (Ic) and the total number of links installed to transfer the information (Cc). Since these are additive, the more links in a structure, the higher the costs. JTF A with 15 nodes is "larger" than JTF B with 8 nodes, thus it is expected that $Oc_{JTF\,A} \geq Oc_{JTF\,B}$.

2. Krackhardt's Original Efficiency

Links, or communication or authority lines, are installed in a physical or social system at some cost. A rooted-tree graph has exactly N-1 links, fewer than this and it

divides into at least two components, and more than this and multiple paths and cycles are created. Excess links may have some optimal number since too many can burden the agents. In Krackhardt's Efficiency, K-Effy = $1-\left[\frac{V}{MaxV}\right]$, a ratio of violations to the maximum possible is calculated, which produces a normalized value. If both JTF A and JTF B are designed with the same mission tasking, it is expected that a proportionate number of links will be included in each architecture. Thus, only a slight difference is expected between the two, resulting in K-Effy $_{JTF\,A} \cong$ K-Effy $_{JTF\,B}$.

3. Mackenzie's Hierarchy Adjusted

Mackenzie's Hierarchy adjusted for resources, M-Hier-adj, looks at the redundancy of organizational structure. It counts the number of *Uncle and Cousins* links, and the redundant links, and compares these with the minimum links *T*, needed for operation. Recall, M-Hier-adj = $1 - \left[\frac{U_T+C+U}{T+U_T}\right]$. This measure depends on the magnitude differences of the numerator and denominator. If the value of C+U/ T is larger for JTF A than it is for JTF B, then the overall JTF A ratio will be larger and will result in M-Hier $_{JTF\,A} \leq$ M-Hier $_{JTF\,B}$. If the JTF A ratio is less than JTF B ratio, then it will be just the opposite, in M-Hier-adj $_{JTF\,A} \geq$ M-Hier-adj $_{JTF\,B}$. Since JTF A has more nodes and links, including cross divisional links such as TACON in the Authority structure and communication links in Formal Communications structures, it is expected that (C+U)/ T will be larger for JTF A than JTF B, and M-Hier $_{JTF\,A} \leq$ M-Hier $_{JTF\,B}$.

4. Krackhardt's Hierarchy Adjusted

Krackhardt's Hierarchy adjusted for resources, K-Hier-adj, also takes the ratio of the number of violations to the maximum possible, K-Hier-adj = $1-\left[\frac{V}{MaxV}\right]$. Again, if the mission assigned to both is the same, the same proportionate number of links is expected by both organizations, and that the K-Hier-adj $_{JTF\,A} \cong$ K-Hier-adj $_{JTF\,B}$.

5. E-I Index Adjusted

The External-Internal index, E-I adj, compares the interdivisional links over the intradivisional links, E-I-adj $= \left[\frac{EL-IL}{EL+IL}\right]$. The JTF B architecture contains fewer nodes and, in most structures, will contain fewer internal links, fewer external links, and thus fewer total links, than the JTF A architecture. For JTF B, with a significantly smaller EL number, the overall E-I adj ratio should be *more negative* than JTF A. It is expected then, that E-I-adj $_{JTF\,A}$ (less negative) $\geq$ E-I-adj $_{JTF\,B}$ (more negative).

6. Least Upper Bound Adjusted

Once again, Lin adjusts the Least Upper Bound, LUB-adj, to account for resources. The unconnected links are those without an LUB and are normalized by the maximum possible pairs, LUB-adj = $1-\left[\frac{V}{MaxV}\right]$. It is expected that JTF A's *V* will be greater than JTF B's *V*, but also JTF A *MaxV* will be *far larger* the JTF B *MaxV*, resulting in a *smaller* ratio for JTF A, and as a result, LUB-adj $_{JTF\,A} \geq$ LUB-adj $_{JTF\,B}$.

C. CALCULATIONS

There are six measures and five structures for each organizational architecture leading to 30 numerical results per organization. The structural node adjacency matrices presented in the previous chapter provide most of the numerical information for calculations of each measure. Care must be taken to ascertain the appropriate number of links to use in each measure since they do not always equal the number of total links. Measures like Mackenzie's Hierarchy Adjusted and Organizational Costs sometimes count the same link twice in their equations.

Table 1 provides a summary of the numerical values of the measures for each organizational architecture. Calculations of each measure for the formal communications structure only are contained in Appendices B and C as representative examples of the computational process.

Table 1. Summary of JTF A and JTF B Organizational Measure Values

JTF ALPHA

	Measure					
Structure	Oc	K-Effy	M-Hier adj	K-Hier adj	E-I adj	LUB adj
Command	59	1	1	0.867	-1	0.148
Authority	67	0.956	0.774	0.829	-0.765	0.167
Formal Comms	155	0.648	0.169	0.533	-0.581	0.305
Informal Comms	220	0.396	-0.1	0.343	-0.318	0.419
National Intel	19	1	0.4	0.943	-1	0.057

JTF BRAVO

	Measure					
Structure	Oc	K-Effy	M-Hier adj	K-Hier adj	E-I adj	LUB adj
Command	38	1	1	0.75	-1	0.173
Authority	38	1	1	0.75	-1	0.173
Formal Comms	56	0.714	0.677	0.536	-0.586	0.218
Informal Comms	79	0.333	0.378	0.25	-0.243	0.278
National Intel	59	0	0.192	0.733	-0.045	0.331

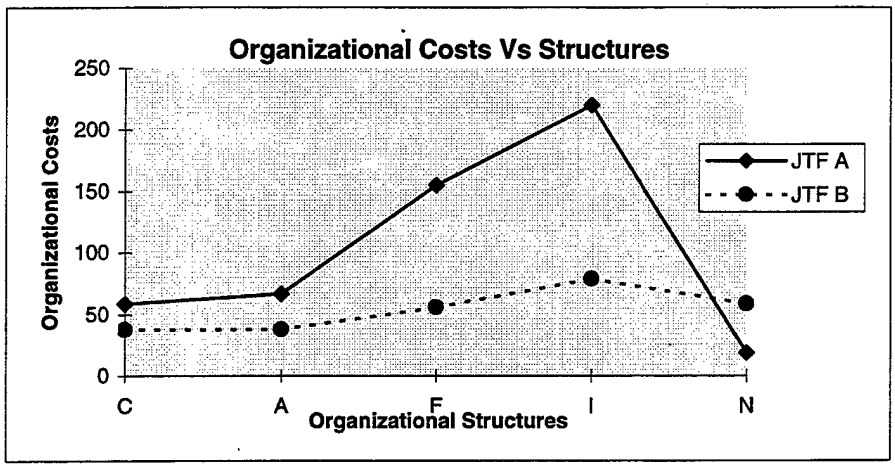
D. ANALYSIS OF ORGANIZATIONAL MEASURES

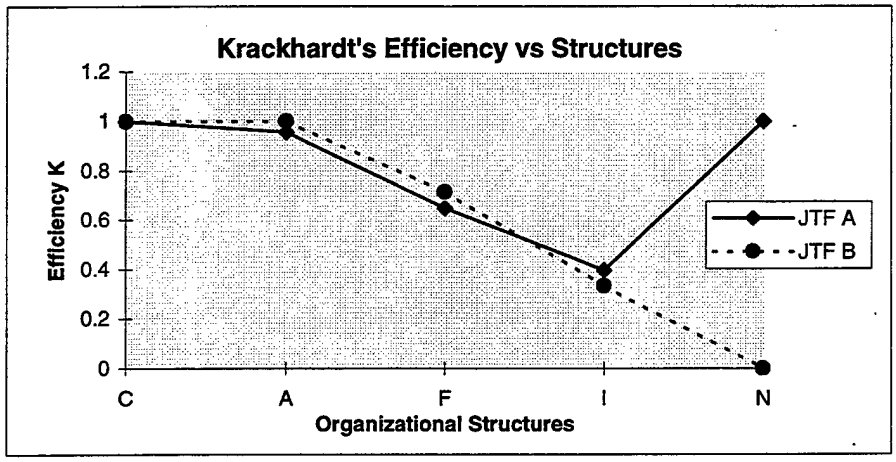
Measures are *useful* if they identify architectures that are operationally different. It is possible that some measures may be more *useful* for some of the structures within the architecture, and other measures are more *useful* for other structures. As the first step in determining which measures are *useful* for identifying differences, the respective measure values of each structure are plotted to gain a graphical description.

1. Initial Measure Analysis

The results of each measure applied to the structures of organizations JTF A and JTF B are shown in the graphs of Figure 27. Visually one can get a sense of which structures each of the measures can be applied to in identifying operationally different architectures. For example, it appears from Figure 27.a that organizational cost may be an effective measure to identify architectures that differ in the formal communication and informal communication structures, but may not be effective in identifying architectures that differ in their command, authority, or national intelligence structures. From Figure 27.b, it looks like the hierarchy adjusted measure would be a poor choice for identifying architectures that differ in any of the structures.

However, considerable judgment is required to determine if seemingly small differences on the graph are significant, or if apparently large differences are insignificant. To assist in this subjective evaluation, *bounds* are constructed at JTF A values ± 15% and ± 30%. The ranges of these bounds were arbitrarily chosen by the author as a starting point and to ensure consistency across the different scales during





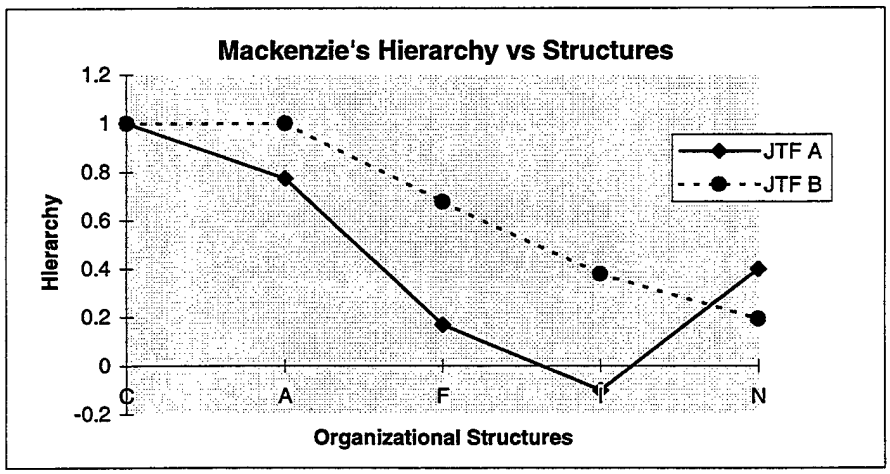
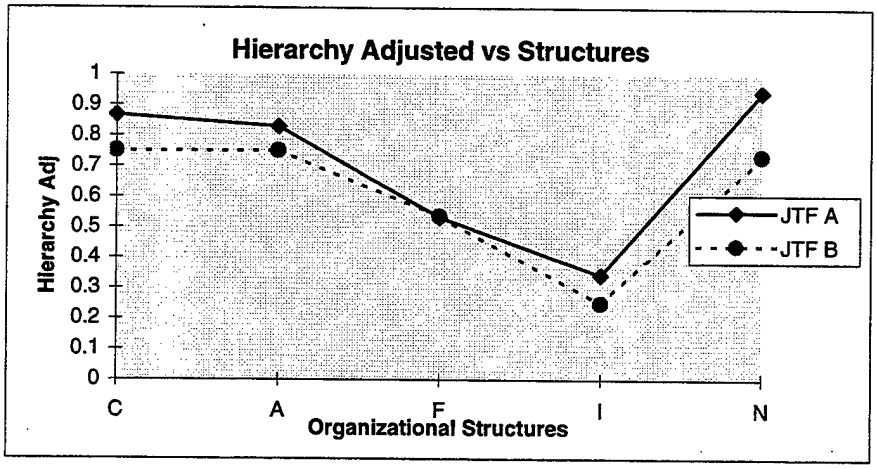
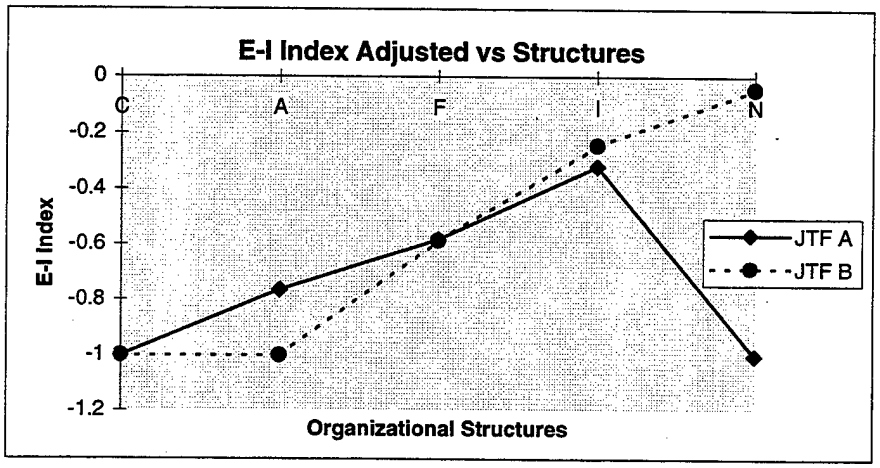


Figure 27a. Organizational Measures versus Structures for JTF A and JTF B

C = Command A = Authority F = Formal Communications -
I = Informal Communications N= National Intelligence





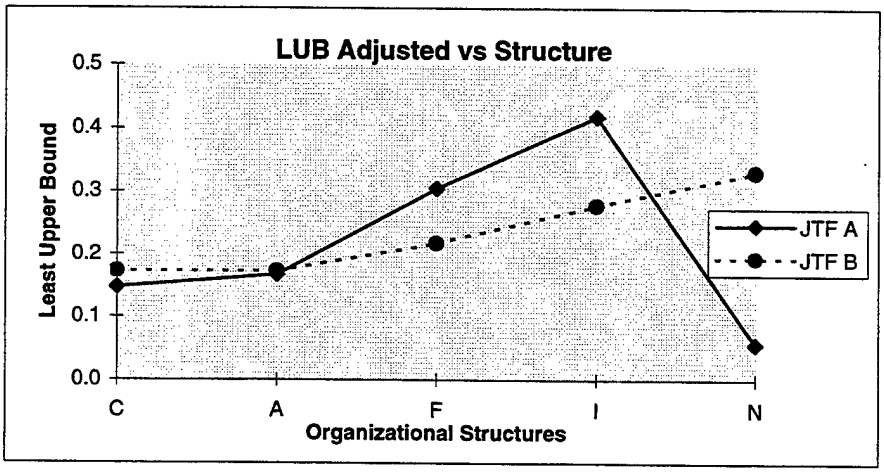


Figure 27b. Organizational Measures versus Structures for JTF A and JTF B

C = Command A = Authority F = Formal Communications
I = Informal Communications N= National Intelligence

the subjective evaluation of the differences. Difference scores are then used to assist in measuring *usefulness.* This method is detailed below.

2. Difference Scores

To help evaluate the significance of the differences between JTF A and JTF B measures, a **difference scoring** method is employed. The bounds defined above are used to score the *differences* between the JTF A and JTF B measures for each structure as follows:

0 if B is within ± 15% of A, indicating no appreciable difference.

1 if B is within ± 15-30% of A, indicating some appreciable difference.

2 if B is greater than ± 30% of A, indicating definite difference.

These scores are tabulated and summed over all structures to determine a final value. It is expected that relatively small measure differences will not be indicative of operationally different structures and thus are assigned a score of 0, whereas relatively large measure differences will be highly indicative and are thus assigned a score of 2. Those measures with the largest final values should be effective in indicating overall operational differences between the two organizational architectures.

Table 2 contains the measure values of JTF A and B for every structure. The ranges are calculated and difference scores are assigned in the last column. The total of the difference scores for each measure is recorded in the Sum of Difference Scores block. Since each difference score has a minimum value at 0 and a maximum value at 2, and the total is summed across five structures, the range of possible Sum of Difference Scores for each measure is 0 to 10. A sum of 6 or greater for a measure is chosen to imply

Table 2. Difference Scoring

Difference Score: 0 = B within ± 15% , 1 = B within ± 15-30% , 2 = B greater than ± 30%

Operational Costs

Structure	Measure value JTF A	JTF B	Upper and Lower Bounds for: ± 15% of JTF A		± 30% of JTF A		Integer Score
Command	59	38	50.15	67.85	41.3	76.7	2
Authority	67	38	56.95	77.05	46.9	87.1	2
Formal Comms	155	56	131.75	178.25	108.5	201.5	2
Informal Comms	220	79	187	253	154	286	2
National Intel	19	59	16.15	21.85	13.3	24.7	2
						Sum of Difference Scores:	10

Krackhardt's Efficiency Original

Structure	Measure value JTF A	JTF B	Upper and Lower Bounds for: ± 15% of JTF A		± 30% of JTF A		Integer Score
Command	1	1	0.85	1.15	0.7	1.3	0
Authority	0.956	1	0.813	1.099	0.669	1.243	0
Formal Comms	0.648	0.714	0.551	0.745	0.454	0.842	0
Informal Comms	0.396	0.333	0.337	0.455	0.277	0.515	1
National Intel	1	0	0.85	1.15	0.7	1.3	2
						Sum of Difference Scores:	3

Mackenzie's Hierarchy Adjusted

Structure	Measure value JTF A	JTF B	Upper and Lower Bounds for: ± 15% of JTF A		± 30% of JTF A		Integer Score
Command	1	1	0.85	1.15	0.7	1.3	0
Authority	0.774	1	0.658	0.890	0.542	1.006	1
Formal Comms	0.169	0.677	0.144	0.194	0.118	0.220	2
Informal Comms	-0.1	0.378	-0.085	-0.115	-0.070	-0.130	2
National Intel	0.4	0.192	0.34	0.46	0.28	0.52	2
						Sum of Difference Scores:	7

Table 2. Difference Scoring

Difference Score: 0 = B within ± 15% , 1 = B within ± 15-30% , 2 = B greater than ± 30%

Krackhardt's Hierarchy Adjusted

	Measure value		Upper and Lower Bounds for:				Integer
Structure	JTF A	JTF B	± 15% of JTF A		± 30% of JTF A		Score
Command	0.867	0.75	0.737	0.997	0.607	1.127	0
Authority	0.829	0.75	0.705	0.953	0.580	1.078	0
Formal Comms	0.533	0.536	0.453	0.613	0.373	0.693	0
Informal Comms	0.343	0.25	0.292	0.394	0.240	0.446	1
National Intel	0.943	0.733	0.802	1.084	0.660	1.226	1
						Sum of Difference Scores:	2

E-I Index Adjusted

	Measure value		Upper and Lower Bounds for:				Integer
Structure	JTF A	JTF B	± 15% of JTF A		± 30% of JTF A		Score
Command	-1	-1	-0.850	-1.150	-0.700	-1.300	0
Authority	-0.765	-1	-0.650	-0.880	-0.536	-0.995	1
Formal Comms	-0.581	-0.586	-0.494	-0.668	-0.407	-0.755	0
Informal Comms	-0.318	-0.243	-0.270	-0.366	-0.223	-0.413	1
National Intel	-1	-0.045	-0.850	-1.150	-0.700	-1.300	2
						Sum of Difference Scores:	4

Krackhardt's LUB Adjusted

	Measure value		Upper and Lower Bounds for:				Integer
Structure	JTF A	JTF B	± 15% of JTF A		± 30% of JTF A		Score
Command	0.148	0.173	0.126	0.170	0.103	0.192	1
Authority	0.167	0.173	0.142	0.193	0.117	0.218	0
Formal Comms	0.305	0.218	0.259	0.351	0.214	0.397	1
Informal Comms	0.419	0.278	0.356	0.482	0.293	0.544	2
National Intel	0.057	0.331	0.048	0.066	0.040	0.074	2
						Sum of Difference Scores:	6

potential *usefulness*. Using this criteria, the tabulated scores in Table 3 indicate that Organizational Costs (Oc), Mackenzie's Hierarchy (M-Hier adj), and Krackhardt's Least Upper Bound Adjusted (LUB Adj) are promising for distinguishing operational differences between two architectures.

