Carnegie Mellon University

CARNEGIE INSTITUTE OF TECHNOLOGY

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE OF Doctor of Philosophy

TITLE **Structural Measurement of Military Organization Capability**

PRESENTED BY **Robert Behrman**

ACCEPTED BY THE DEPARTMENT OF

Engineering and Public Policy

Kathleen M. Carley
ADVISOR, MAJOR PROFESSOR

May 01, 2014
DATE

M. Granger Morgan
DEPARTMENT HEAD

May 07, 2014
DATE

APPROVED BY THE COLLEGE COUNCIL

Vijayakumar Bhagavatula
DEAN

May 14, 2014
DATE

Structural Measurement of Military Organization Capability

Submitted in partial fulfillment of the requirements for

the degree of

Doctor of Philosophy

in

Engineering and Public Policy

Robert A. Behrman

B.A., Mathematics and Philosophy, University of Saint Thomas
M.S., Engineering and Public Policy, Carnegie Mellon University

Carnegie Mellon University
Pittsburgh, PA

May 2014

Acknowledgements

THESIS CHAIR: Professor Kathleen M. Carley
Institute for Software Research International
Carnegie Mellon University

COMMITTEE MEMBERS: Professor M. Granger Morgan
Department of Engineering and Public Policy
Carnegie Mellon University

Professor David Krackhardt
Heinz School of Public Policy
Carnegie Mellon University

Lieutenant Colonel Ian McCulloh
United States Central Command

This research was sponsored in part by the National Science Foundation Integrative Graduate Education and Research Traineeship program; the Office of Naval Research; the Carnegie Mellon University, School of Computer Science, Institute for Software Research, Center for the Computational Analysis of Social and Organizational Systems; and the Carnegie Mellon University, Carnegie Institute of Technology, Department of Engineering and Public Policy.

Abstract

This research presents a structural model of the effect of the organization of military units upon their capability. This research is oriented towards a more complete understanding of military capability and policy decisions about the structure and development of military forces. We identify the types of national and military policy decisions that claims of military capability inform, and find that there are five distinct types of capability claims relevant to military policy. We show how these types of capability claims are logically related to each other, but have different premises, predicates, and standards of proof. We find that one of these types of claims, *General Organization Capability Claims*, ties together the various military policy decisions. The remainder of this research shows how these capability claims can be formally structured based on military doctrine and structurally evaluated using a network-science based model. The interaction between the structural elements of a military organization (personnel, materiel, and information) and the things it is supposed to do (military tasks) can be represented and analyzed with network science methods, and represents a type of general organization capability claim. We present a method for representing policy decisions about unit structure and tactical doctrine. We then develop two versions of a structural model of capability – one that links the individual elements of an organization to the tasks it performs; another that considers the capacity of a set of organizations to meet a set of requirements. We show that network statistics of organizations represented off of authoritative, rather than observational, data are still consistent with network science findings but require interpretation. We also show how alternate methods of aggregating organizations can expand the utility of the capability measurement. This research presents five new contributions to the fields of military policy analysis and network science – (1) a taxonomy of military capability claims, (2) a meta-network model of doctrinal organization and task data, (3) a structural model of organization capability, (4) a structural model of organization capacity, and (5) a network-based method integer programming method.

Table of Contents

Figures

Tables

Dedication

To those who have come before - Thanks Mom and Dad
To those who will come after - to Erin and family to follow

From August 2002, when I came to Carnegie Mellon University, to now, May 2014, when I'm leaving it, I've become measurably closer to achieving my life goal of knowing everything, including a bit about science and a lot about my own capabilities.

I would like to thank M. Granger Morgan and Kathleen Carley for varying degrees of material, emotional, personal, academic, and inspirational support; and the staff of both the department of Engineering and Public Policy and the Center for the Computational Analysis of Social and Organizational Systems for their unwavering support and professionalism. While working on this I have been called to active duty in the United States Army five times, including two overseas combat deployments to Iraq. Granger and Kathleen gave me encouragement to come back, forgiveness for forgetting half of what I've learned, patience to allow me back onto the course of this work, and support when I did. The department staffs have worked with me, helped me, and generally bent over backward to help. Their support has been far in excess of what is required by the law or university policy. I hope that I haven't made it difficult for other reservists by how much of that support I've needed. I would like to thank Granger for his personal leadership and dedication, and Kathleen for her constant encouragement. I would like to thank Ian and David for serving on my committee and the education they've given me.

I would like to thank my mother and father for preventing me from giving up, in her and his own ways. Mom through her constant love, affection, and a fair dose of 'suck it up' when needed; Dad through his constant pride that his son would achieve something that he hadn't. Dad has expressly required that I cite his Master's thesis as an example of the previous ignorance I go beyond in my criticism in chapter 2.

I would like to thank the U.S. Army, for providing the other heaping dose of growing-up I've received during these years. The Army has given me a job that might make this research useful; and I hope that it is an honorable use.

I would also like to thank my wife Erin. Our marriage was my commitment to a specific future, and she has made sure that it will be a pleasant, successful, loving, productive, and good one.

I would like to thank my sister-in-law Meaghan Rodgers, who coded several of the unit models.

I hope that this research will be useful within its domain, and that it will be useful to society as a whole. Militaries and their operations can be done well or poorly, for right or wrong. This research can't help with the latter; but I sincerely believe that doing the former well is important to both the Army and the United States.

Introduction

CHAPTER 1

During the course of the research for this dissertation, its subject matter – the structure of tactical and operational forces in the United States Army[1] - has changed continuously. The Army transformed its basic unit of combat power from the Division to the Brigade Combat Team (BCT) (Feickert 2005); fielded an entirely new type of combat organization, the Stryker BCT (or SBCT); cancelled major transformational initiatives; moved to Army Force Generation (ARFORGEN), a rotational model of force generation[2] and employment; and adopted rapid fielding initiatives to support troops in the field. The process of changing force structure to meet changing requirements is ongoing – from + 1939 to 1999, the Army conducted 11 reviews of the structure of its divisions (CSI 1999). In the near term, the Budget Control Act of 2011[3] and the 2012 Defense Strategic Guidance (OSD, The White House 2012, OSD 2012) are driving further, near-term structure changes.

These changes are explained, argued, and justified in terms of capability and cost; but it is notoriously difficult to measure or articulate changes to either (Tellis, et al. 2000, Biddle 2004). It is difficult to articulate the effect of specific organizational changes – like the difference between two and three maneuver battalions per BCT – upon the capability of the overall organization. Claims of capability do not share common terms of reference, and it is difficult to determine which resource decisions among the myriad are responsible for capability provided. The Army has gotten this wrong, before – the 'Pentomic Division' reorganization during the 1950s was an infamous failure, as the division structure did not have the inherent capacity and capabilities to perform its basic warfighting functions, and the Joint assets (airlift, communications) necessary were not resourced (CSI 1999).

This research addresses military organization and capabilities-based planning by presenting a network-science based model of military capability that can be used to link organization structures to provided capabilities, establish common grounds for certain capability claims, and quantify the benefit of organizational decisions in terms of capability. This research incorporates insights from organization theory, network science, and policy analysis to form the groundwork for a model of capability that can provide rigorous support to military policy decisions.

The basic approach this research develops involves comparing the doctrinal structure of military units with the tasks that they are expected to perform.[4] This involves several components, including the rigorous representation of both doctrinal organization structures and doctrinal tasks; the development of a mechanism to compare tasks against organization structures; and the validation of these structures and predicted capabilities against qualitative and quantitative standards of performance and capability. This is a novel approach in military theory, as it divorces the study of capability from the specific operational context or enemy; though I argue that it is a familiar concept within the institutional military in chapter 2. This is also a novel approach in organization theory as it treats organizations in the abstract, without relying on observations of particular organizations designed around those templates.