Table 3. Summary of Difference Scores for JTF A and JTF B.

	Measure					
Structure	Oc	K-Effy	M-Hier adj	K-Hier adj	E-I adj	LUB adj
Command	2	0	0	0	0	1
Authority	2	0	1	0	1	0
Formal Comms	2	0	2	0	0	1
Informal Comms	2	1	2	1	1	2
National Intel	2	2	2	1	2	2
Σ Difference Scores	10	3	7	2	4	6

3. Difference Probability Mass Function

The difference scoring method previously described provides an initial quantitative method to identify measures that may be useful in analyzing two different organizational architectures. Other quantitative methods are possible for identifying the usefulness of measures in assessing the significance of the differences. One such method, a difference probability mass function, is described below because it is related to this thesis and it presents an opportunity for additional research. This method was not explored, however, since its execution requires extensive computer simulation that was deemed beyond the scope of this thesis.

Dr. Carley is currently researching the difference probability mass function method at Carnegie Mellon University. The method involves determining the *probability*

mass function for *differences* in the measure between all pairs of architectures of N nodes or less. One could then calculate the differences for a test set of known operationally different pairs of architectures (the Delta statistic, Δ). If each of these differences were to have a small probability of occurring by chance (e.g.; $\alpha = 0.05$), then the measure would be deemed *useful*.

To apply this method to JTF architectures, the probability mass function should be determined for the set of 'operationally relevant' architectures. Operationally relevant architectures are those with N nodes or less, and with the necessary number of links, that could result in viable organizational structures with practicable applications. Given an architecture with N nodes, high and low constraints on the number of links would eliminate many, *but not all*, operationally unrealistic structures. For example, an architecture with 10 nodes has a maximum number of links equal to 45, and over 3.15×10^{13} possible combinations (2^{45}). The command structure for such an organization would not have a practicable underlying graph composed of only 2 links, nor one with 20 links. Constraining the 'operationally relevant' number of links between 8 and 15 would eliminate many impracticable candidates and would reduce the computational time.

To identify useful measures with the *difference probability mass function* method the following steps are required (a simple example is provided in Appendix D if the reader wishes to follow while reading these steps):

1. Develop computer algorithms to perform the following:
    a. Generate the set of underlying graphs for a given N node architecture, subject to constraints.
    b. For each underlying graph, calculate every measure.

c. Develop the *probability mass function* for all operationally relevant architectures.
d. Develop the *difference probability mass function* using the probability mass distribution from (c) and the measures differences.

2. When presented with two *known* operationally different architectures, apply each measure to every structure of both architectures.

3. Check the significance of each observed difference, the Δ statistic, using the *difference probability mass function* to identify *useful measures*.

The node adjacency matrix used to mathematically define the structures in this paper can serve as the basis of a methodology for building each underlying graph in a computer algorithm.

4. Comparison with A Priori Beliefs

Comparison between the difference scores and the a priori beliefs are discussed in the next few sections. The graphs in Figure 27 and the difference scores in Table 2 are referred to often in these discussions.

a. Carley's Organizational Costs

It was expected that $Oc_{JTF\ A} \geq Oc_{JTF\ B}$. The graph for Oc shows this is true for all structures except national intelligence. In this structure, JTF A intelligence dissemination was limited to the three middle subordinate commands, whereas in JTF B was widely disseminated as a product of enhanced intelligence security and processing capability. The costs of information processing and organizational linkage are higher in the case of JTF B. Graphically, Oc appears to be a candidate measure for identifying this difference. The difference score value of 10, the maximum possible, confirms this measure as a strong candidate.

b. Krackhardt's Original Efficiency

Expectations held that K-Effy $_{JTF\ A} \cong$ K-Effy $_{JTF\ B}$. Graphically this looks correct except for the national intelligence structure. The large difference for the national intelligence structure is easily explained. In JTF A, the number of links in excess of N-1 is zero, resulting in a K-Effy $_{JTF\ A}$ = 1-0 = 1. In JTF B, a JTF with a minimum organizational hierarchy, the number of excess links equals the number of maximum links, yielding a K-Hier = 1-1= 0. Thus, the overall measure difference is 1-0 = 1. This measure is deemed not very useful since it has a difference score of 3 and it identified a difference between architectures in only 1 out of 5 structures.

c. Mackenzie's Hierarchy Adjusted

A priori beliefs held M-Hier $_{JTF\ A} \leq$ M-Hier $_{JTF\ B}$. In 4 out of 5 structures, M-Hier-adj $_{JTF\ A} \leq$ M-Hier-adj $_{JTF\ B}$, showing that the flattened architecture with its fewer redundant cross divisional linkages gives a lower redundancy ratio and results in a higher value for M-Hier adj. The anomaly, national intelligence, has a higher degree of redundancy in JTF B than JTF A due to a more distributed intelligence capability. Mackenzie's Hierarchy difference score of 7 is the second highest, confirming that this measure is a strong candidate for identifying operationally different architectures.

d. Krackhardt's Hierarchy Adjusted

This measure, which looks at the reciprocal reachability of a structure, was expected to be nearly equivalent, that is K-Hier-adj $_{JTF\ A} \cong$ K-Hier-adj $_{JTF\ B}$. In this case, the ratio of reciprocal reachability violations to the maximum number of links possible,

$\frac{V}{MaxV}$, is proportionately the same for JTF A and JTF B despite their operational differences. The graph of this measure and a difference score of 2 support the a prior belief. K-Hier-adj is thus not considered a candidate measure.

e. E-I Index Adjusted

Expectations for this measure, E-I-adj $_{JTF\ A}$ (less negative) $\geq$ E-I-adj $_{JTF\ B}$ (more negative), is graphically supported only by the authority structure. The expectation is contradicted by the informal communications and national intelligence structures. The more negative values are attributed to more *intra*divisional links than *inter*divisional links, indicating less crossing of divisional boundaries. With a difference score of 4, this measure shows little potential to indicate appreciable differences between organizational architectures.

f. LUB Adjusted

The expectation that LUB-adj $_{JTF\ A} \geq$ LUB-adj $_{JTF\ B}$ is neither supported nor contradicted graphically, but a difference score of 6 indicates some potential as a *useful measure*. In the formal and informal communications structures, JTF A with more nodes than JTF B, has a higher MaxV. JTF A's more dense structure results in fewer node pairs without a vertical LUB, and thus a higher degree of LUB in this situation. Again, national intelligence is just the opposite condition, the JTF B network is more dense than the JTF A network, producing a higher degree of LUB. The difference score of 6 indicates this measure may be *useful* in detecting a difference in structures that are *significantly* different from each other as the result of technology or processing capability.

5. Summary

For this thesis, the **difference scoring** method is used as an initial quantitative method to identify organizational *measures* that may be *useful.* As mentioned earlier, the measures with scores equal to or greater than a value of 6 are to be considered the promising candidates. Three measures (and their scores) that meet this criteria are Carley's Organizational Costs (10), Mackenzie's Hierarchy Adjusted (7), and Krackhardt's Least Upper Bound Adjusted (6). Of these three, **Carley's Organizational Costs** and **Mackenzie's Hierarchy Adjusted** are identified as the strongest candidate measures based on their graphical results and their high difference scores. These two measures are selected for use in the next section to demonstrate an application of these measures.

E. APPLICATION OF THE MEASURES

It is ultimately desired to understand and model the relationship between operational organizational architectures and organizational performance for the full spectrum of missions that a JTF is liable to be assigned. With this knowledge, it is possible to evaluate current and future JTF architectures with respect to adaptability and mission performance. For a given mission, this objective can be broken down into two research steps:

1. Understand the relationship between a measure and the type of architecture (for each structure).
2. Understand the relationship between a measure and organizational performance.

To adequately model the above relationships, analysis using a large data set collected over a suitable range of architectures and missions is required. Ideally this data would be obtained from a series of experiments specifically designed to examine the relationships between JTF architectures and organizational performance. To date, however, no experiments have been conducted to collect this data.

As a result, limited data collected from a related A2C2 command and control (C^2) experiment is used in the following sections to *illustrate* the analytical processes that would be performed. This is only a demonstration, *not* a complete analysis. Research is ongoing to develop the data needed for a comprehensive analysis. In this example, two architectural measures are computed for each of two organizational architectures and then linear regressions of performance data on the architectural measures are used to model the relationships between organizational architectures and organizational performance. Descriptions of the C^2 experiment and the JTF architectures are presented in the following sections.

1. Command and Control Experiment

As part of the research for this thesis, the author participated in the design of a C^2 experiment conducted at the Naval Postgraduate School (NPS) in March 1996 in support of the ONR sponsored A2C2 research project. There were two experimental factors: organizational architecture and task type, each controlled at two levels.

The levels of organizational architecture were 2-tier hierarchy and 3-tier hierarchy. The two levels of task type were tasks that required units at the lowest level in the hierarchy to compete for assets owned by one of them, and tasks that required these

same units to compete for assets owned by a node higher in the hierarchy. Four teams of six military officers participated in the experiment, with each team experiencing all four experimental conditions in counterbalanced order. Each member of a team represented a different command node within a JTF (e.g., CJTF,CVBG, etc. ...).

There were four scenarios, one for each experimental condition. Each scenario presented the players with a set of competition events, which caused the lowest level players to compete over scarce assets. These assets were owned by one of them in two of the scenarios, and owned by a node higher in the hierarchy in the other two. Of interest to this thesis are the MEDEVAC events. There were two MEDEVAC events in each of the scenarios that generated competition for assets owned by a node higher in the hierarchy. The latency times of these MEDEVAC events (the times from the introduction of the MEDEVAC requirements to their completion) are used to demonstrate the use of the selected measure.

The experiment was conducted on the Distributed Dynamic Decision Making Simulator III in the NPS Systems Technology Laboratory. The simulator recorded all of the actions taken by each of the players and the times that the actions were taken. From these, the values of many dependent variables can be determined. The values for the MEDEVAC latency times were extracted from these records, and are in Table 4.

2. Development of JTF 2 and JTF 3

Two new simple JTFs were developed based on the architecture designs of the experiment. JTF 2 is a symmetric 2-tiered organization, and JTF 3 is a symmetric 3-tiered organization. For this demonstration, only the *Authority* and the *Formal*

Communications structures were developed. These two structures were chosen because both are relevant to the experiment which involves potential authority conflicts, and both include the main differences between the JTF2 and JTF3.

Table 4. MEDEVAC Latency Times

Team (a)	Task Type (b)	Scenario Time Task Generated (c)	Scenario Time that JTFs act on tasks		Latency Times	
			JTF 2 (d)	JTF 3 (e)	JTF 2 (d)-(c)	JTF 3 (e)-(c)
A	MEDEVAC Blue Team	2	701.5	734	699.5	732
	MEDEVAC Red Team	2	1356	1598.5	1354	1596.5
B	MEDEVAC Blue Team	2	436.5	406	434.5	404
	MEDEVAC Red Team	2	608.5	476	606.5	474
C	MEDEVAC Blue Team	2	541	860	539	858
	MEDEVAC Red Team	2	656.5	949.5	654.5	947.5
D	MEDEVAC Blue Team	2	751.5	689	749.5	687
	MEDEVAC Red Team	2	441	586.5	439	584.5

3. Measures versus Performance Analysis

The first step of the objective mentioned at the beginning of this section is to understand the relationship between the measure and the type of architecture for each structure. To accomplish this in our example, the Oc and M-Hier adj values are calculated for the Authority and the Formal Communications structures of operational architectures JTF 2 and JTF 3. These values are:

	Authority		Formal Communications	
	JTF 2	JTF 3	JTF 2	JTF 3
Oc	16	37	39	52
M-Hier adj	0.91	0.85	0.61	0.51

Analysis of these measures reveals that the order relationship is *consistent across structures.* That is, $Oc_{JTF2} < Oc_{JTF3}$ for both the Authority and Formal Communications,

and M-Hier $_{JTF2}$ > M-Hier$_{JTF3}$ also for both of these structures. This is only an illustration, however, using limited data from two architectures. A proper understanding of this relationship requires additional Oc and M-Hier adj values calculated for other practicable JTF architectures.

The second step is to understand the relationship between the measure and organizational performance. To accomplish this, a *simple linear regression* line was fit to the 16 latency times for each measure, for each structure. The model for this is:

$$t_i = \beta_0 + \beta_1 x_i + e_i, \ \mathrm{i} = 1,\ldots 16.$$

In this model the response variable t_i is the MEDEVAC latency time, and the predictor variable x_i is Oc or M-Hier adj. Since this experiment contains only two architectures there are only two values for the predictor variable for each structure (e.g., Authority Oc only has two values, 16 and 37). It is acknowledged that in this case, the 16 MEDEVAC latency times regressed onto the two values of Oc (or M-Hier adj) merely constitutes a line with its slope determined by the averages of the performance values at the two design points. Regression analysis with data from an experiment that contains additional Oc and M-Hier adj predictor values obtained from additional JTF architectures in the design might well reveal that the relationship is not linear, nor even monotone. Figures 28.a and 28.b show the fitted lines for each simple linear regression.

The regression of MEDEVAC latency times onto Organizational Costs for both structures is shown in Figure 28.a. As previously noted, for *both* the Authority and Formal Communications structures, Oc$_{JTF2}$ < Oc $_{JTF3}$. Thus, the positive slopes in the

two regressions indicate that architectures with *lower* Oc measures in these structures tend to have *lower* latency times for MEDEVAC type tasks.

Figure 28.b shows MEDEVAC latency times regressed onto Mackenzie's Hierarchy adjusted for both structures. It is seen, again, that the relationship between latency times and the measure is the same for both structures. That is, in this example, $\text{M-Hier}_{JTF2} > \text{M-Hier}_{JTF3}$ for both Authority and Formal Communications. Thus, the negative slopes indicate that architectures with *higher* M-Hier adj measures for these structures tend to have *lower* latency times for MEDEVAC type tasks.

Based on the simple linear regression of just this one data set, it is implied that for MEDEVAC type tasks and for these structures, as Oc ↑ the latency times ↑, and as M-Hier adj ↑ the latency times ↓. The estimator values for each simple regression are shown in Table 5. Since this is only a demonstration, the quality of fit for this experimental data is inconsequential and the usual accompanying regression parameters for analysis of variance, estimated standard deviation s, coefficient standard errors $s_{\beta 0}$, $s_{\beta Oc}$, and $s_{\beta MHier}$, t statistic, and confidence intervals are omitted in Table 5.

Next, a *multiple linear regression* was performed, regressing the Latency times on both Oc and M-Hier adj within a structure. The model for this regression is:

$$t_i = \beta_0 + \beta_1 x_{i1} + \beta_1 x_{i2} + e_i, \quad i = 1,\ldots 16.$$

In this model, x_{i1} and x_{i2} represent the Oc and M-Hier measures respectively. The estimator values for the multiple regression are also shown in Table 5.

In a simple linear regression model, the sign of the estimator values represents the change in latency times given a unit increase in the measure. In a multiple regression

model, the sign of the estimators describe the combined effect of both predictor variables as one moves from point to point in the design space.

Table 5. Regression Results

Simple Linear Regression Estimator Values

Authority		
Measure	Coefficient	Estimate
Oc	β_0	607.7
	β_{Oc}	4.8
M-Hier	β_0	3374.5
	β_{MHier}	-2959

Formal Communications		
Measure	Coefficient	Estimate
Oc	β_0	381.9
	β_{Oc}	7.7
M-Hier	β_0	1304.9
	β_{MHier}	-1008.8

Multiple Regression Estimator Values

Authority		
Measure	Coefficient	Estimate
both	β_0	-133.2
	β_{Oc}	6.1
	β_{MHier}	792.4

Formal Communications		
Measure	Coefficient	Estimate
both	β_0	81.6
	β_{Oc}	10.3
	β_{MHier}	328

From Table 5 it is seen that, unlike the simple linear regression, all of the multiple linear regression predictor estimators are positive:

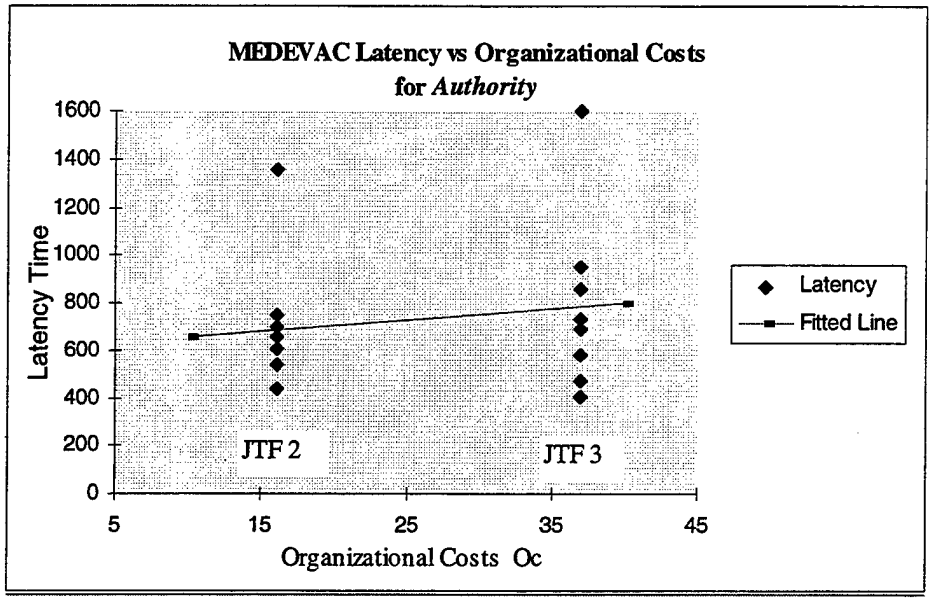
$t_i = -133.2 + 6.1x_{i1} + 792.4x_{i2} + e_i, \quad i = 1,\ldots 16$ Authority

$t_i = 81.6 + 10.3x_{i1} + 328.0x_{i2} + e_i, \quad i = 1,\ldots 16$ Formal Communications

At face value, it appears that for the Authority and Formal Communications structures, a unit increase in one of the predictor variables while the other one is held constant results in an increase in the expected value of the latency time. However, because this multiple linear regression model is based on a limited data set that results in large predictor variable standard errors and an unresolved degree of collinearity, analysis of the

correlation between the predictor variables leads to inconclusive findings. Thus, neither analysis nor resulting inferences of the model will be discussed. What is gained from this multiple linear regression example is that, given a sufficient data set, it can be a useful technique in explaining the combined effect of predictor variables as one moves across the design space.

In summary, this section presents only a **demonstration** of the potential *usefulness* of *architectural measures* in predicting organizational performance for JTFs. **Results** from the above illustrative analysis are tentative since the sample set is small (n=16) and there are only two predictor points in the design space for the linear regression models. To gain a better understanding of the relationship between JTF architectures and organizational performance, data needs to be collected on additional measures of organizational performance, and more experiments need to be developed that include additional architectures that would provide added predictor measures across all structures.



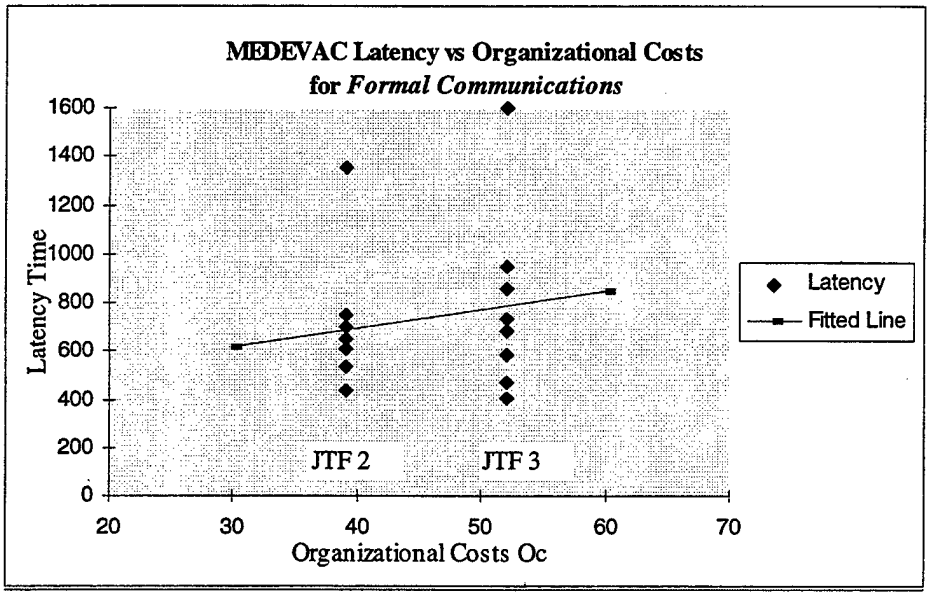
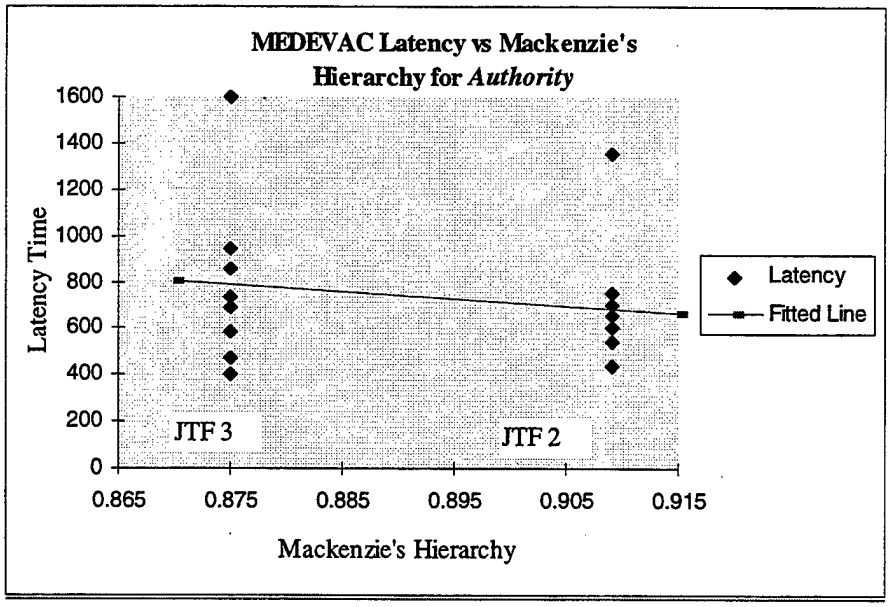


Figure 28.a. Latency Times versus Organizational Costs Hierarchy measure. The charts show two points: 1) the 2-tiered architecture, JTF 2, has a *lower* Organizational Cost for both the Authority and the Formal Communications structures than the 3-tiered architecture, JTF 3; 2) The *lower* Organizational Costs values have *lower* latency times. Based on this set of experiment data, it is implied that operational architectures with lower Organizational Costs values take less time than those with_ higher values in completing MEDEVAC type tasks.



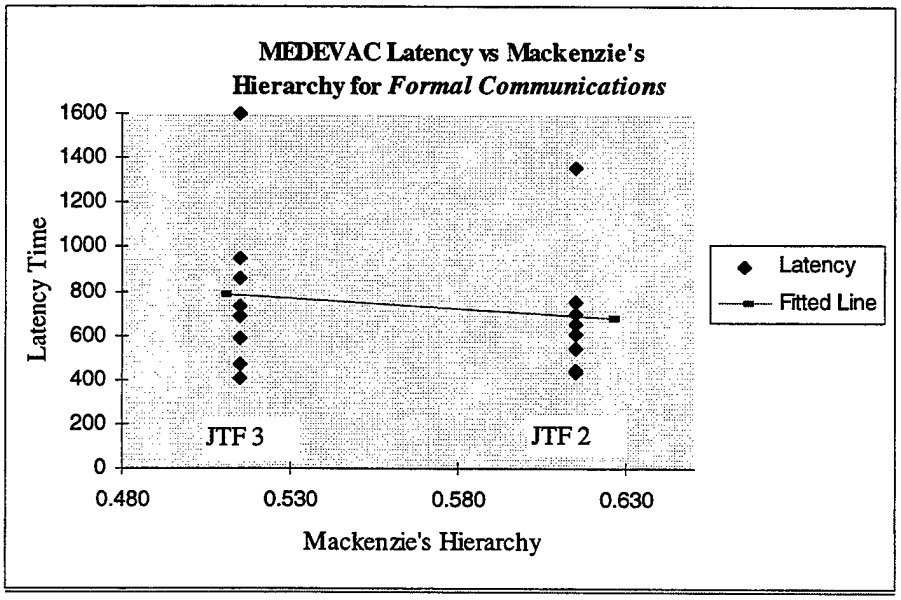


Figure 28.b. Latency Times versus Mackenzie's Hierarchy adjusted measure. The charts show two points: 1) the 2-tiered architecture, JTF 2, has a *higher* Mackenzie's Hierarchy for both the Authority and the Formal Communications structures than the 3-tiered architecture, JTF 3; 2) The *higher* Mackenzie Hierarchy values have *lower* latency times. Based on this set of experiment data, it is implied that operational architectures with higher Mackenzie's Hierarchy values take less time than those with lower values in completing MEDEVAC type tasks.

V. CONCLUSIONS AND RECOMMENDATIONS

A. RESEARCH GOAL

The goal of this research is to identify and define an initial set of structures of organizational architectures, and to evaluate the applicability of organizational measures found in the literature, to each of the structures and the architecture as a whole. If these measures are able to distinguish differences between the two operationally different architectures presented in Chapter III, they are considered *useful measures.*

B. ORGANIZATIONAL STRUCTURES

Five organizational structures were selected to characterize a military JTF architecture:

1. Command
2. Authority
3. Formal Communications
4. Informal Communications
5. National Intelligence

The **Authority, Formal Communications, Informal Communications, and National Intelligence** structures show strong potential as structures that can be helpful in modeling and defining the dimensions of organizational architectures. The difference scores in Table 3 of Chapter IV support this in that these four structures have scores of 1 or 2 for three or more of the six measures. It is of interest to note that the Informal Communications and the National Intelligence structures have difference scores of 1 or 2 across *all* the measures. In particular, the National Intelligence structure has the maximum difference score value of 2 in five out of the six measures. This indicates that

National Intelligence is an excellent structure to help define operationally different architectures.

The **Command** structure shows little potential as a helpful structure. Even though for this research it defines two known contrasting architectures, it has difference scores in only two of the six measures. Thus, the Command structure, which is important to a commander of a JTF, is of little use in modeling and defining the dimensions of organizational architectures.

In summary, Authority, Formal Communications, Informal Communications, and National Intelligence are structures *effective* in analyzing operationally architectures.

C. ORGANIZATIONAL MEASURES

Six measures from the literature are selected for analysis to determine their *usefulness*. These are:

1. Organizational Costs
2. Krackhardt's Efficiency original
3. Mackenzie's Hierarchy adjusted
4. Krackhardt's Hierarchy adjusted
5. E-I Index adjusted
6. Least Upper Bound adjusted

The Difference Scoring method clearly shows that **Organizational Costs** and **Mackenzie's Hierarchy** adjusted are *useful measures* that identify different operationally relevant architectures. To some degree, **Least Upper Bound adj** is *useful*, mainly in structures that contain several cross-divisional relationships.

These three measures show distinguishable differences in values when applied to the contrasting JTF A and JTF B architectures. In addition, Organizational Costs and

Mackenzie's Hierarchy also display distinguishable differences in values between JTF 2 and JTF 3 architectures. These three measures are thus identified as *useful measures.*

The demonstration of **measure utility in predicting organizational performance** for a MEDEVAC task type shows that there is *strong potential* for further application of this concept. This paper presents a simple illustration using only one performance indicator from one experiment with only two different operationally relevant architectures. Experiments with additional operationally relevant architectures need to be incorporated in experiments to increase the number of *observations* of measure *values* across all structures. Additionally, more *performance* measures needs to be looked at. This would allow better analysis of overall measure utility with respect to architecture influence in organizational performance.

D. RECOMMENDATIONS

1. Identify Additional Structures

This paper develops five structures drawing from material in the literature and from discussions with senior joint military officers. This is a first attempt in identifying a set of useful structures, but it is not a complete set. As seen above, the Command structure proves to be of little value for identifying differences between the two developed architectures in the paper using the measures from the literature. There are, perhaps, more structures that may be pertinent to a military JTF that are not presented here. Further research is needed in this area.

2. Expand Set of Operationally Relevant Architectures

Two practicable and different operational architectures were developed for this paper. For any follow-on analysis to be conclusive, the set of candidate architectures needs to be enlarged and can be accomplished through computer simulation.

3. Develop a Difference Probability Mass Function

The Difference Probability Mass Function procedure shows great promise in identifying different operationally relevant architectures through the use of these measures. The existence of this function would provide a more precise method for determining the significance of the operational differences between architectures in the analysis. Through more analysis and computer simulation, this function could become the **primary** method in identifying differences between organizational architectures.

4. Incorporate Time and Cost

Each measure was applied to structures that are static. In an actual JTF operation, these structures may change over time as a result of environmental drivers of adaptation. This change over time may be captured in some or all of the measures.

These structures are simple graphs, some of which may be complete networks. In this paper, information that is passed carries a unit cost of 1, which makes measure calculations simple. In reality, information processed and decisions made within the same structure may carry weighted costs that vary with each node pair. For example, in a JTF mission that is predominantly oriented towards an air warfare campaign, the links between the JFACC and command nodes with air assets and deep strike weapon systems, would have higher costs than links between the JFMCC and NAVFOR.

E. SUMMARY

This paper is an initial effort to identify the organizational structures and measures that will assist in research of organizational adaptability. Four of the five organizational structures developed appear to be helpful in modeling and defining organizational architectures, and three of six measures are identified as useful candidates for modeling the relationship between architectures and measures of performance. The difficulties faced by commanders in developing JTF organizations are presented to highlight the challenges faced now, and those that will be faced in the next decade. Useful quantitative analysis of current and future JTF organizations is necessary to ensure that available resources are properly committed to the personnel, equipment, doctrine, and organizational architectures that look to be the most promising for the year 2010.

This research is only a first step in identifying the 'optimum' architecture. The analysis of relationships between the six organizational measures and the two contrasting operationally relevant architectures provides limited results, but it shows strong promise in predicting organizational performance based on the structural dimensions of a JTF architecture.

APPENDIX A

JOINT TASK FORCE ABBREVIATIONS AND DEFINITIONS

Abbreviations for JTFs

Top and Middle Level Commands

AFFOR	Air Force forces Service Component Commander
ARFOR	Army Forces Service Component Commander
CJTF	Commander Joint Task Force
JFACC	Joint Force Air Component Commander (functional)
JFLCC	Joint Force Land Component Commander (functional)
JFMCC	Joint Force Maritime Component Commander (functional)
MARFOR	Marine Forces Service Component Commander
NAVFOR	Naval Forces Service Component Commander

Baseline Level Commands

22 AND 24 MEU	22 and 24 Marine Expeditionary Units, work for SPMAGTF
AIRBORNE	102 Airborne Division
ARG	Amphibious Ready Group
AW1 and AW2	Air Wing 1 and 2
CVBG	Carrier Battle Group
LT INF	10th Mountain Light Infantry Division
SPMAGTF	Special Purpose Marine Air-Ground Task Force

Resource Assets

ACE	Air Combat Element (aircraft available to respective commander)
CM	Cruise Missiles (air or ship launched Tomahawk cruise missile)
CUA	Common Use Air (aircraft directed by JFACC for common
mission,	e.g., Close Air Support, deep strikes)
DSA	Direct Support Air (aircraft given local tasking by local commander, e.g. Combat Air Patrol for ships)
GCE	Ground Combat Element (infantry, artillery, engineering support)
HCE	Helicopter Combat Element (helicopters assigned to commanders)
SCE	Surface ship Combatant Element (ships in the ARG and CVBG)

APPENDIX A

Definitions

Functional Component Command. A command normally, but not necessarily, composed of forces of two or more Military Departments which may be established across the range of military operations to perform particular operational missions that may be of short duration or may extend over a period of time. (Joint Pub 1-02)

Joint Force Air Component Commander. (JFACC) The joint force air component commander derives authority from the joint force commander who has the authority to exercise operational control, assign missions, direct coordination among subordinate commanders, redirect and organize forces to ensure unity of effort in the accomplishment of the overall mission. The joint force commander will normally designate a joint force air component commander. The joint force air component commander's responsibilities will be assigned by the joint force commander (normally these would include, but not be limited to, planning, coordination, allocation, and tasking based on the joint force commander's apportionment decision). Using the joint force commander's guidance and authority, and in coordination with other Service component commanders and other assigned or supporting commanders, the joint force air component commander will recommend to the joint force commander apportionment of air sorties to various missions or geographic areas. (Joint Pub 1-02)

Joint Force Land Component Commander. (JFLCC) The commander within a unified command, subordinate unified command, or joint task force responsible to the establishing commander for making recommendations on the proper employment of land forces, planning and coordinating land operations, or accomplishing such operational missions as may be assigned. The joint force land component commander is given the authority necessary to accomplish missions and tasks assigned by the establishing commander. The joint force land component commander will normally be the commander will normally be the commander with the preponderance of land forces and the requisite command and control capabilities. (Joint Pub 1-02)

Joint Force Maritime Component Commander. (JFMCC) The commander within a unified command, subordinate unified command, or joint task force responsible to the establishing commander for making recommendations on the proper employment of maritime forces and assets, planning and coordinating maritime operations, or accomplishing such operational missions as may be assigned. The joint force maritime component commander is given the authority necessary to accomplish missions and tasks assigned by the establishing commander. The joint force maritime component commander will normally be the commander with the preponderance of maritime forces and the requisite command and control capabilities. (Joint Pub 1-02)