Section 1: The military force structure problem

My approach to this research was inspired by my experiences with the various types of Army BCTs. I have served with an Armored Cavalry Regiment (ACR); a SBCT; a Combined Arms Battalion, originally from a Heavy HBCT (HBCT, also known as ABCT for "Armored BCT"), which was attached to an Infantry BCT (IBCT), and an IBCT headquarters. These units have substantially different Tables of Organization and Equipment (TO&Es); but in each case had similar postures on the ground and tactics.[5] At the tactical level, the differences seemed driven by their experience in theater and the size and composition of their companies. At headquarters, there were notable differences in the organization and responsibilities of the sections, the size of the headquarters, and how they accepted enabling units.

Two of these struck me in particular: First, why are enablers in some BCTs organized into Brigade Special Troops Battalions (BSTBs), others not? Second, why is the Stryker Mobile Gun System (MGS) integrated with infantry at the Company level, but tanks and mechanized Infantry integrated at the battalion level?

1. Organizing Enablers into Special Troops Battalions

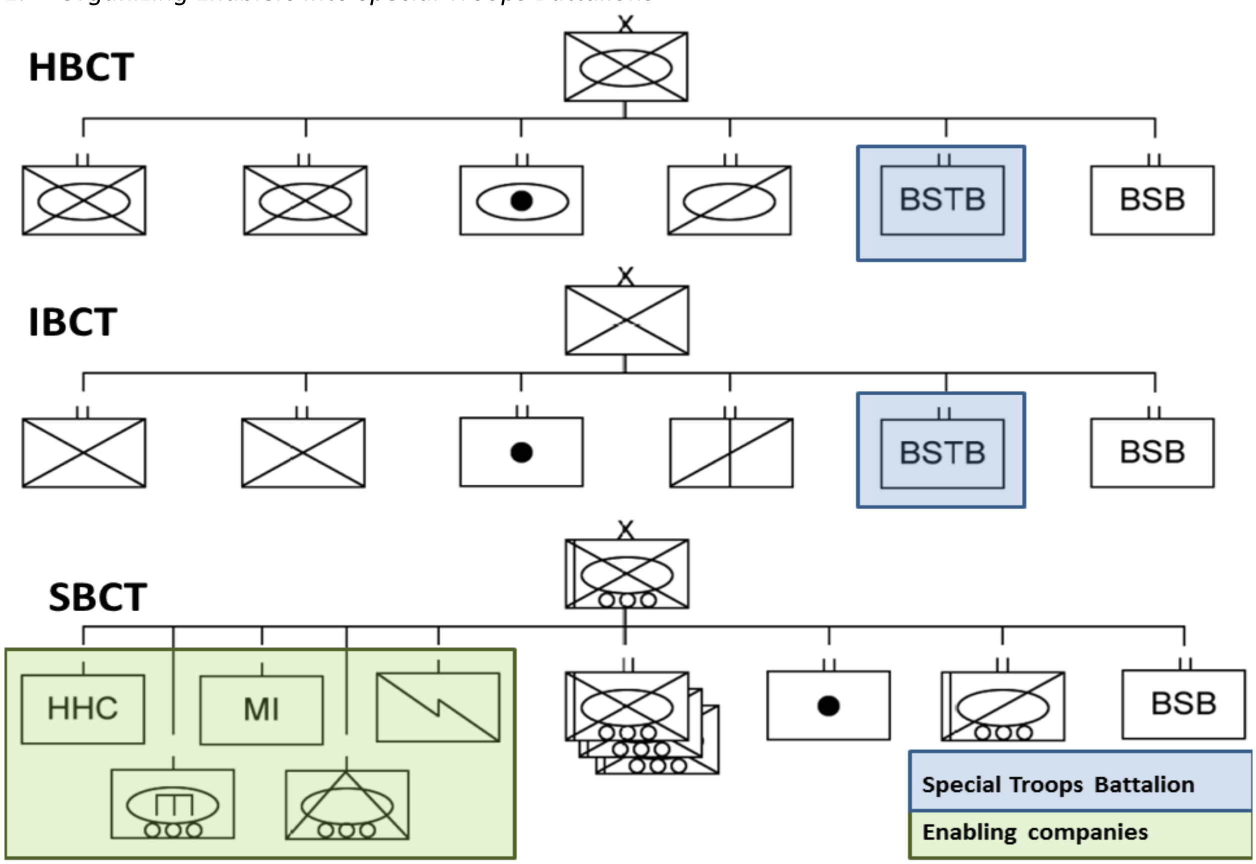


Figure 1 - BCTs, with a Special Troops Battalion or not[6]

Figure 1 shows the organization of the types of BCT, as of 2010. In the HBCTs and IBCTs, the enablers are in BSTBs; in the SBCT they report to the Brigade Commander. Which of these options is better, and by what criteria? Does the inclusion of the BSTB restrict the freedom of action of the brigade commander, by putting more layers of middle management between him and his enablers; or does it free him from the distraction of additional forces to control directly? Does the additional capability added by a BSTB justify the additional personnel authorizations that go into its headquarters?

2. Integrating Infantry and Armor

The second question deals with the combat organization of a unit – in this case, the difference between Armored and Stryker formations. The Stryker formations incorporate a variant of combined arms at the company level; while ABCTs integrate combined arms at the battalion level.

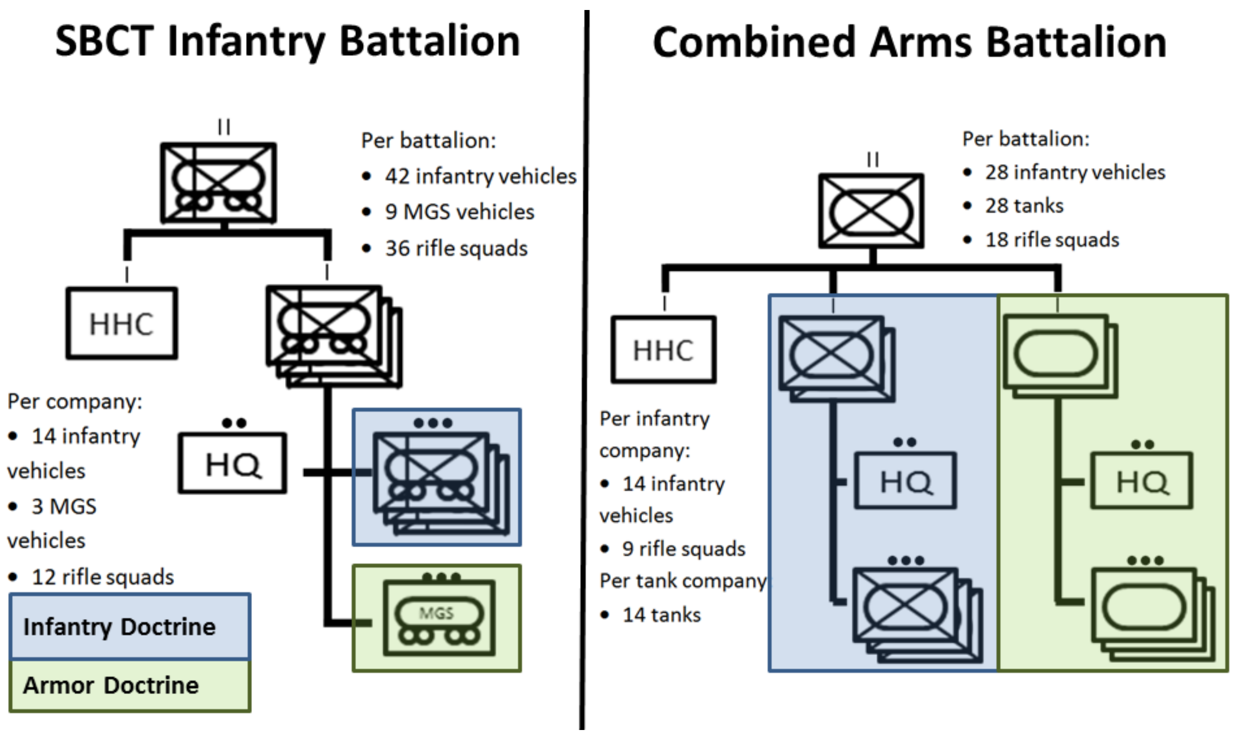


Figure 2 - Comparison of the Stryker Infantry Battalion and the Combined Arms Battalion[7]