APPENDIX A

Operational Control (OPCON). Transferable command authority that may be exercised by commanders at any echelon at or below combatant commander. OPCON may be delegated and is the authority to perform those functions of command over subordinated forces involving organizing and employing commands and forces, assigning tasks, designating objectives, and giving authoritative direction necessary to accomplish the mission....OPCON includes authoritative **direction over all aspects** of military operations and joint training necessary to accomplish missions assigned to the command...OPCON normally provides **full authority** to organize commands and forces and to employ those forces as the commander in operational control considers necessary to accomplish assigned missions. (Joint Pub 1-02)

Service Component Command. A command consisting of the Service component commander and all those Service forces, such as individuals, units, detachments, organizations and installations under the command including the support forces , that have been assigned to a combatant command, or further assigned to a subordinate unified command or joint task force. (Joint Pub 1-02)

Tactical Control (TACON). Command authority over assigned or attached forces or commands or military capability or forces made available for tasking, that is **limited** to the detailed and, usually, **local** direction of control of movements or maneuvers necessary to accomplish missions or tasks assigned. TACON is inherent in OPCON. TACON may be delegated to, and exercised at any level at or below combatant commander. (Joint Pub 1-02)

APPENDIX B

JTF A

Organizational Structure Diagrams
Node Adjacency Matrices
Formal Communications Structure Measure Calculations

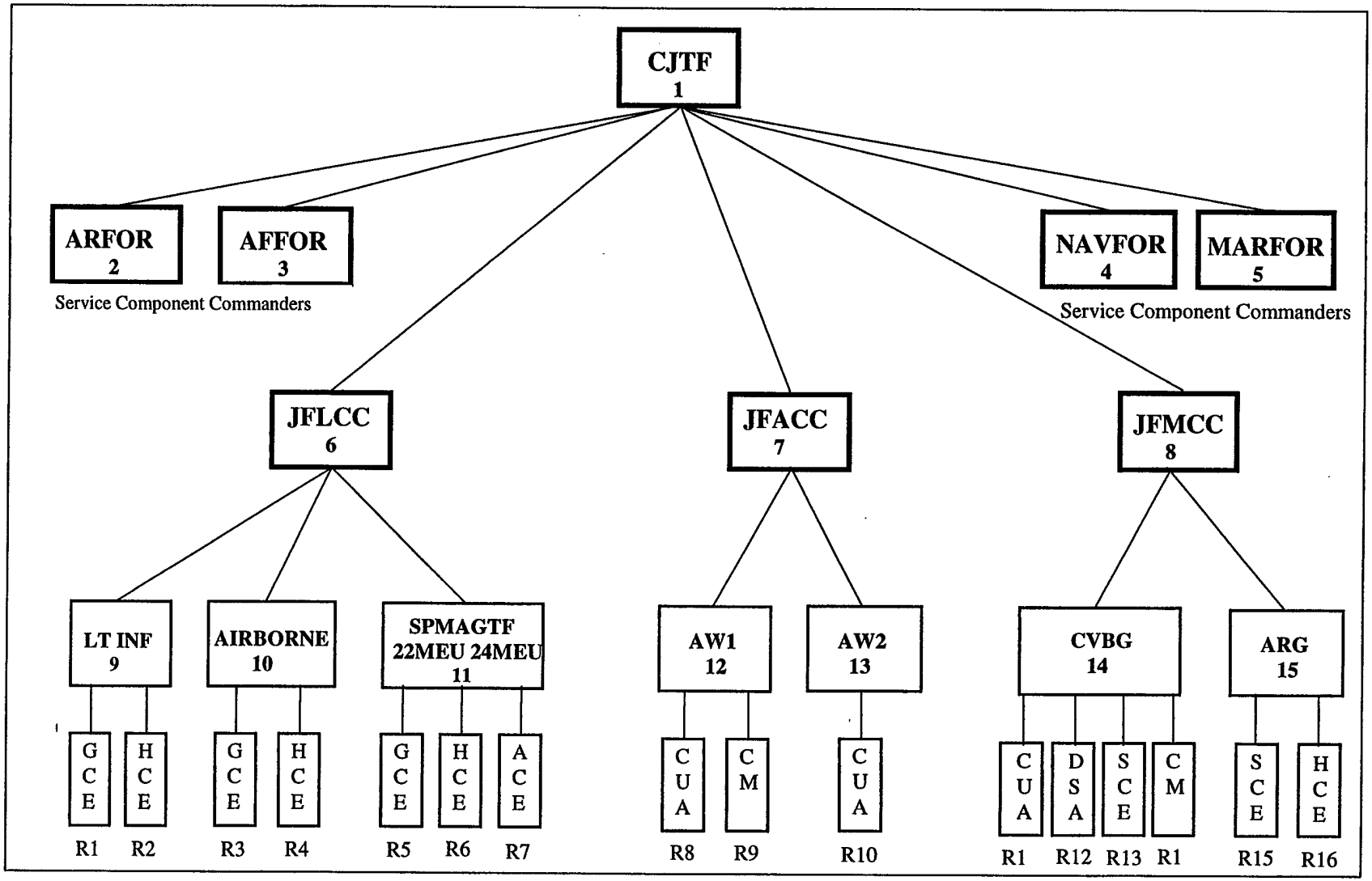
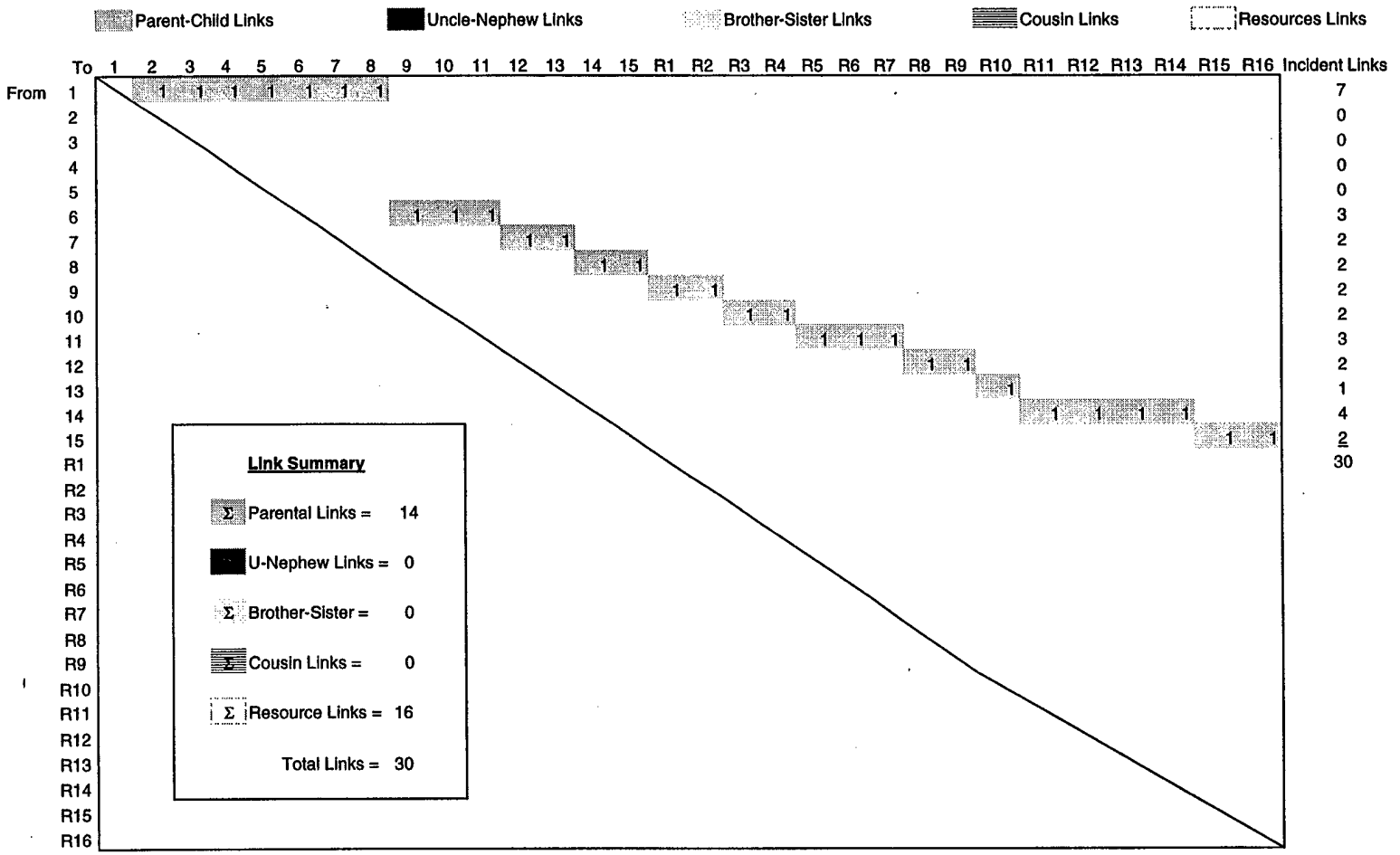


Figure 29.a. Command Structure of JTF A. The letter R indicates JTF resources.

JTF ALPHA *Command Structure* Node Adjacency Matrix



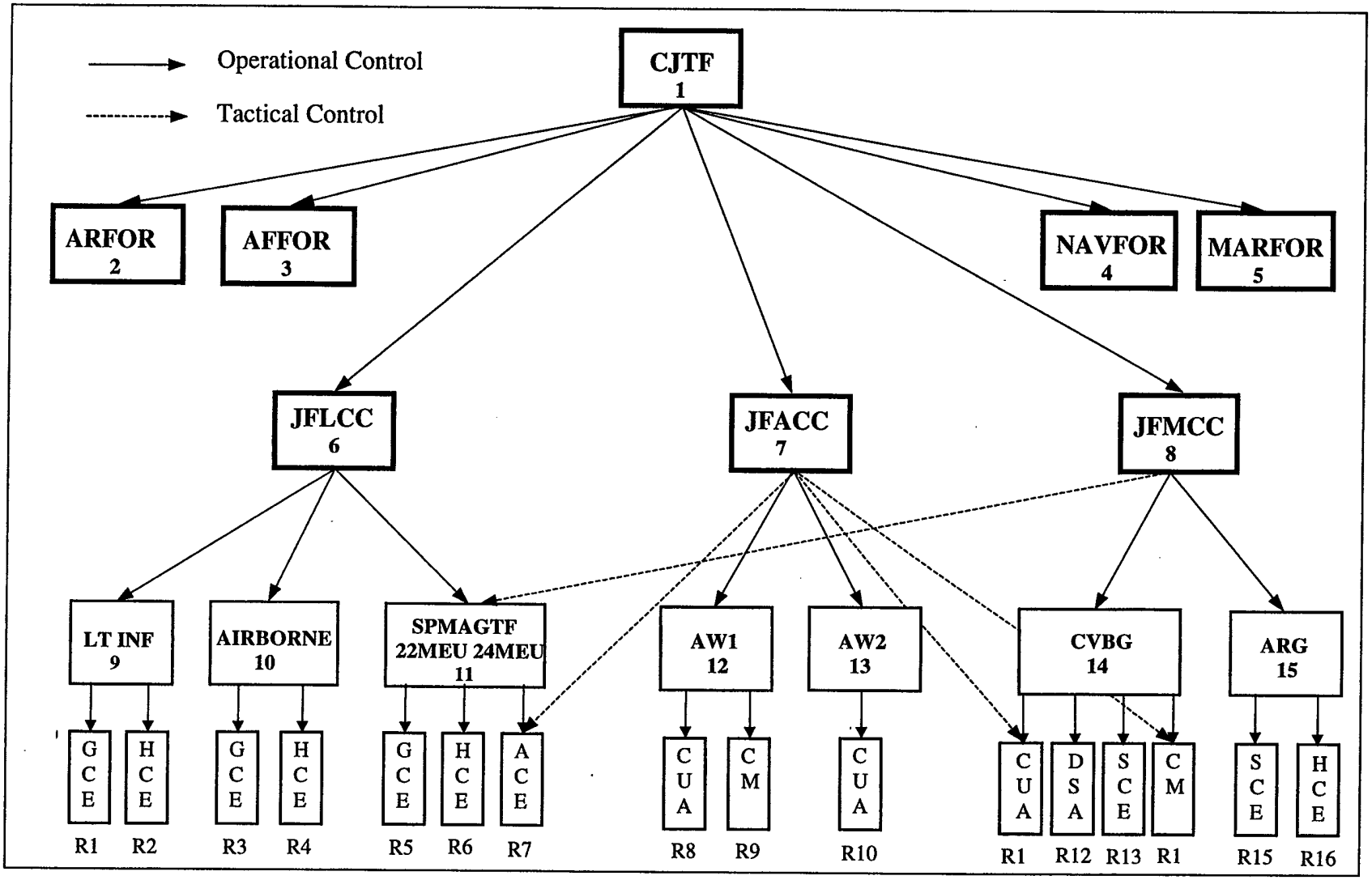
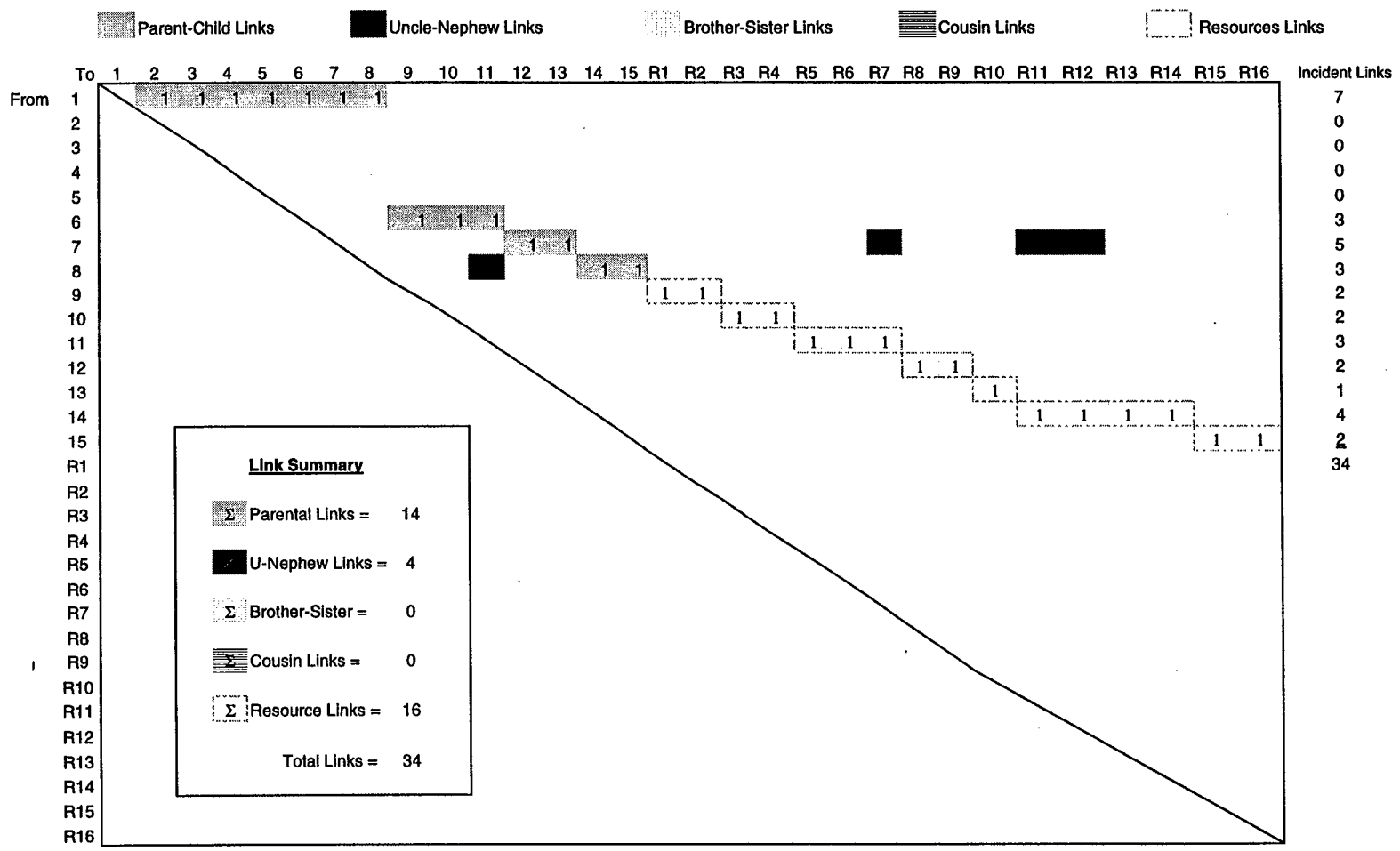


Figure 29.b. Authority Structure for JTF A. The letter R indicates JTF resources.

JTF ALPHA *Authority Structure* Node Adjacency Matrix

Directed Adjacency Matrix: (1,2) -> 1 has authority over 2



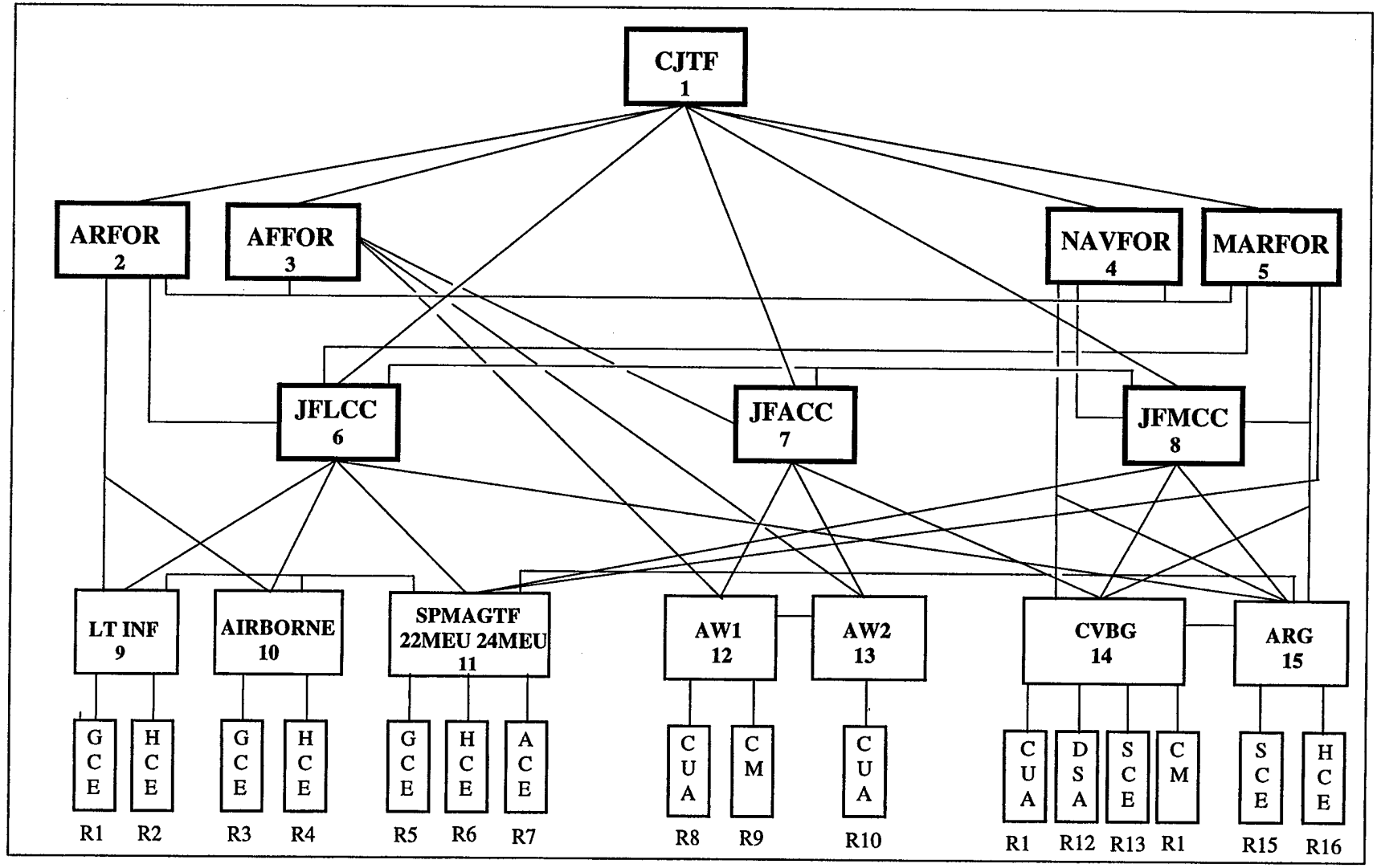
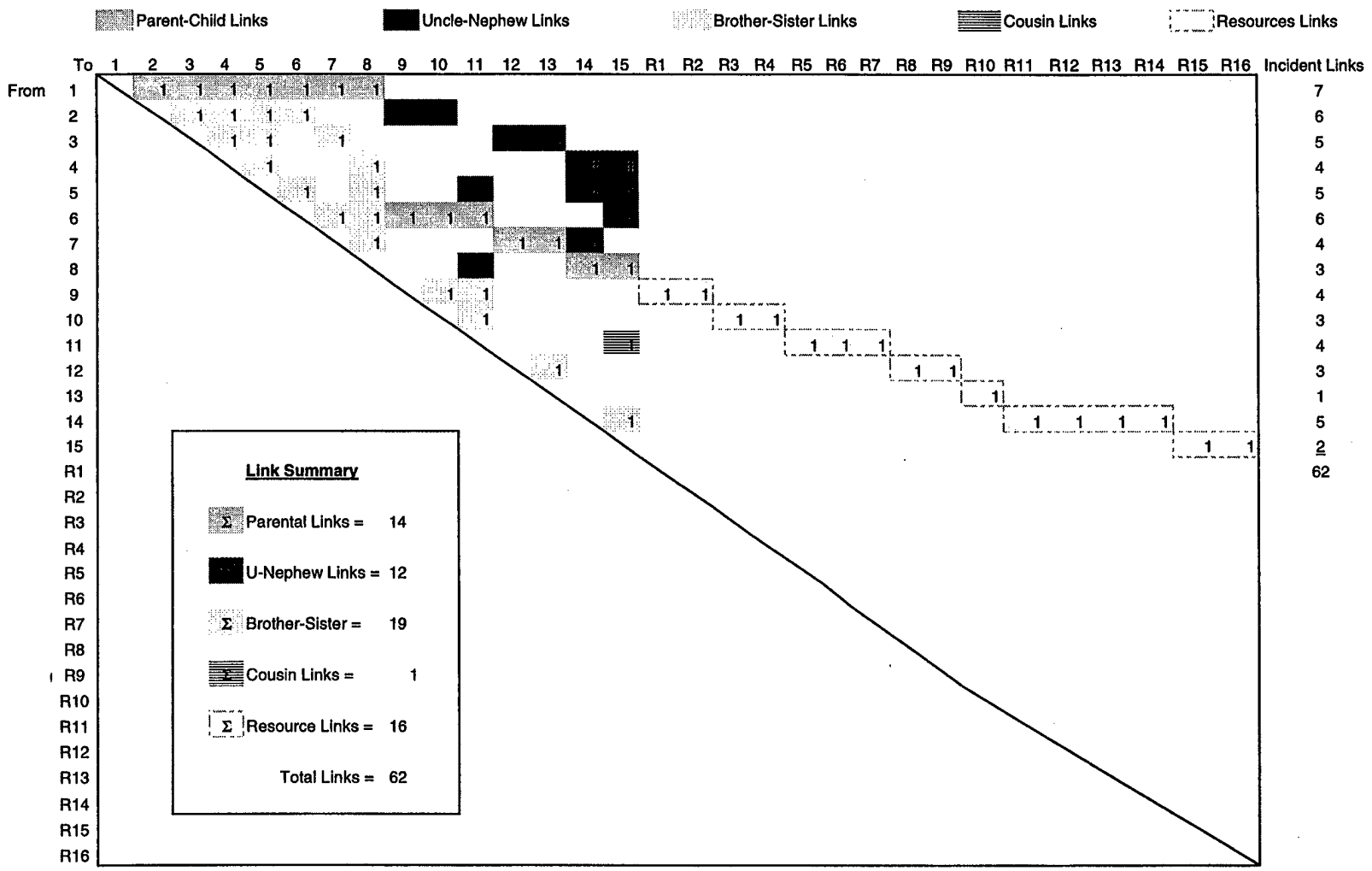


Figure 29.c. Formal Communications Structure for JTF A. The letter R indicates JTF resources.

JTF ALPHA *Formal Communications Structure* Node Adjacency Matrix



Formal Communications Structure
Measure Calculations
JTF A

1 Organizational Cost (original)

Oc = Ic + Cc

Ic = Informational Links: Σbase (in+out) + Σmiddle(in+out) + Σtop(in+out)
Cc = Established Links: Σ(Baseline to Middle) + Σ(Middle to Top) + Σ(Cousins)

Ic:

Node	In+Out	Value	Node	In+Out	Value
1	(7+1)	8	9	(4+2)	6
2	(6+1)	7	10	(4+2)	6
3	(6+1)	7	11	(6+3)	9
4	(6+1)	7	12	(3+2)	5
5	(8+1)	9	13	(2+2)	4
6	(8+1)	9	14	(5+4)	9
7	(6+1)	7	15	(4+4)	8
8	(7+1)	8			
	Subtotal	62		Subtotal	47
		Total Ic =	109		

Cc = (19) + (7) + (20) = 46

Oc = 109+46 = 155

2 Krackhardt's Efficiency (original)

EffK = 1- [V / MaxV]

V = number of links in excess of N-1
MaxV = Maximum possible number links in excess of N-1

N-1 = 15-1 = 14
V = (14+12+20)-14= 32
MaxV = N*(N-1)/2 - (N-1)
15*14/2 - 14 = 91

EffK = 1-32/91 = 0.648

3 Mackenzie's Hierarchy (adjusted)

H = 1- [(Ut+C+U) / (T+Ut)]

Ut = Redundant Links into and out of each Baseline and Middle Nodes
C= Cousin+Brother-Sister Links
U = Uncle-Nephew Links
T = Minimum Links Needed to receive and report Information
Σmin-base (in+out) + Σmin-middle(in+out) + Σmin-top(in+out)

Ut :	12+19+1=	32
C :	19+1 =	20
U:	12 =	12
T:	Baseline: (2+1)+(2+1)+(3+1)+(2+1)+(1+1)+ (4+1)+(2+1)=	23
	Middle: 4*(0+1) + 1*(3+1) +1*(2+1) + 1*(2+1) =	14
	Top: (7+1) =	8
	Total T:	45

HierM = 1- [(32+20+12) / (45+32)] = 0.169

4 Krackhardt's Hierarchy (adjusted)

HierKadj = 1- [V / MaxV]

V = Number of Reciprocal Links (uncle-nephew + cousin+parents)
MaxV = maximum possible unordered pairs N*(N-1)/2

V =	14+15+20 =	49
MaxV =	15*(14)/2 =	105

HierKadj= 1 - (49 / 105) = 0.533

5 External - Internal Index (adjusted)

E-I = [(EL-IL) / (EL+IL)]

EL = number of external links across divisions
IL = number of internal links within divisions

EL:	12(uncle-nephew)+1(cousin) =	13
IL :	14(parents)+19(brothers-sisters)+ 16(resources)=	49
EI =	(13-49)/ (13+49) =	-0.581

6 Krackhardt's Least Upper Bound (adjusted)

LUBadj = 1- [V / MaxV]

V = Number of paris of nodes without a LUB, counting resource links
MaxV = maximum possible unordered pairs without a LUB

(Na-1)*(Na-2)/2 + Ni*Nb

Na: number of decision making agents
Ni: number of pieces of information from resources
Nb: number of baseline agents

V =	203-62=	141
MaxV =	14(13)/2 +16(7) =	203

LUBadj= 1 - (141 / 203) = 0.305

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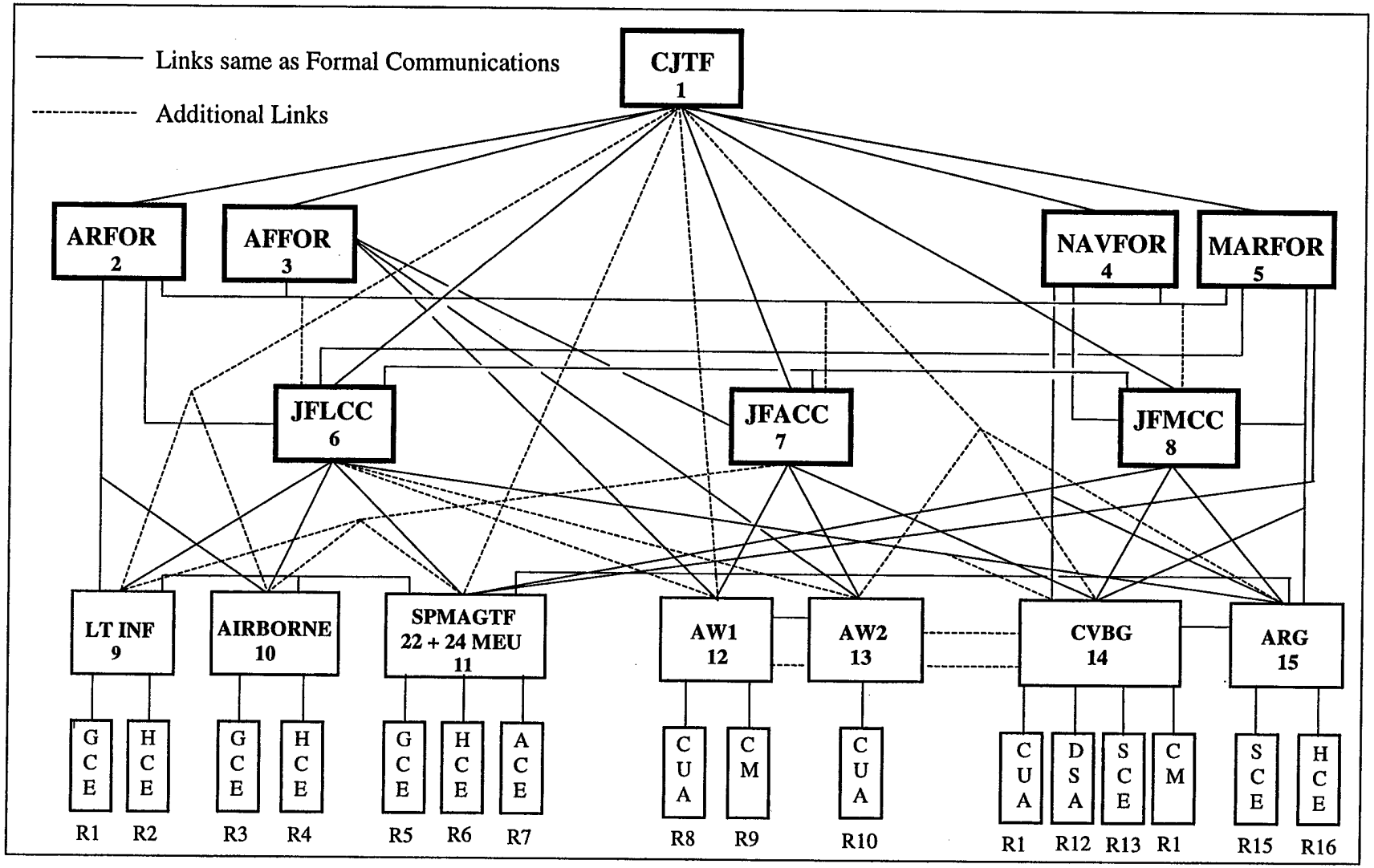
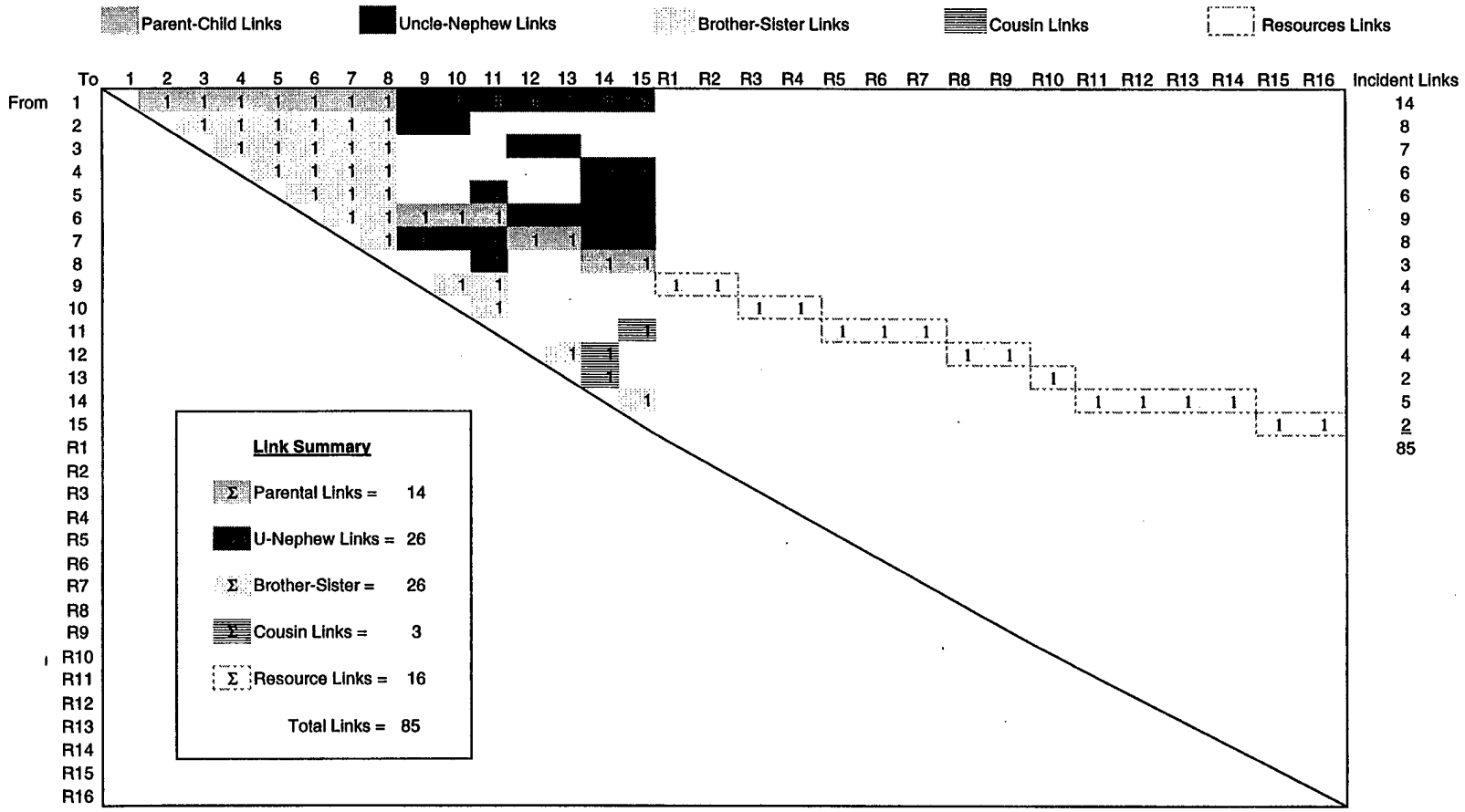


Figure 29.d. Informal Communications Structure for JTF A. The letter R indicates JTF Resources.