In each case, the battalion has both mechanized infantry and armored/fire support forces, but the two different battalions organize them at different echelons. There are other alternatives available, as well – the Stryker Company could integrate its Mobile Gun Systems at the platoon level, and organize them into a separate element as needed; or Armor Brigades could organize their tanks and mechanized infantry into separate battalions in the same brigade (this was the doctrinal organization before Army Modularity). Each organization type is similar, save for a possible change to the distribution of officers in the battalion; but each organization type should have different advantages and disadvantages. How do we quantify these? Is it better to have stronger companies with more assets, or stronger battalions with a functionally specialized division of labor?

At first glance, these are fairly esoteric questions about relatively small tactical formations. However, there are several nuances that make them, and questions like them, significant:

1. They are abstract organizational questions. They do not require observation of existing organizations of similar type to answer, and they can be (and routinely are) considered in detail long before the organization is fielded.
2. The data required to analyze these questions is accessible, comprehensive, and arbitrarily accurate. There is no ambiguity as to what a doctrinal SBCT has – it is all written down on the TO&E.
3. Decisions on questions like these obligate most of the defense budget, including the personnel, procurement, and operations and maintenance accounts.
4. There is a tremendous body of literature in both military theory and organization theory that addresses these subjects, which we can validate predictions of the effectiveness of alternate organization structures.
5. There is consensus about what values – military capability, efficiency and effectiveness – should be addressed by decisions about military organization.
6. These questions, and many more like them, are not answered.

Section 2: Network approaches to understanding military organization

Some of the familiar tenets of organization theory and network science resemble basic tenets of military practice and doctrine. Organization theory and network science have been used to study military organizations since the 1960s – especially in relation to the strategic decision-making processes involved in nuclear war (Schelling 1960, Schelling 1966). Doctrinally, such military organizational concepts as 'unity of command' and 'span of control' have exact parallels in organization theory (in this case, 'Least-Upper-Boundedness' (Krackhardt 1994) for the former, degree centrality for the latter) (Carley and Krackhardt 1999)

1. Applicable Organization Theory Concepts

Several general organization theory concepts touch on the questions under scrutiny in this research. "High-Reliability Organizations" organize in specific ways – become flatter and more responsive – in times of stress (LaPorte and Consolini 1991). Military organizations are boundedly-rational (Cyert and March 1963 (1992)), and their decision spaces are constrained by both information available, how that information is presented to the organization (Allison and Zelikow 1999) and preexisting forms and templates for the interpretation of data and appropriate response (Klein 1999). Perhaps most interestingly, military organizational forms come from a constrained space of options, and new organizational forms are often variations of old ones, (Padgett 2001) adapted for new technology.

Formal tests of these concepts were developed as mathematic methods for *social network theory*, and are based on the observation of communication and interaction in organizations (Wasserman and Faust 1994, Krackhardt 1994). Meta-Network models (K. Carley 2002, K. M. Carley 2003, K. M. Carley, J. Reminga, et al. 2010) incorporate additional data above and beyond person-to-person interactions (*i.e.,* they are multi-modal). The PCANS and original meta-network models (Krackhardt and Carley 1998, K. M. Carley 2002) define three or four node classes, respectively - Agents, Tasks, and Resources (PCANS) or Agents, Knowledge, Tasks, and Organizations (Meta-Network). However, there is no inherent limit to the number of entity classes or networks of relationships defined within a meta-network. The relationships between the personnel, materiel, relevant information, and procedures of military organizations are amenable to modeling as a meta-network (Krackhardt and Carley 1998, K. M. Carley 2002).

Network science methods became particularly popular among military force developers during the late 1990s, with the introduction of the 'Network Centric Warfare' concept (Cebrowski and Garstka 1998, Alberts, Garstka and Stein 1999) and system-of-systems based targeting (Warden 1989, Warden 1995). This spread to the operational force during the Global War on Terror (McChrystal 2011), because of their utility in describing terrorist networks (K. M. Carley 2003, Moon, Carley and Levis, Vulnerability Assessment on Adversarial Organization: Unifying Command and Control Structure Analysis and Social Network Analysis 2008, Gerdes 2008) and describing ways to degrade them (Carley, Lee and Krackhardt 2002, Carley, Reminga and Kamneva 2003). Network science studies have shown that structural predictions of information diffusion, especially information diffusion about other agents' activities, are good predictors of group performance (Carley and Krackhardt 1999). Cognitive Demand has been shown to be an accurate predictor of individual agent importance in a network (Carley, Ren and Krackhardt 2000).

Many of the published organization theory studies of military organizations have focused on characterizations of staffs conducting training missions (Schreiber and Graham's 2005 studies of Battle Laboratory experiments are an excellent example (Schreiber 2006, Graham 2005)) or idealized staffs conducting specific missions. Of the former, Meta network models characterize agents by attributes such as command (Carley, Ren and Krackhardt 2000, Tsvetovat and Carley 2006, Moon, Carley and Levis, Vulnerability Assessment on Adversarial Organization: Unifying Command and Control Structure Analysis and Social Network Analysis 2008), efficiency (Carley, Lee and Krackhardt 2002, Carley, Reminga and Kamneva 2003), or shared situational awareness (Graham 2005). Of the latter – idealized staffs conducting simulated operations - studies include analyses of organizations conducting radar classifications (Carley and Ren 2001, Papageorgiou and Carley 1993, Carley and Krackhardt 1999), humanitarian aid missions (Dekker 2002), cadet C2 at the United States Military Academy (McCulloh, Garcia, et al. 2007), and collection strategies for the exploration and destabilization of terrorist networks (Tsvetovat and Carley 2006), among many others. The model of work backlogs in an idealized joint staff with dual responsibilities for both routine planning and crisis response Kalloniatis *et al* (Kalloniatis, Macleod and La 2009) provides a basic description of a joint staff and differentiates between routine (battle-rhythm) events and non-routine work, and shows how competition in operational priorities and missions can affect staff performance.

2. Decision Support Tools for the design of military organizations

A number of organization-theory and network-science inspired decision support tools have been created and employed by the Army for assistance in the design of Army organizations.

The Army Research Laboratory (ARL) has developed a number of assessment tools - Command, Control, and Communications: Techniques for the Reliable Assessment of Concept Execution (C3TRACE) (Kilduff, Swoboda and Barnette 2005) and the Improved Performance Research Integration Tool (IMPRINT) (Mitchell 2000)- that provide human performance models of operations, tested against operations in Battalion Tactical Operations Centers (TOCs) and Fires and Effects Coordination Centers (FECCs). These models are based off human performance models in specific environments, down to the individual granularity of tracking time required to process incoming messages and click on them. While this method is uniquely useful for computing the distinct effects of different information technologies for extremely time-sensitive tasks (such as processing a fire mission in the shortest time possible).