JTF ALPHA *Informal Communications Structure* Node Adjacency Matrix



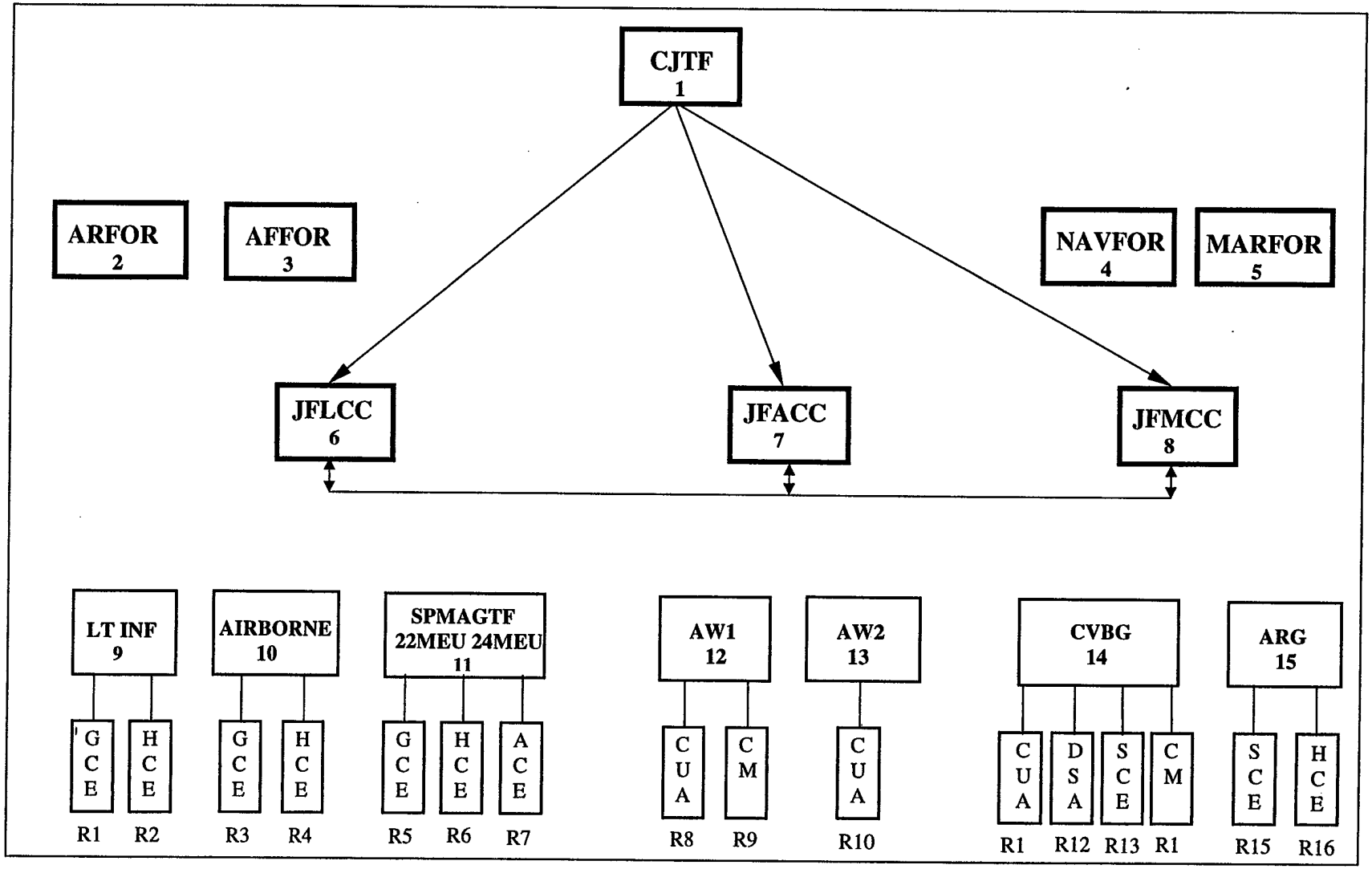
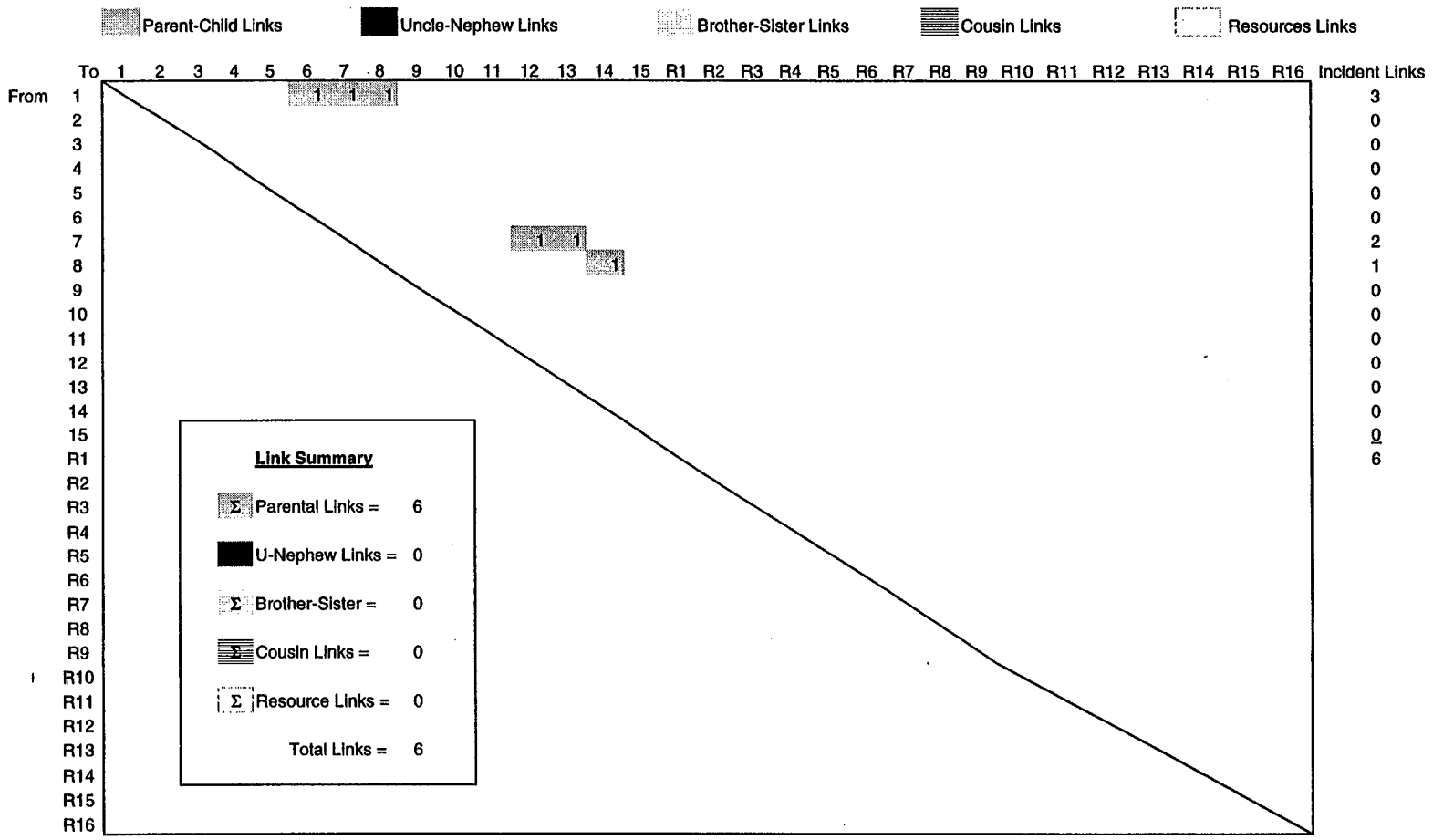


Figure 29.e. National Intelligence Structure for JTF A. The letter R indicates JTF resources.

JTF ALPHA *National Level Intelligence Structure* Node Adjacency Matrix



APPENDIX C

JTF B

Organizational Structure Diagrams
Node Adjacency Matrices
Formal Communications Structure Measure Calculations

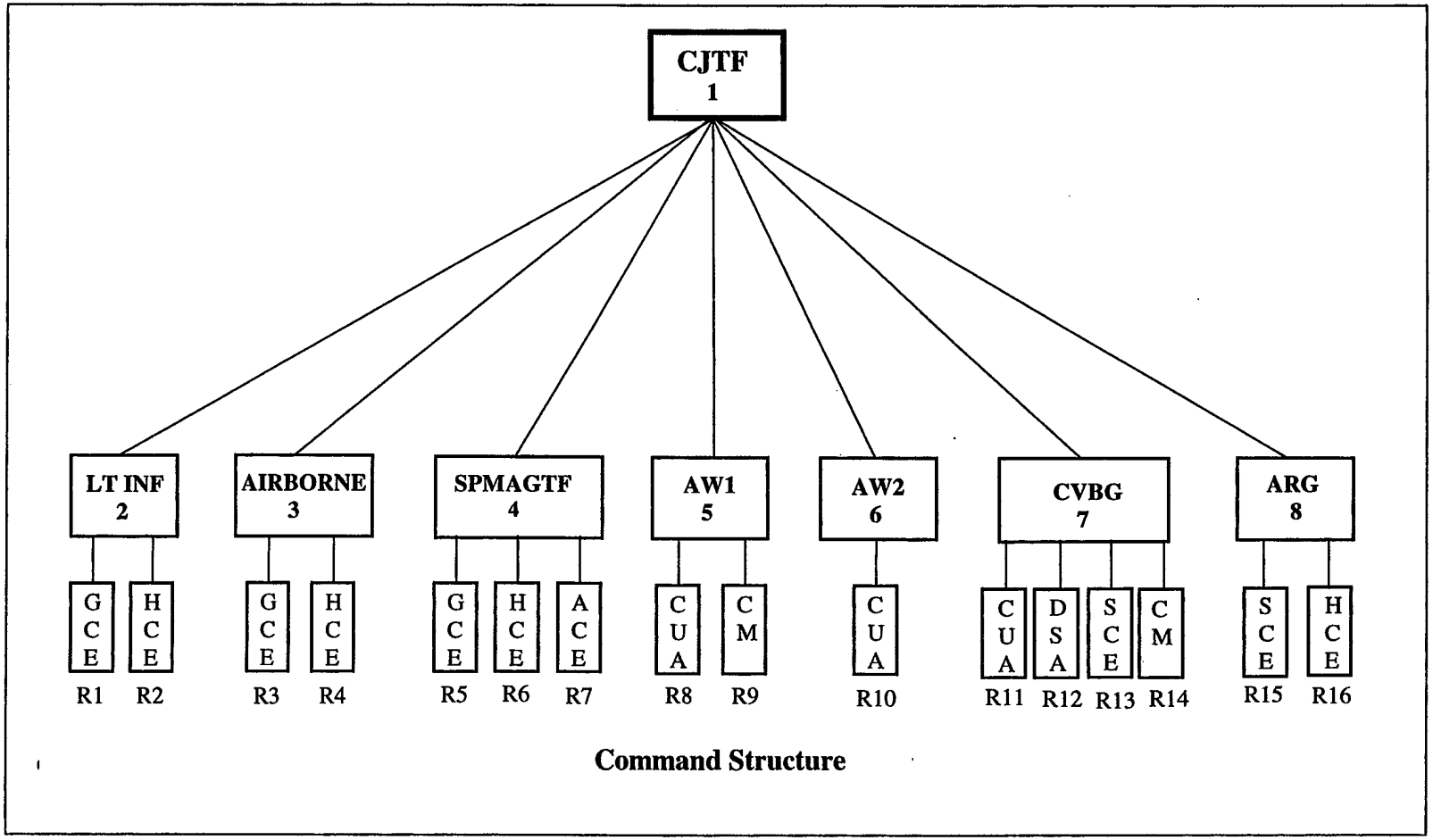
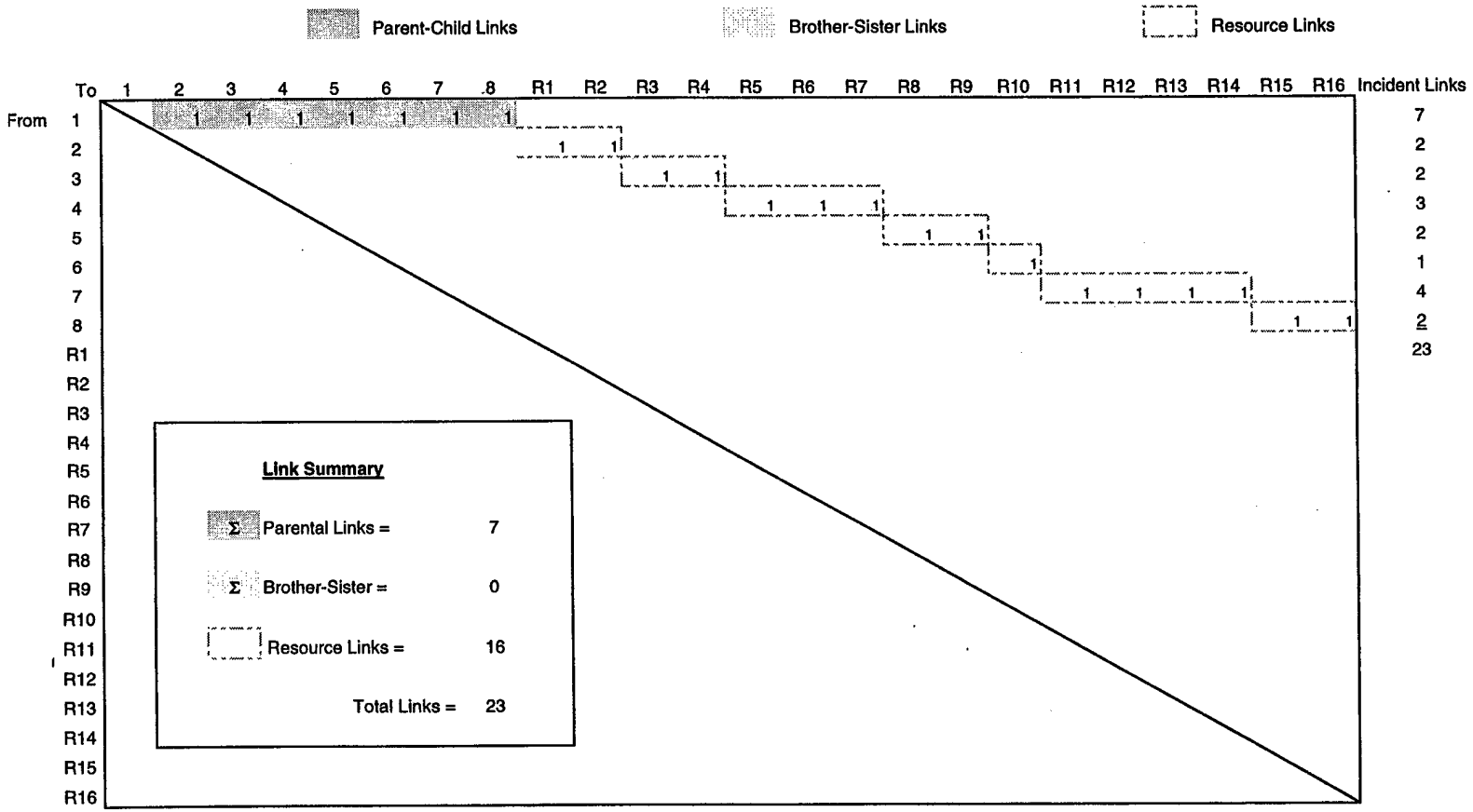


Figure 30.a. Command Structure of Joint Task Force BRAVO. The CJTF command node encompasses the responsibilities of the JFLCC, JFACC, JFMCC, NAVFOR, MARFOR, ARFOR, and the ARFOR Commanders. The operational commands own resources designated by the letter R.