The Personnel-Based Unit of Action Design Environment (PERSUADE) developed by Aptima, Inc. with ARL approaches the problem of organization design from a different direction; focusing on optimizing the matching of tactical tasks to resources and C2 nodes within a defined mission plan (G. M. Levchuk, Y. Levchuk, et al. 2006).

All of these tools are designed to optimize or improve the performance of an organization to conduct a defined task – the C3TRACE and MPRINT models to minimize the human factor costs involved in the performance of the task, and the PERSUADE model to minimize the organizational cost (G. M. Levchuk, Y. N. Levchuk, et al. 2002, G. M. Levchuk, Y. N. Levchuk, et al. 2002) of selecting forces for a defined mission.

3. Foundation of this approach

The foundation of this approach lies in the realization that Army doctrine provides an excellent data set for network science analysis. Data development off of doctrine, rather than observation, has several advantages – it is arbitrarily correct, more-or-less public, free of observer bias, and free. In addition, *it is what we actually make military policy decisions based on.* While the doctrine itself may be informed by observations of real organizations, it is the doctrine that defines the organizations and structures how we acquire personnel, equipment, and training to support them.

However, network science methods seem like they *should* be a natural approach to answering the organizational questions posed above. First, Network Science can make quantitative characterizations of organizations based on the relationships between their elements, not the properties of those elements (National Research Council 2006). These methods can reveal, for example, the structural properties of the job of 'Brigade Special Troops Battalion Commander', without knowing whether or not that officer is Engineer or Intelligence branch. Finally, we can test alternate organizations and generate hypotheses about their performance without additional, costly, field experimentation (National Research Council 2008).

Our approach to modeling the data used within and questions posed by this research focuses on the elements relevant to military policy decisions. We have been strongly informed by the methods of cost-benefit analysis (Mishan 1978), risk analysis (Morgan, Henrion and Small 1992) , and decision analysis (Keeney 1982) in order to structure the policy problem and the kinds of decisions that affect it. The network science methods used are based on standard network statistics (Wasserman and Faust 1994), upon organizations modeled according to the logic of the PCANS model.

Section 3: Dissertation outline

This dissertation presents a body of network modeling and structural analysis research built upon the network representation of doctrinal U.S. Army units at the Brigade Combat Team (BCT) level and below. This research is oriented towards a more complete understanding of military capability, including the types of capabilities that are relevant to military policy decisions. The basic question addressed here is whether we can relate the structural elements of a military organization (personnel, materiel, and information) and the things it is supposed to do (military tasks) in order to assess its capability.

The argument in this dissertation is built over six chapters and several appendices. This chapter focuses on introductory matters, including the inspiration for both the topic and the approach used. The bulk of the argument is developed in chapters 2-4. Chapter 5 presents findings and future work, and chapter 6 concludes the dissertation.

Chapter two seeks to address the potential value of a structural model of military organization capability by addressing the kinds of policy decisions that claims of military capability inform. Chapter 2 articulates how policy decisions about strategy and concepts inform military policy decisions about operation planning, force structure, and force development. Chapter 2 shows how different kinds of claims about capabilities inform these policy decisions, and then develops a logical structure for these capability claims. Chapter 2 finally shows that one form of capability claim – general organization capability – is centrally important to military policy and is amenable to a structural model of capability.

Chapters three and four build upon this to develop a network-science based model for the assessment of general organization capability according to the doctrinal structure of units and tasks. Chapter three shows how Army units and doctrinal tasks can be represented as meta-networks and quantitatively compared.

Chapter four builds a model of organization capability on the network models for units and tasks. The fundamental approach involves deriving linkages between the agents and resources in the organization and the roles and resource requirements in the task, and then assessing the availability of sufficient agents and resources to meet the task requirements by echelon within the organization. Chapter 4 then shows other methods for assessing capability based on this general framework, including measurements with given organization capability data and methods of aggregating across non-hierarchical dimensions.

Chapters five and six conclude this work by bringing together the findings, assessing their value, and identifying future work that can be done to refine the model or practically apply it.

Section 4: Limitations and scope

There are several important limitations to this research, focused on both the type of data used and the scope of the research.

1. This research uses Field Manuals and doctrine versus authoritative structure documentation.

The authoritative data used for programming and budgeting Army structure is contained in the TO&Es and Modified TO&Es (MTOEs), and is classified at minimum 'For Official Use Only.' In order to limit the sensitivity of the data used in this research, all displayed data is from U.S. Army field manuals that are approved for public release and unlimited distribution.[8] Some data used is from manuals that are unclassified, but only approved for release to the US government and contractors. This presents three challenges: (1) FMs and doctrinal publications are not authoritative sources for structure information; (2) some of the Field Manuals for tactical organizations are not current (e.g., most of the Artillery field manuals are still published form the 1990s); (3) Field Manuals tend to focus on the core competencies of the organization, and may not reflect all of the assigned support or staff.

2. Not a survey of Army organizations.

Though this research codifies data on a large number of Army organizations, it does so for the purpose of general validation of the modeling procedure and measurement of capability, not for the purpose of studying or surveying Army tactical organizations per se. The methods developed in this research can be used to study Army organizations in general – in fact, that is one of our recommended future topics for research – but this work does not.

3. Does not consider force employment.

The focus of this research is on matters appropriate to certain military policy problems – specifically, the force structure and force development problems, and decisions regarding them contribute to the capability of Army forces. It does not focus on matters related to the employment of these forces, such as what capabilities are more effective or how they can or should be employed. Nor is it primarily concerned with the content of force structure decisions or force development decisions – this research will not recommend whether the Army should change its number of BCTs or acquire a new fighting vehicle. Rather, it focuses on the relationships between force structure and force development decisions and plan or concept requirements.

Section 5: Key Findings

Chapter 2 focuses on structuring the policy problem of capabilities-based planning. In doing so, it reveals several important nuances about the nature of capability claims used to argue for specific military policies or programs:

- *There are five different types of capability claims, and they are each related to different policy problems.*
- *One type of capability claim, claims of general organization capability, brings together force structure and force development decisions.*
- *Assessment of general organization capability by doctrinal analogy is the only way to assess claims of organization capability prior to initial fielding and experimentation.*

The meta-network models of military organizations and tasks developed in chapter 3 reveals several important findings:

- *The doctrinal structure of both Army organizations and tasks can be represented as meta-networks.*
- *Unit doctrine provides inconsistent Task-organization data for network modeling.*
- *The results of some network science methods defined to characterized observational data mean something different when applied to doctrinal data.*

Chapter 4 brings together the work presented in chapters 2 and 3 by showing how meta-network models of doctrinal organizations and tasks can be compared to present a robust, quantitative method of assessing general organization capability claims by consistency with doctrine. It finds that:

- *General organization capability can be quantitatively assessed based on meta-network representations of organizations and tasks.*
- *Aggregate organization capacity can be quantitatively assessed based on a set of organizations, requirements, and capability data.*
- *Network models can be used to articulate certain types of set-covering integer programming problems*
- *Both models of capability assessment can be applied to multiple concepts of organization.*

In addition to its primary finding, chapter 4 develops a network-based integer programming method for solving network assignment problems based on meta-network data that includes a supply network, requirement (or demand) network, and suitability network. This network programming method can also be extended to include organization based exclusivity data or alternate aggregation data.

Notes for Chapter 1

---

[1] All references towards military forces and institutions will refer to the United States, unless noted otherwise.

[2] 'Force generation' is an important concept throughout this work. It is a catch-all term used to refer to the various processes by which the Army mans, equips, trains, and organizes its units to achieve readiness objectives. There are two basic types of force generation models – *progressive readiness* (like the ARFORGEN model), which builds up the readiness of a unit over a timed cycle to meet specific readiness objectives in the 'available' year; and *tiered readiness*, which prioritizes resources to units required to maintain certain readiness levels, and resources other units at lower levels (to be increased upon mobilization).

[3] Public Law 112-25. URL: http://www.gpo.gov/fdsys/pkg/PLAW-112publ25/html/PLAW-112publ25.htm

[4] Doctrinal, in this sense, means that the organization and task data are drawn from Field Manuals, Army Doctrinal Publications, and Army Doctrine Reference Publications. These data sources have several advantages for research, in that they are generally unclassified and approved for public release, provide good outlines of the structure and functions of units, and include extensive explanations of the tasks and functions. They are limited in that they are not authoritative sources for what the organizations have (those are contained in the Table of Organization and Equipment and Modified Table of Organization and Equipment), often do not go into detail about enabling or supporting organizations, and can be out of date or incomplete.

[5] Controlling for the amount of time that the unit had been deployed - units behave differently at the start and end of their rotations.

[6] Redrawn from FM 3-90.6, *the Brigade Combat Team* (Figure 1-1, p. 1-7 (HQDA 2010)). Note how the BSTB changes the relationship with the support companies.

[7] Redrawn based on FM 3-90.6, *The Brigade Combat Team;* FM 3-21.21, *The SBCT Infantry Battalion*; and FM 3-90.5, *The Combined Arms Battalion* (HQDA 2010, HQDA 2003, HQDA 2008). Note the different ratios of vehicles, weapons, and infantry at company and battalion.[7]

[8] See chapter 3 for how these documents are used, and Appendix A for a comprehensive list of used documents.

The Logic of Military Capability Claims

CHAPTER 2

On any given day working in the Pentagon, one might see an advertisement of the 'unconventional capabilities' of the F-35 fighter, read a pitch that a given service component provided '80% of the Army's Judge Advocate General Capability', hear a pitch about the 'Joint Force Capabilities in 2020', recommend a solution to an identified capability gap, be told that 'the Army must retain the capability inherent in its mid-grade leaders', and read an article decrying that while 'the west is accelerating its strategic decline' it 'continues to have capabilities second to none.'

In each of these assertions, 'capability' is used substantially differently to refer to various military policy decisions. How do these appeals to military capability relate to each other and the military policy of the United States? This question is relevant, as capability is the logical basis of defense planning processes. The 2001 Report of the Quadrennial Defense Review (QDR), published shortly after 9/11, prioritized shifting the basis of "defense planning form a 'threat-based' model that has dominated thinking in the past to a 'capabilities-based' model for the future (OSD 2001)". The 2006 and 2010 QDRs reaffirmed this approach, with the 2010 QDR adding the notion of the aggregate *capacity*[1] of the force as measure for defense planning (OSD 2006, OSD 2010). Despite the general significance of the concept of 'capability' in military policy matters, there is no common language for integrating or evaluating capability claims. For example, acquisition and force planning decisions to meet Joint Capability Areas (JCAs) consider military tasks (CJCS 2011), but capabilities for operation planning are defined in terms of courses of action (CJCS 2013). This lack of a common language for capability claims creates ambiguity in the continuous Department of Defense debates about forces, resources, and priorities.

This chapter addresses ambiguity in the concept of capability for military policy analysis by identifying the various aspects of military policy that capability claims address (section 1); considering the elements that capability claims share in common (section 2); and developing a taxonomy of the types of capability claims, their implications, and standards for validating them (section 3). Finally, we consider the logical relationships between types of capability claims in section 4, and summarize the findings in section 5.

Section 1: Public policy aspects of military capability

The assessment of military capabilities is essential to three major, interrelated elements of military policy, and one element of national policy:

1. Planning military operations.
2. Developing new systems and organizations.
3. Planning military force structure decisions.
4. Foreign policy or 'grand strategy'

The aspects of military policy – the primary focus of this research – share many things in common. They occur in peacetime, or under peacetime policies and processes. They are influenced by the needs of the Combatant commands, but ultimately led by the Services. Decisions about them determine most of the United States Department of Defense's budget. These processes, since the end of the Cold War, have also increasingly reflected the policy tension between various concepts of the proper role of the military and the preferred methods of military involvement, and the political tension between which services receive the most resources in support of their force structure.

The aspect of national policy cited above sits 'above' the military policy, and under the Joint Strategic Planning System (CJCS 2008) drives the other aspects of military policy.[2] Criticisms of this system (see (Hammes, Let Strategy Drive Procurement 2013), for example) generally argue that resource decisions – the elements of military policy described above – actually drive the national policy, not vice-versa. Whether or not military policy is driven by, or drives, national policy; the process of assessing a national strategy relies on the assessment of 'total military capability,' or military power, of various states (Tellis, et al. 2000).

None of these policy questions share the same definition of the term 'capability', evaluation criteria, level of aggregation, time horizons, or budgetary impacts. In part because of this, defense decisions are notoriously difficult to evaluate in terms of either cost or risk versus benefit. It is hard to compare the value of incremental technological changes (e.g., a better Bradley in Armored BCTs) versus wholesale organizational changes (e.g., the Stryker BCT). Finally, it is hard to quantify the effects of various operational or institutional concepts – such as AirSea Battle or Army Force Generation (ARFORGEN) – on military capability. Understanding how the relevant types of capability relate to each other may help resolve this by providing a logical framework for comparison.

1. Operation Planning

Planning for wars, contingencies, and other military operations requires a sense of what forces can be used to complete what portions of a task. Forces are identified first for the major portions of the task; second, to mitigate potential risks; and third, to sustain and enable the forces identified in parts one and two. The Geographic Combatant Commands are responsible for the development of Contingency and Operations Plans (CONPLANS and OPLANS, respectively) with the assistance of the services, for approval by the Secretary of Defense. In general, one service is given the lead based on the theater – for example, the Navy in Pacific Command, or Army in Korea[3] – but this is not mandatory.

The Army's capability claims in major operations planning are expressed in terms of the forces allocated to specified tasks (usually the major ground force) and rules of allocation for the appropriate security, combat support, and combat service support forces. The major combat formation is determined based on a host of factors, including the mission, enemy, terrain, time and troops available, civilian considerations, etc. Various methods are used to predict or validate the capability of this force, including qualitative methods.[4] Aggregated combat models (Naval Postgraduate School 2000) can be used in the case of force-on-force engagements against a conventional enemy. There are fewer methods for other types of operations – as illustrated by Obama's complaint that no matter what strategy he went with in Afghanistan, the answer was 40,000 troops (Woodward 2010).

Operation planning is highly institutionalized in the Army and Department of Defense. During the Cold War, operation planning was the single determinant factor of all primary elements of military policy, including force structure and technological development. This paradigm, known as 'threat-based planning' (OSD 2001), focused on designing a military that could prevail in active conflict with the Soviet Union. The most dangerous enemy course of action was identified, and a force structure that could defeat it was tailored through repeated wargames, simulations, and exercises. The gaps in this plan and any other specified lesser contingencies drove both force structure and military technology development. Here we find our first sense of the term 'Capability': the <u>*capability of a specific organization*</u> to execute the assigned task in an OPLAN subject to specified conditions (including the enemy). This paradigm creates a specialized force that is tailored to defeat a specific enemy but must be reorganized, adapted, and recommitted to face others. This paradigm also specifies *readiness* criteria for available forces, based on the time frame in which those forces must be available.