JTF BRAVO *Command Structure* Node Adjacency Matrix



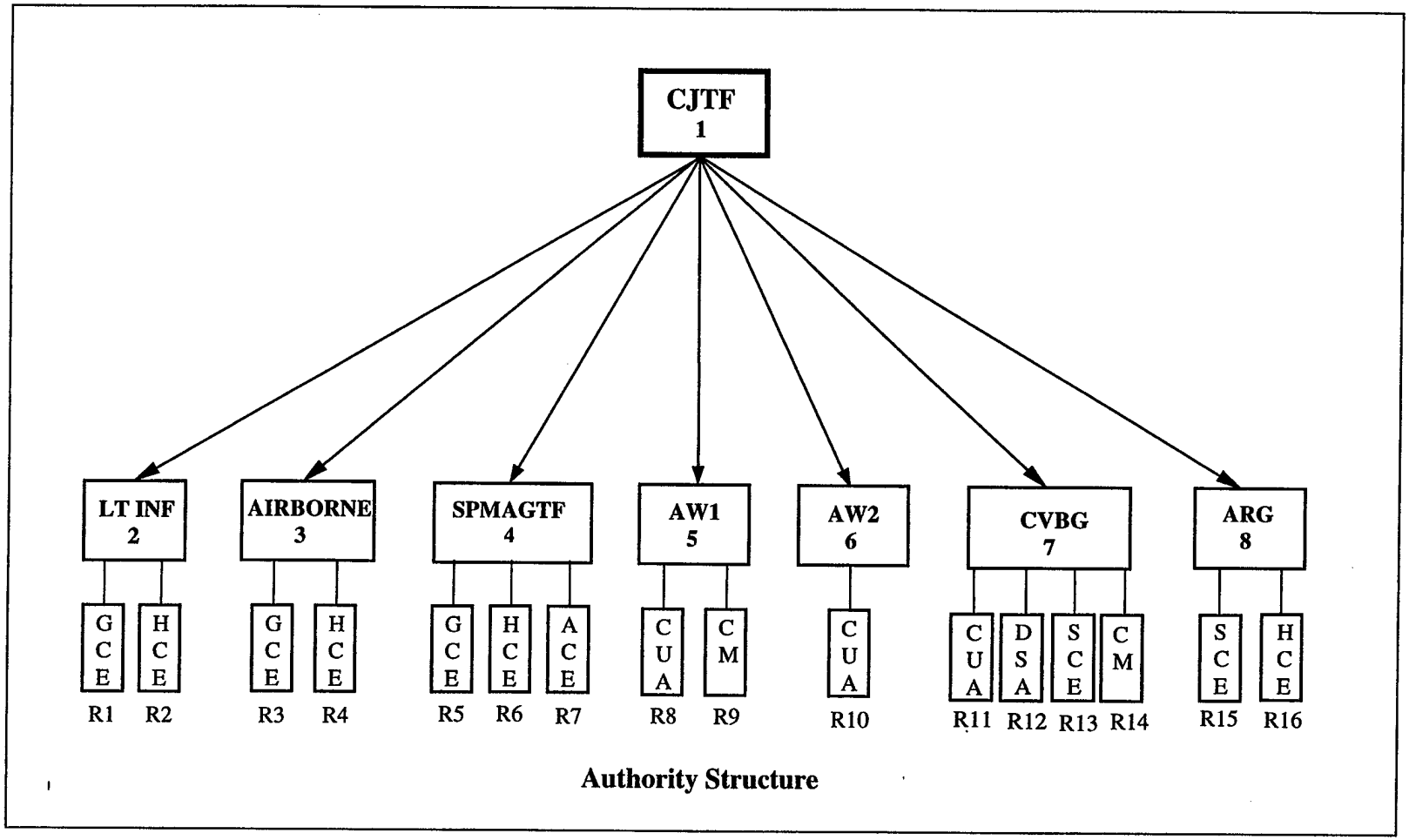
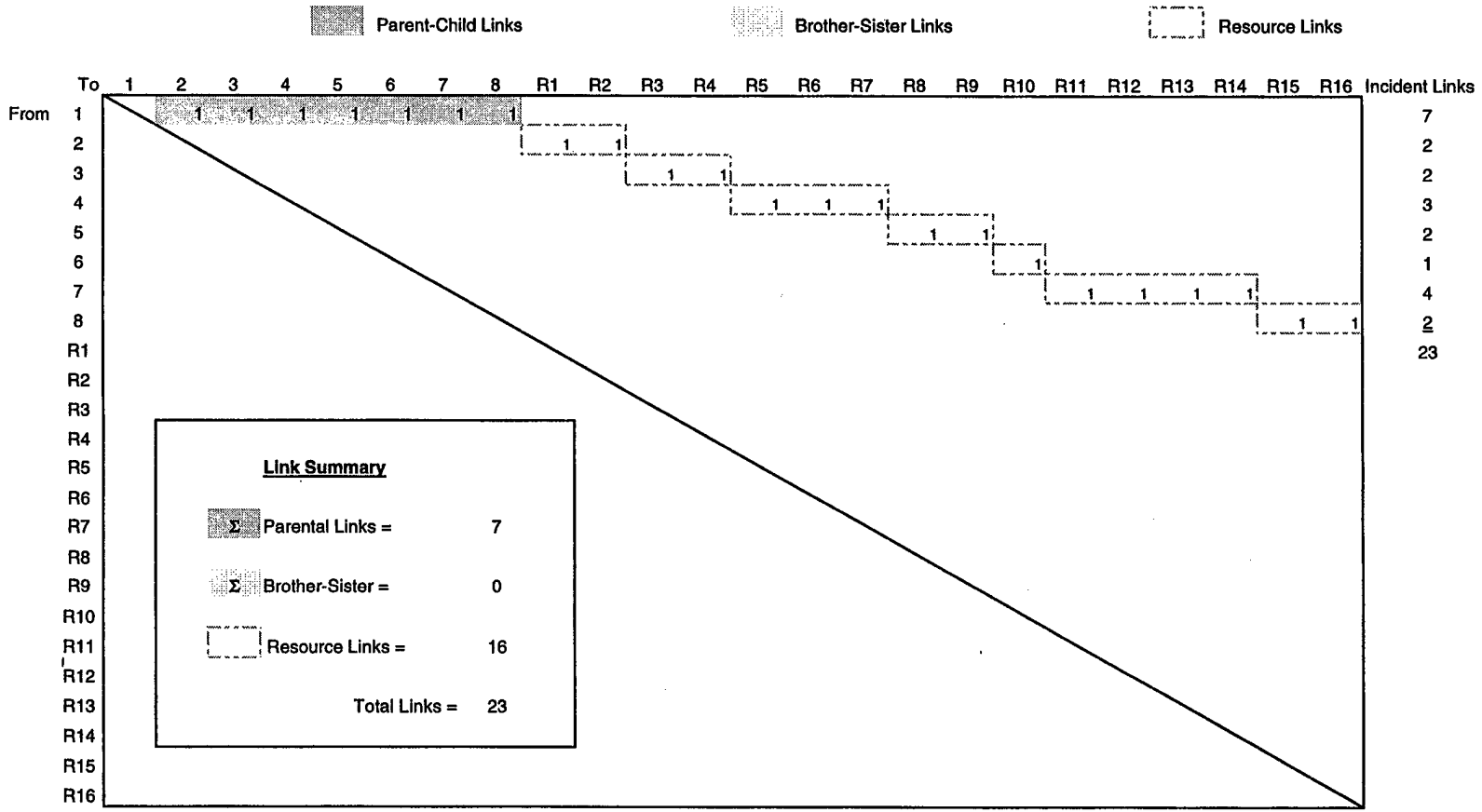


Figure30.b. Authority Structure of Joint Task Force BRAVO. The CJTF command node encompasses the responsibilities of the JFLCC, JFACC, JFMCC, NAVFOR, MARFOR, ARFOR, and the ARFOR Commanders. The operational commands have resources designated by the letter R.

JTF BRAVO *Authority Structure* Node Adjacency Matrix



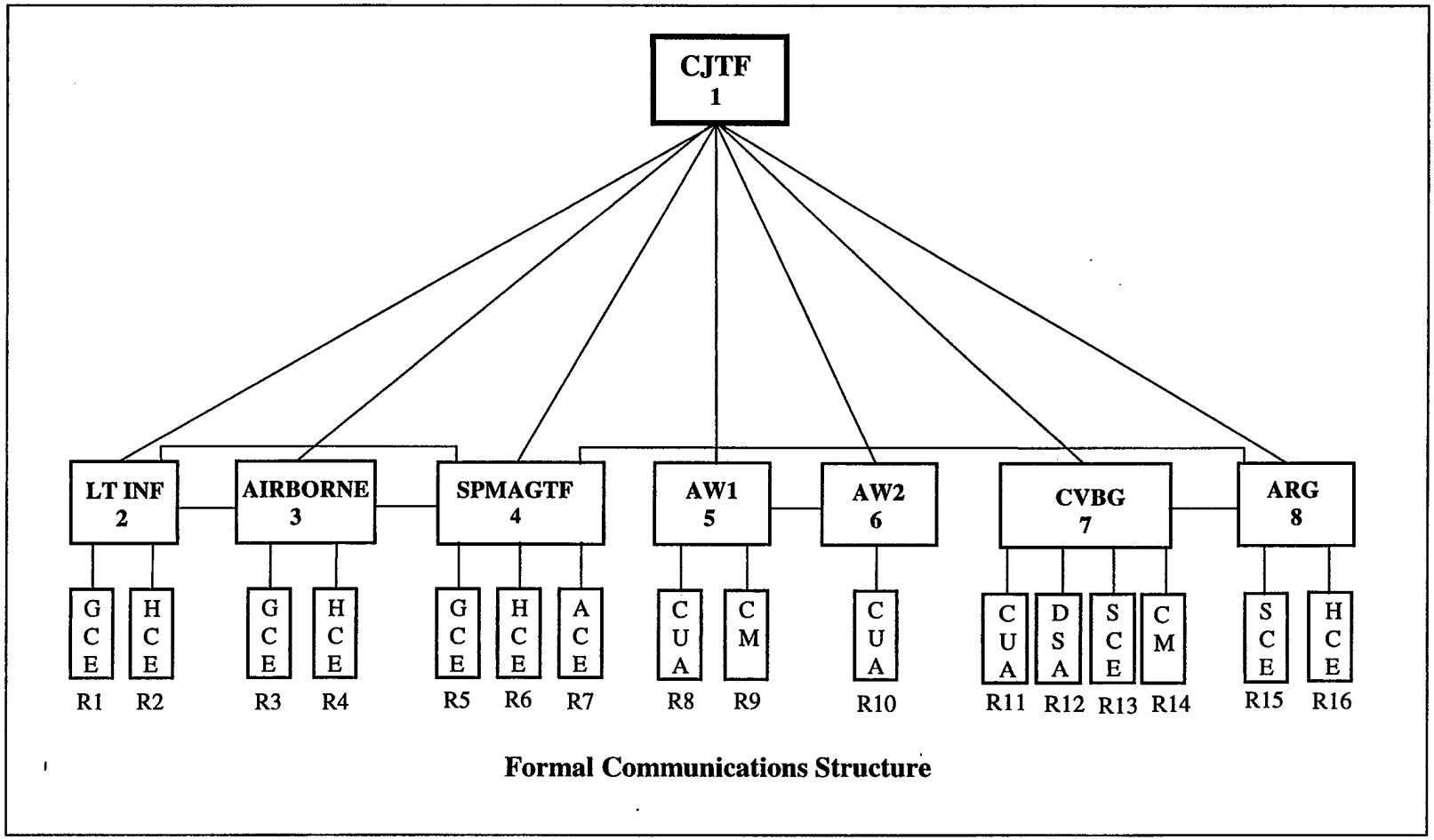
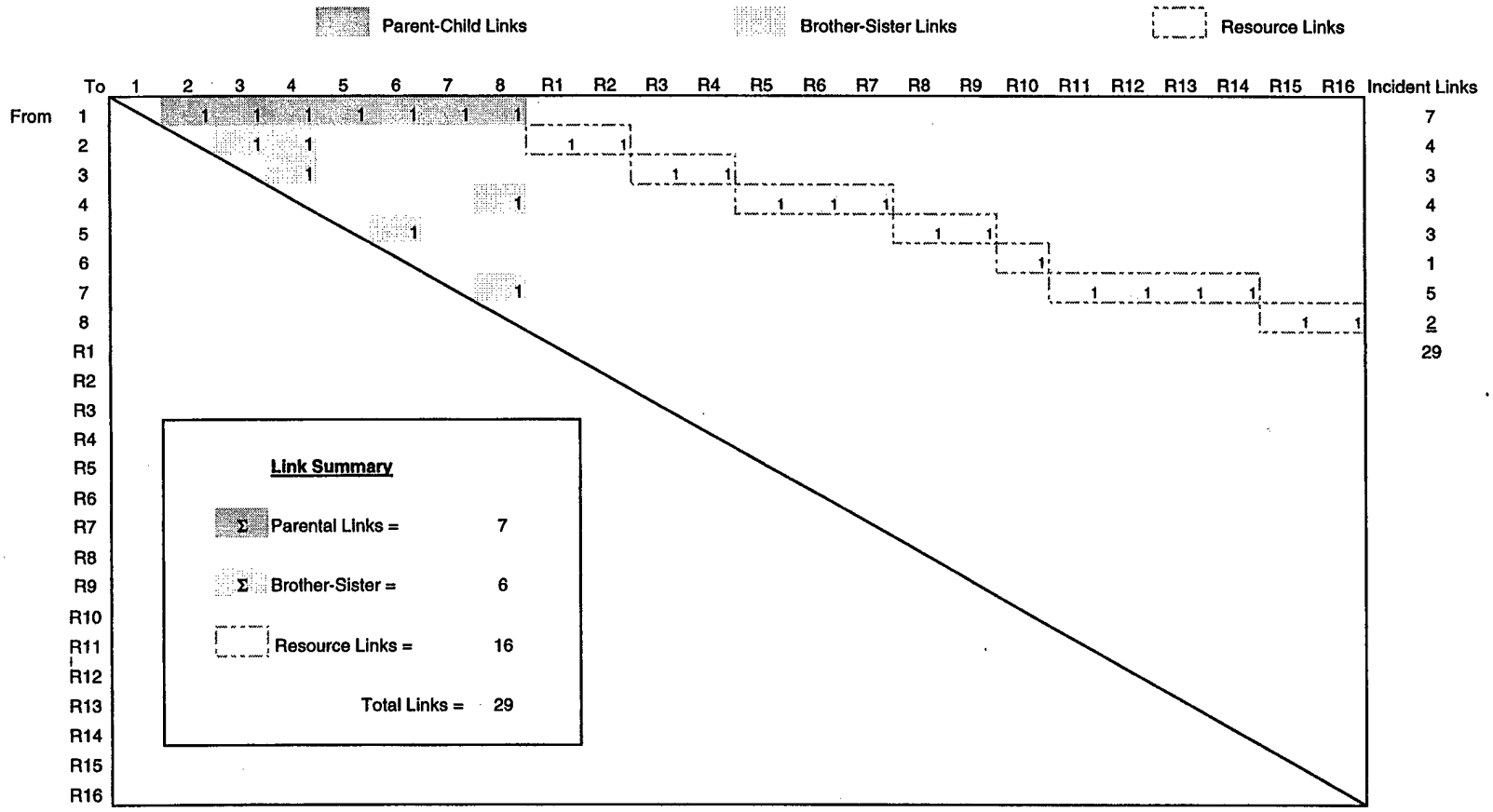


Figure 30.c. Formal Communications Structure of Joint Task Force BRAVO. The CJTF command node encompasses the responsibilities of the JFLCC, JFACC, JFMCC, NAVFOR, MARFOR, ARFOR, and the ARFOR Commanders. The operational commands own resources designated by the letter R.

JTF BRAVO *Formal Communications Structure* Node Adjacency Matrix



Formal Communications Structure
Measure Calculations
JTF B

1 Organizational Cost

Oc = Ic + Cc

Ic = Informational Links: Σbase (in+out) + Σtop(in+out)
Cc = Established Links: Σ(Baseline to Top) + Σ(brother-sister)

Ic:

Node	In+Out	Value
1	(7+1)	8
2	(2+2+1)	5
3	(2+2+1)	5
4	(3+3+1)	7
5	(2+1+1)	4
6	(1+1+1)	3
7	(4+1+1)	6
8	(2+2+1)	5
	Total Ic =	43

Cc:

Links From :To	Number
1:2,3,4,5,6,7,8	7
2:3,4	2
3:4	1
4:8	1
5:6	1
6:0	0
7:8	1
8:0	0
Total Ic =	13

Ic=	43=	43
Cc =	13 =	13
Oc =	31+7	56

2 Krackhardt's Efficiency (original)

EffK = 1- [V / MaxV]

V = number of links in excess of N-1
MaxV = Maximum possible number links in excess of N-1

N-1 =	8 -1 =	7
V =	13-7	6
MaxV =	N*(N-1)/2 - (N-1)	
	8*7/2 - 7 =	21
EffK =	1- 6/21 =	0.714

3 Mackenzie's Hierarchy (adjusted)

H = 1- [(Ut+C+U) / (T+Ut)]

Ut = Redundant Links into and out of each Baseline Node
C= Cousin links
U = Uncle-Nephew Links
T = Minimum Links Needed to receive and report Information
Σmin-base (in+out) + Σmin-top(in+out)

Ut :	6=	6	
C :	6 =	6	
U:	0 =	0	
T:	Baseline: (2+1)+(2+1)+(3+1)+(2+1)+(1+1)+ (4+1)+(2+1)=		23
	Top: (7+1) =		8
	Total T:		31

H = 1- [(6+6+0) / (31+6)] = 0.676

4 Krackhardt's Hierarchy (adjusted)

HierKadj = 1- [V / MaxV]

V = Number of Reciprocal Links (uncle-nephew + cousin+parents)
MaxV = maximum possible unordered pairs N*(N-1)/2

V =	7+6	13
MaxV =	8*(7)/2 =	28

HierKadj= 1 - (13 / 28) = 0.536

5 External - Internal Index (adjusted)

E-I = [(EL-IL) / (EL+IL)]

EL = number of external links across divisions
IL = number of internal links within divisions, counting to resources

EL:	6(brother-sister) =	6
IL :	7+16 =	23

EI = (6-23)/ (6+23) = -0.586

6 Krackhardt's Least Upper Bound (adjusted)

LUBadj = 1- [V / MaxV]

V = Number of paris of nodes without a LUB
MaxV = maximum possible unordered pairs without a LUB
(Na-1)*(Na-2)/2 + Ni*Nb
Na: number of decision making agents
Ni: number of pieces of information from resources
Nb: number of baseline agents