Since the end of the Cold War, the military has been called upon to conduct an increasing number and variety of tasks (Priest 2003, Fitzsimmons 2007). Without a preeminent threat and with the recognition of both sustained commitments and a variety of contingency requirements, the task of designing a force structure around the 'most-dangerous and lesser included' contingencies has grown more complex. The Capabilities-Based planning paradigm is intended to give the Combatant Commands the ability to tailor a force for specific operations from the forces available at the time, based on the requirements of the mission and the abilities of the forces. In order for this to work, the capability of the forces available must be defined in a more general sense, because those forces may not be trained or validated against the specific course of action they are likely to employed in prior to alert. This leads us to another sense of the term 'Capability' – the <u>*capabilities of organizations in general*</u> to execute standard tasks under various conditions. These conditions require a military force that is more adaptable than the 'threat-based' model, as it must be able to perform under a variety of conditions.

2. Concepts and Force Development

When the military acquires new military technology or organizes forces in new combinations, it hopes that the result is more effective than the organization or technology that came before. The United States has been successful at this – since the demonstrated, rapid success of U.S. military forces in Operation DESERT STORM the U.S. has possessed the most technologically capable force in the world. DESERT STORM led many observers to believe that technological change had ushered in a 'revolution in military affairs': that modern weapons and Command and Control technology could drastically increase the combat power of military formations. However, the force that achieved such a revolution was designed for a specific threat, and (despite predictions at the time (Biddle 2004)) proved to be highly applicable to the conditions in Kuwait and the weaknesses of the Iraqi Army.

The Department of Defense implemented various capabilities-based acquisitions systems, including the Joint Capabilities Integration and Development System (JCIDS) (CJCS 2012), Joint Concepts and Experimentation, Materiel Development Decision, and Capability Portfolio Management in order to manage and prioritize the force development activities of the various services and enforce interoperability within Joint Warfighting Concepts (GAO 2008). These systems identify areas where the force lacks capability ('capability gaps') and force development options to remedy them ('capability solutions'). These planning systems are heavily weighted towards materiel solutions (National Research Council 2005) – new equipment or systems – because the Services have fairly extensive authority to reorganize themselves within budgetary or strength limits (CJCS 2012) without JCS approval.

The focus on materiel solutions accounts for another major public policy interest in military force development. Materiel development and procurement activities constitute a significant portion of the defense budget. Research, Development, Testing and Evaluation is 13.2% of the Fiscal Year (FY) 13 Base Budget Request. The procurement account – which includes the purchase of modernized equipment for units – accounts for an additional 18.8% (Harrison 2012). It is difficult to account for how much of the other primary accounts (Operations and Maintenance and Military Personnel) are involved in the fielding of new capabilities, as their budget lines are not tied to specific capability requirements. For non-materiel systems, involvement in a formal capabilities determination is only required if the capability requires significant changes to Joint doctrine or combinations of forces across services.

For materiel developments, however, the JCIDS system requires that materiel solutions be tied to both identified Joint Capability Areas (Joint Staff 2007) and Key Performance Parameters. The Joint Capabilities Areas correspond to desired effects, for example 'the ability to kinetically engage targets reinforced (with armor, concrete, dirt, etc.) to protect against blast, heat, or radiation' (CJCS 2011). Key Performance Parameters define thresholds such as armor penetration or operational range. These categories of effects and thresholds are also the standards used in defense Capability Portfolio Management (Hiromoto 2013). These requirements lead us to another, significantly different sense of the term capability: the ***technical capability*** of a specific system to achieve a specific effect or threshold. These claims of technological capability are used to justify either long-term needs – such as the Army's need for a transport that enables en route mission planning and rehearsal for forces traveling to a theater of operations (Higginbottom and Adkison 2012)-or emergent needs, such as the Mine Resistant Ambush Protected vehicle (Lamb, Schmidt and Fitzsimmons 2009).

3. Force Structure

The operational planning paradigm of aligning specific organizations to specific tasks became much more difficult after the first rotations of troops to Operations IRAQI FREEDOM and ENDURING FREEDOM had been replaced by the second, and the Army started identifying organizations for the third rotation. The Army's inventory of forces was sufficient to meet the first and second year requirements of the war, but began to stretch for certain capabilities – especially low-density, high demand capabilities such as Special Forces, Explosive Ordinance Disposal, and Civil Affairs – by future rotations.

In order to meet these demands in a predictable manner, the Army instituted ARFORGEN: a three-phased process of building readiness in Army units to provide a balanced force capability and a 'sustained flow of forces for current commitments and to hedge against unexpected contingencies'

(HQDA 2011). Under this model, units are available for deployment or mobilization[5] for 9 months out of every 36 (Active Component) or 12 months out of 60-72 (Reserve Components). This force generation construct provides an orderly set of requirements for military units between available years; relatively predictable mobilization schedules for Soldiers; and a sustained flow of trained, cohesive and ready units to Combatant Commanders.

However, ARFORGEN also increases the complexity of the force management problem the Army faces. Under a 'threat-based' paradigm, the Army can still match individual units to various military tasks and generate readiness as required by the relevant OPLANs and CONPLANs. Under a rotational model, however, each period's available force pool must be capable of the predicted military requirements, and additional forces outside of immediate requirements must be able to become ready as needed

These capability requirements are of the same form as those given under operations planning (see above) – and many of the enduring capability requirements are linked to standing OPLANS – but the need to maintain a sustainable rotation requires assessing the capability of multiple force pools against the various task sets. This led to the requirement in the 2010 QDR that enduring requirements 'shape not only considerations on the *capabilities* our Armed Forces need but also the aggregate *capacity* required to accomplish their missions now and in the future' (OSD 2010). This leads us to the last purely military sense of the term capability – the capability of a large organization or a group of organizations to meet a set of tasks, possibly subject to constraints such as time or distance. In order to distinguish this sense of the term from the generalized sense of organization capability mentioned on page 9, and to highlight the relevance to the 2010 QDR mandate, this research refers to it as <u>*aggregate organization capacity*</u>.

4. Foreign Policy and Strategy

The oldest, and most academically recognized, sense of 'military capability' is the ability, through violence, to compel our opponent to fulfill our will (Clausewitz 1832/1976). This sense of the term – the relative power of one combatant over another – has long tradition in realist international relations theories. It is the 'quantity' that balance-of-power theorists argue is balanced (for the first explicit definition, see (Hume 1742/1987)).[6] The classical definition of military capability is given in terms of means and will (Clausewitz 1832/1976)[7]. The total means available, which correspond to the above *aggregate capacity* measurement, is measurable; but the 'will' is generally articulated either *pre hoc* in terms of the strength of objectives, or *post hoc* in terms of the revealed behavior of the combatants.

Policymakers assess military capability to inform decisions about the use, or potential use, of force in foreign policy. This policy process determines the contingencies that military planners address in the operational planning processes described above. This assessment is relative to the target or policy objective at issue, and can include assessments of non-military aspects of national power, the target's military capability, and desired objectives. There are numerous methods of assessment for this form of policy-making, which take into account different aspects of context relevant to the decision. In general, these take a different form from the other capability assessments described above.

At the national level, assessments of total relative military power inform foreign policy. Common criteria for assessing a nation's capability for 'industrialized warfare' include assessments of its total military forces 'in being' (the amount and capability of a potential belligerent's military forces) and its potential military forces (the amount and capability of military personnel and equipment that can be acquired in the event of conflict). Both of these measurements focus on military *means;* and consider the aspect of will in terms of the enemy's objective and the amount of available resources the enemy is willing to mobilize for the conflict. For nuclear war, strategic assessments differentiate between 'counterforce' and 'countervalue' capabilities, which target the enemy's *means* and *will* respectively. While the *means* available were articulated in terms of the available nuclear arsenal, *will* is articulated in terms of the amount of population damage the enemy is willing to sustain. Other studies attempt to assess will in terms of the relative cost tolerance and strategic aims of belligerents (*e.g*., (Sullivan 2012)), and assess these variables *a posteriori* for various observed conflicts. *A priori* estimates of strategic will remain the purview of strategic intelligence.

RAND offers another definition of total capability, as "the ability of a military force to successfully prosecute a variety of operations against a country's adversaries" or the 'output' of national power (Tellis, et al. 2000). Their given framework seeks to measure the 'inputs' to the military apparatus of a country, and how those 'inputs' are translated into a variety of output capabilities. RAND's definition is intended less towards prediction of success in war, and more towards the accurate identification of potential threats and changes in the international environment.

More limited assessments of total relative capability add nuance by considering how the means available are employed. Stephen Biddle's 'formal model of capability' defines military capability as the ability to succeed at an assigned mission (Biddle 2004), but measures it in terms of variables such as dispersion, concealment, frontage, and depth of penetration. This method of assessment considers military doctrine and employment in terms of conventional battle. Other methods, such as those employed in aggregated combat models (Naval Postgraduate School 2000) use combinations of means, employment, and probability of effect to predict success, casualties/losses, and resource expenditure.

These more limited models depend on extensive circumstantial factors, and serve primarily as a way of assessing the costs in or efficacy of operations plans. These assessments, in turn, inform can inform the national or strategic-level assessment of whether or not the operation is worth the political or strategic risk. To the extent that they can aid in the assessment of plans, they indirectly inform the identification of capability gaps for force development decisions. Service-driven wargames, such as the Army's UNIFIED QUEST (U.S. Army 2013), often use self-generated futuristic scenarios to identify capability gaps outside of the federal programming and budgeting time frame (7 years).

The assessment of the target's military capability, and the military means available to address it, becomes the final sense of the term 'capability' – ***relative military capability***, or the ability of one force to militarily influence (compel, coerce, deter, or assure) another. Assessments of relative capability can in fidelity from the relative power of nations to the relative capability of specific military forces.

5. Relationships between types of capability claims

These policy applications for assessments of military capability and the types of claims that support them are similar and related, but not the same. Figure 3, below, depicts these aspects of policy and capability and their relationships.

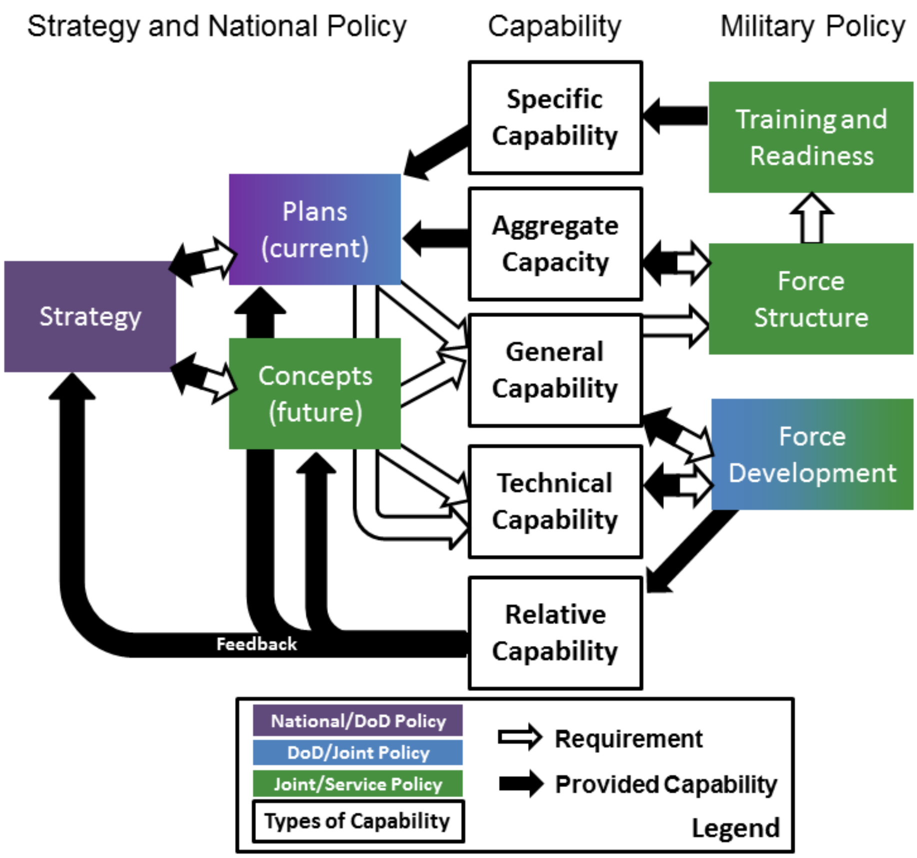


Figure 3 – Relationships between the types of capability claims.

Going from left to right, we have a description of how the identified policy problems and the capabilities associated with them relate. National policy should drive both current plans and future concepts. Each of these requires both *general* and *technical* capabilities. For the purposes of meeting plans, these general capability requirements are met by what the force structure can provide – either in terms of the *aggregate capacity* to meet the requirements or the *specific capability* of trained and ready forces. Technical capability requirements for operation plans result either from anticipated shortfall in capability or from requirements developed during the conduct of ongoing operations. These capability requirements drive a 'rapid' force development process[8] that is intended to rapidly produce or increase the force's *relative capability.*

For the purpose of developing the force towards a future concept, both the general capability and technical capability requirements are addressed by the force development function, which designs and organizes new systems. These functions are intended to provide the relative capability the new concept addresses.[9]

Section 2: The Semantics of Capability

When a proponent for a plan, system, organization, or force structure change articulates the benefits of the proposal, they do so in terms of capability. However, the various types of proposals do not have the same semantics, reference points, or standards of proof. In order to discuss and compare these proposals, we analyze them in terms of capability.

1. Capabilities-Based Planning

The capabilities-based planning paradigm standardized the articulation of military benefit in terms of capability. Since it became policy in the 2001 QDR, much ink and thought has been expended in nailing down exactly what it means and how it applies to the services. The best definition of Capabilities-Based Planning was penned in a 2002 RAND monograph – 'Capabilities-Based Planning is planning, under uncertainty, to provide capabilities suitable for a wide range of modern-day challenges and circumstances while working within an economic framework that necessitates choice' (Davis 2002).

If we assume that we can accurately and consistently model military requirements and their link with the means to address them then we can discuss the relationship between capabilities-based planning and the planning and force structure decisions described above. Let us assume that national strategy chooses the driving military policy between three choices – a single dominant OPLAN (the Cold war is the prime example), multiple major contingency requirements (the 'wide range of modern military challenges' mentioned in (Davis 2002)), or a capacity-constrained force. For each paradigm, let *N* be the total number of requirements, and let *M* be the inventory of forces. The military planning problem is how we link those forces and requirements, described on Table 1.