V = 133 - (7+6+16) = 104
MaxV = 7(6)/2 +16(7) = 133

LUBadj= 1 - (104 /133) = 0.218

Intentionally Blank

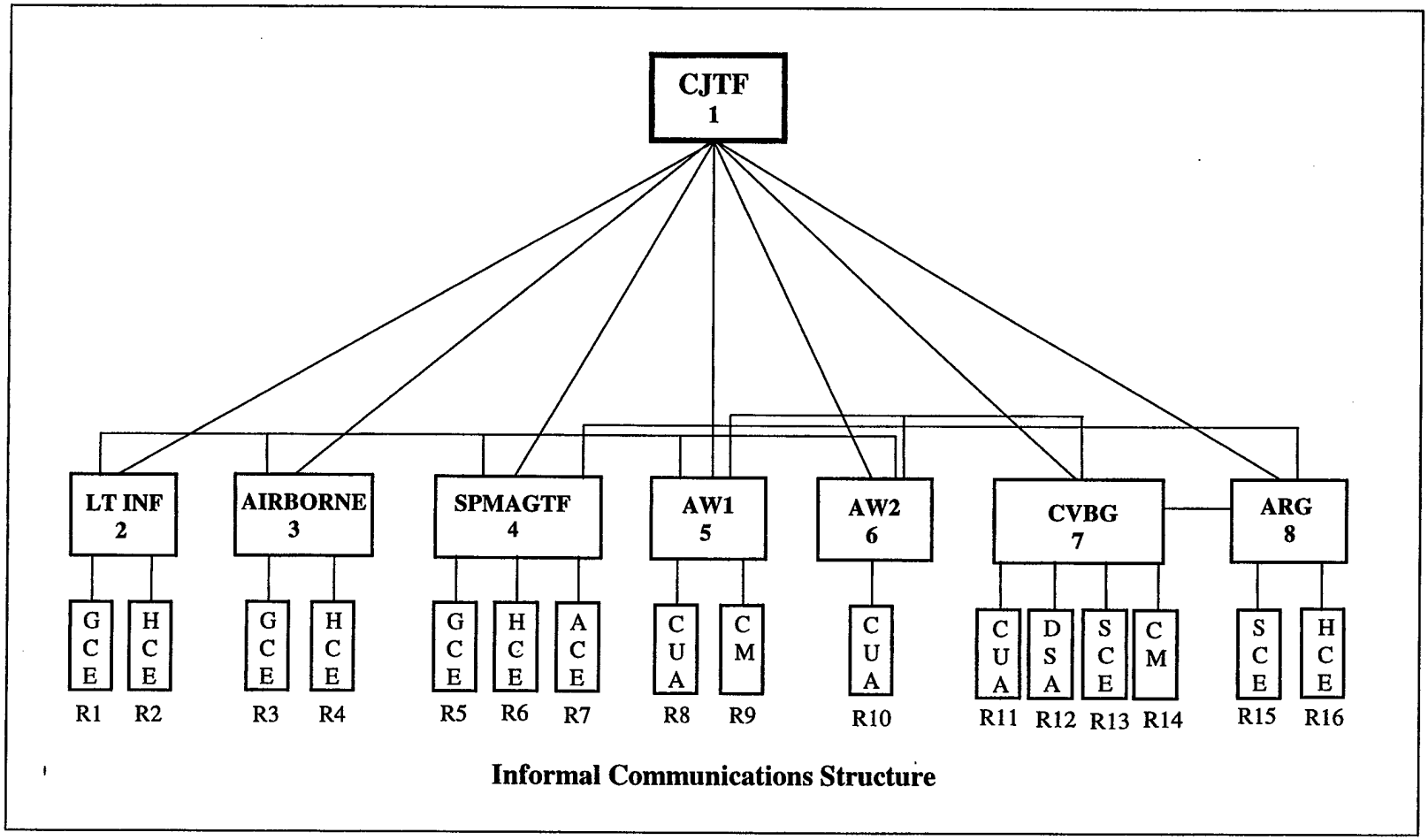
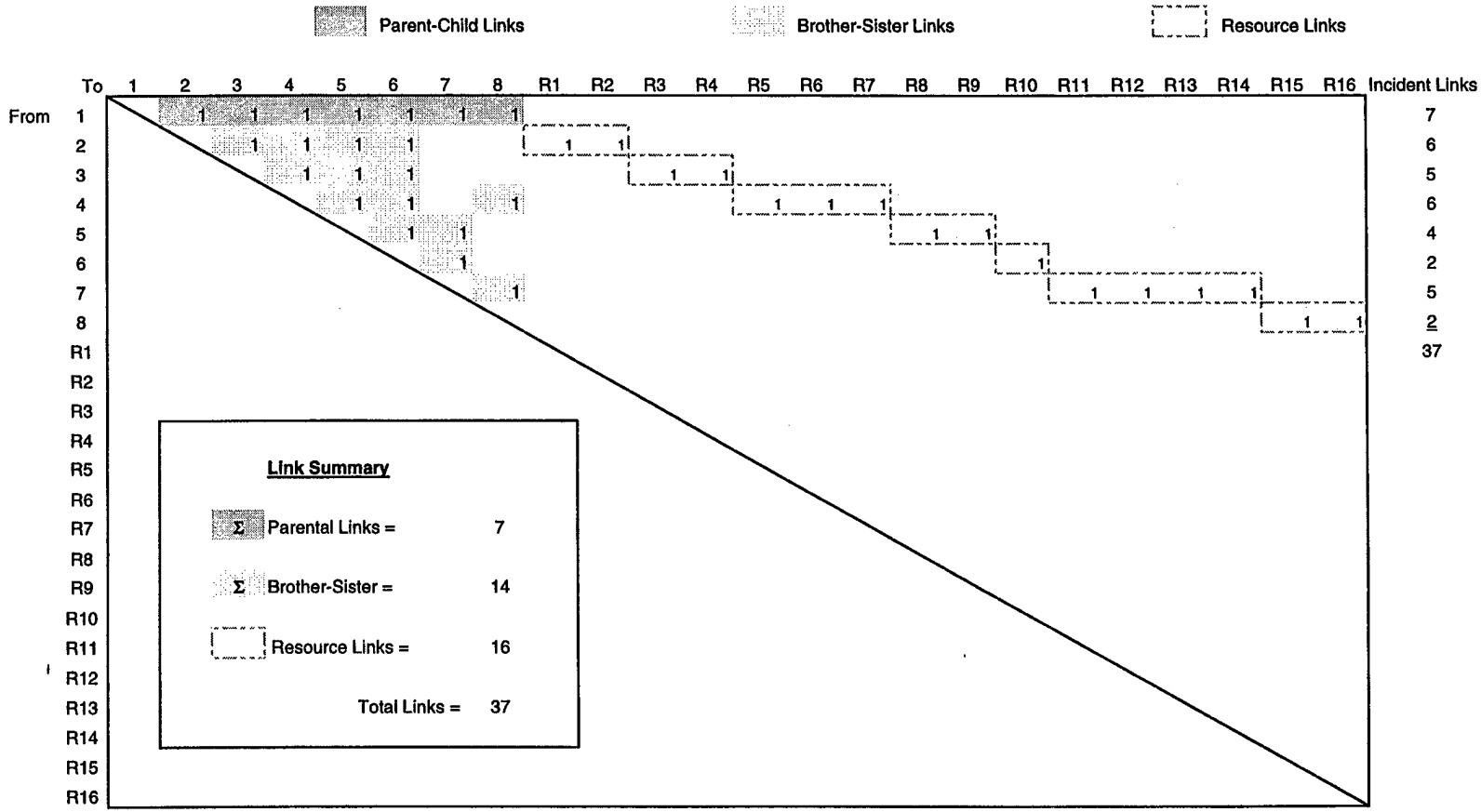


Figure 30.d. Informal Communications Structure of Joint Task Force BRAVO. The CJTF command node encompasses the responsibilities of the JFLCC, JFACC, JFMCC, NAVFOR, MARFOR, ARFOR, and the ARFOR Commanders. The operational commands own resources designated by the letter R.

JTF BRAVO *Informal Communications Structure* Node Adjacency Matrix



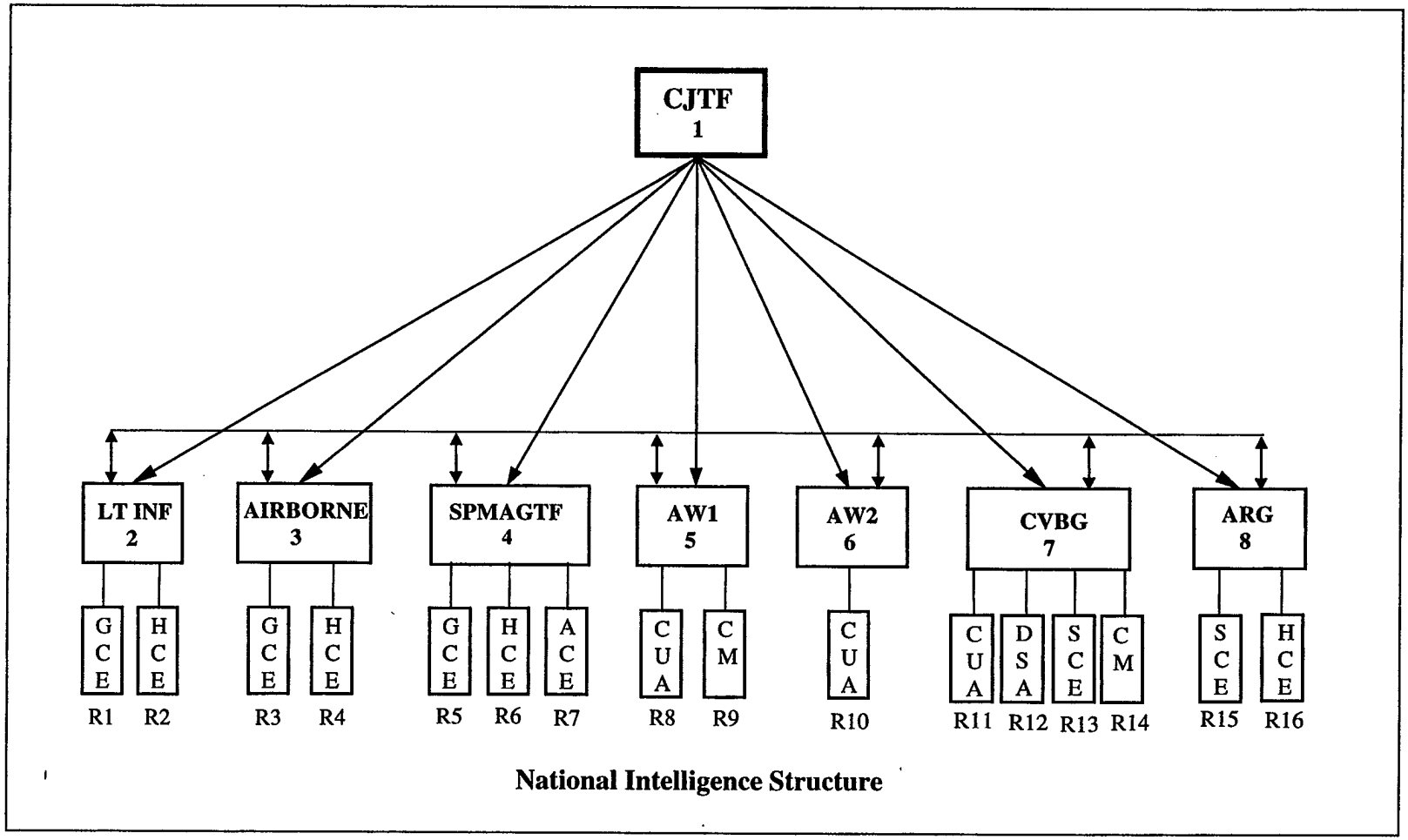
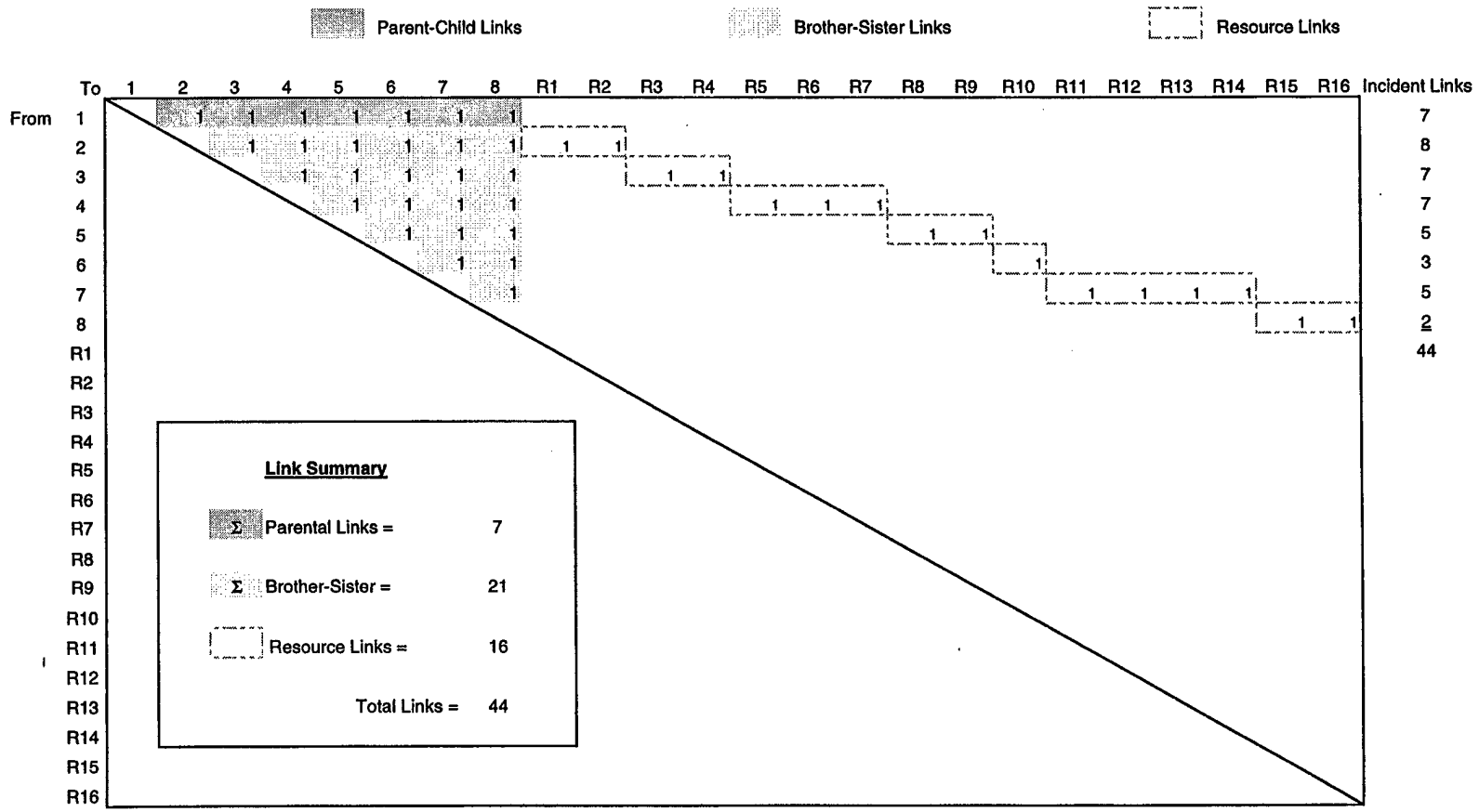


Figure 30.e. National Intelligence Structure of Joint Task Force BRAVO. The CJTF command node encompasses the responsibilities of the JFLCC, JFACC, JFMCC, NAVFOR, MARFOR, ARFOR, and the ARFOR Commanders. The operational commands have resources designated by the letter R.

JTF BRAVO *National Intelligence Structure* Node Adjacency Matrix



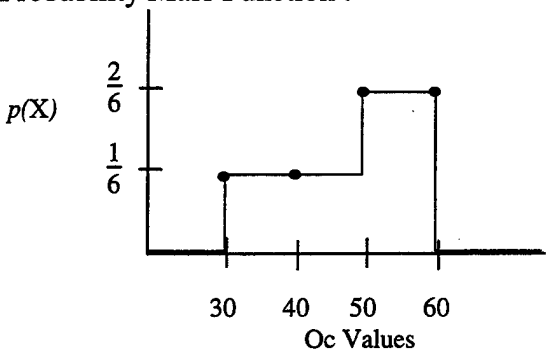
APPENDIX D. Δ PROBABILITY MASS FUNCTION EXAMPLE

Step 1.a: Given: 6 underlying graphs developed by a computer algorithm for an N node architecture subject to constraints.

Step 1.b: The Operational Cost measure is applied to all these underlying graphs, with the following numerical results:

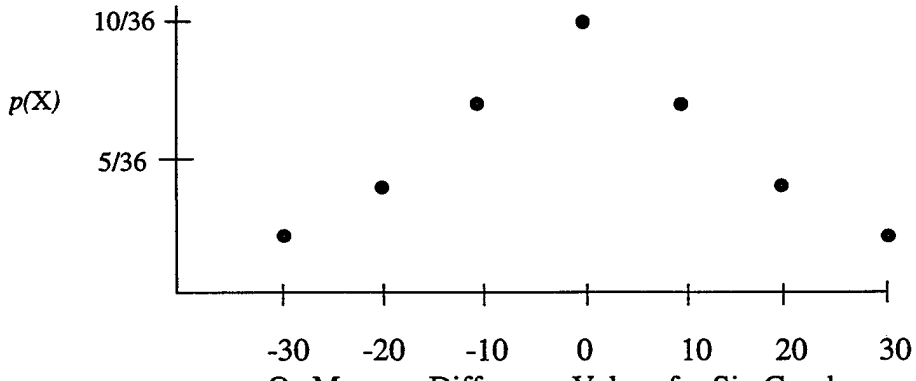
Graph:	1	2	3	4	5	6
Oc:	30	50	60	50	60	40

Step 1.c: Develop a Probability Mass Function :



Step 1.d: Develop the Difference Probability Mass Function:
All possible Oc Difference Measure Values for the six architectures are:

Difference	Combination Pairs	Probability
-30	(30-60)	1/6*2/6 = 2/36
-20	(30-50), (40-60)	1/6*2/6 + 1/6*2/6 = 4/36
-10	(30-40), (40-50), (50-60)	1/36 + 2/36 + 4/36 = 7/36
0	(30-30), (40-40), (50-50), (60-60)	1/36 + 1/36 + 4/36 + 4/36 = 10/36
10	(40-30), (50-40), (60-50)	1/36 + 2/36 + 4/36 = 7/36
20	(50-30), (60-40)	2/36 + 2/36 = 4/36
30	(60-30)	2/36 = 2/36



Step 2: Two architectures, *known* to be operationally relevant and different, are presented for analysis. Their respective Oc measure values are:

JTF A Oc	JTF B Oc	Δ Oc
60	40	+ 20

Step 3: The p-value for a $\Delta = +20$ is 2/36 from the Difference Probability Mass Function.

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