	Requirements/Tasks	**Capabilities**	**Capabilities**
Single Dominant OPLAN	*N* requirements determined by OPLAN	One capability linked to each requirement, *M*=*N*	1-1 mapping between each capability and its requirement
Multiple Contingency Requirements	$n \in N$ requirements for each contingency (*t* total), where $\bigcup_1^t n_t = N$	*M* total capabilities linked to multiple requirements for various contingencies	1-*n'* (where $n' \in N$) map, with each capability mapped to multiple requirements.
Capacity-Constrained Force	Same as for 'multiple contingency requirements, above	*m'* capabilities at any given time available (where $m' \in M$).	*m'*-*N* mapping between $m' \in M$ capabilities and *N* requirements

Table 1 - The capability problem within military policy constructs[10]

Capabilities-based planning was designed to be a solution to this mapping problem, specifically the 'Multiple Contingency Requirement' problem. Under the 'Single Dominant OPLAN' requirement, each capability is associated with the organization, function, or system that performs it. This paradigm implies a flexible way of matching available capabilities with military requirements or missions. However, there are inconsistent standards for applying this paradigm. In Davis's approach, capabilities reflect 'building blocks' of a force, but those blocks are inconsistently defined. Davis's examples alternate between shooting platforms for narrowly-defined scenarios, such as air attack to stop enemy maneuver; to general operational design identifying the functions required for a successful operation (see (Davis 2002), figure 4-3 and 4-5). Other methods, including Capability Portfolio Analysis (CJCS 2012, Hiromoto 2013) focus on linking individual systems to necessary effects. The Army's Total Army Analysis (TAA) system (HQDA 1995) focuses on applying units to major combat scenarios, but defines supporting capability requirements via rules of allocation for enabling units. In addition, the TAA process only examines a limited number of scenarios.

The process of matching available capabilities against requirements informs the force development problem as well. Where requirements exist without capabilities to address them, the JCIDS system identifies a capability gap and either a materiel or non-materiel solution to it. This system addresses the total capabilities in the force but does not address the *availability* of those capabilities.

The table above describes a complicated policy problem in relatively simple mathematical language. Reality is not so clear-cut. As the Analytic Architecture for CBP (Davis 2002) puts it:

> "The bounding-scenario (*i.e., Threat-Based Planning against the most dangerous course of action)* method was ultimately a trick, a shortcut that served reasonably well for many years. There were few illusions in the minds of the secretaries, who understood full well that the forces developed would be used in a myriad of ways unlike those of the bounding scenarios. The trick worked because the Soviet Union was an immense and multifaceted threat- challenging us worldwide and in the air, land, sea, and space. The trick no longer works. Indeed, it has not worked for more than a decade, but Secretary Aspin prolonged its life by substituting the bounding scenario with the concept of planning for two major regional contingencies, later named major theater wars."

In part, this is due to the way we define capabilities and requirements. Practically, we have *always* operated under a 'capacity-constrained force' oriented towards 'multiple contingency requirements,' since the military never has everything and policy changes. However, military policy attempts to answer national strategy in its own terms. If a single dominant OPLAN drives military policy then building needed capacity becomes a requirement within the plan[11] linked to standing organizations. Similarly, if a force is designed against multiple contingency requirements, then the force wishes to provide the most capabilities to address them.

2. Definition of Capabilities and Requirements

Requirements and capabilities are defined in terms of each other. The DoD dictionary (CJCS 2013) does not define 'requirement', but it is variously defined in the JCIDS manual (CJCS 2012) as either a *capability requirement* ("a capability that is required to meet an organizations roles, functions, and missions in current or future operations”) or a *Joint Military Requirement* (“a capability necessary to fulfill or prevent a gap in a core mission area of the Department of Defense”). The JCIDS definitions are recursive – organizations’ roles, functions, and missions should themselves be defined in terms of requirements; and gaps in mission areas correspond to unfulfilled requirements.

The definition of capability itself provides little clarification, in part because it has changed drastically over the course of this research. Beginning in 2004, the DoD defined capability as ‘the ability to achieve a desired effect under specified standards and conditions through combinations of means and ways to perform a set of tasks. (Fitzsimmons 2007, CJCS 2011).’ This definition, despite its obscurity, lasted into 2011. The current definition is far more succinct – ‘the ability to execute a specified course of action (CJCS 2013).’

From a military policy perspective, the current definition of capability addresses the ‘operational planning’ policy problem, but must be stretched to apply to other policy aspects – especially the ‘force development’ problem, which the JCIDS system is intended to address. The 2004 definition of capability articulates various components that can be applied to all of the uses of capability described above, but the uses differ so substantially that it is difficult to compare them. For the purpose of this research, we will use the 2004-2011 definition, as it is more comprehensive.

3. Common elements of capability claims

The purpose of this research is to explain the different types of capability claims and how they relate to each other. We are less concerned with the definition of capability than in the parts of a capability claim, which ones are relevant to each sense of ‘capability’, and how they interact. The 2004-2011 definition of capability incorporates four elements – *effect, conditions & standards, means and ways,* and *tasks.* Since requirements and capabilities are defined recursively, it is also appropriate to describe the requirements that drive these capability claims. Each of these elements has a different meaning, depending on the type of capability being discussed.

Task – The definition of the ability, which is likely to achieve the desired effect.

Conditions and Standards (*Context*) – Situational variables that describe the circumstances the ability is likely to be employed in. Context can include risk, or the probability of effect given situational variables.

Ways and Means (*Organization*) – How the capability is employed. What systems, organizations, personnel, and/or information the capability requires to be used.

Effect – The requirement the capability meets.

Finally, given that the DoD must also prioritize and evaluate capability claims from various proponents, it is important to also describe the *Standards of Proof* relevant for different types of capability claims. These standards of proof describe what it takes to determine the validity of a capability claim in peacetime or wartime. We focus on validation in peacetime, as that is when the debates about defense priorities are most heated and when capability is hardest to evaluate.

Section 3: Taxonomy of capability claims

Section one identified five types of capability claims common among the various aspects of military policy:

1. Specific Organization Capability
2. General Organization Capability
3. Technical Capability
4. Aggregate Organization Capacity
5. Total Relative Capability

Section two discussed the definitions of both capabilities-based planning and capability. Each definition implies common elements of action, organization, context, effect, and standards of proof:

1. Requirements
2. Task
3. Context
4. Organization
5. Effect
6. Standards of proof

In order to tie these types of capability claims to the actual policy decisions being made (to approve a plan, develop a new system, field a new organization, or change force structure), we examine the specifics of each type of capability claim by the elements given above.

1. Specific Organization Capability

The original, and most consistently defined type of capability claim, asserts the ability of a specific organization to perform a specified task or course of action. This is the only sense of the term that the official definition of capability (given above) applies to without any stretching or interpretation. During operations, these claims are defined by the course of action in the specific plan; otherwise, these claims are validated against the tasks the unit is explicitly designed to perform. Claims of this form are very familiar to Army commanders, who report monthly (or quarterly, for reserve component units) on their organization's ability to perform the tasks on its Mission-Essential Task List. These claims can be validated against a specific training task; or against the rehearsal or execution of a specific mission.

Requirements for specific capabilities – OPLANs or CONPLANs require the services to provide capable, validated[12] organizations in order to be executed, but articulate their needs as general organization capability requirements because the services can meet them from any of the forces available. In general, only the early or immediate requirements in the plan require validated, specifically capable organizations on hand, and these forces are assigned to the Combatant Command that will carry out the plan. For other requirements, the OPLANs or CONPLANs provide requirements for general organization capabilities, and the services specify the organizations that will be validated as specifically capable to meet them.

Task – What the 'organization' element is doing. This is the only sense of the term 'capability' that the official definition of task – 'A clearly defined action or activity specifically assigned to an individual or organization … imposed by an appropriate authority' (CJCS 2013) – applies to. Practically, this can be either a task given by an OPLAN or CONPLAN, or a generic training task.[13]

Context – The particulars of the organization or individual conducting the task, the environment, and, if applicable, and the enemy or opposing force give context for specific organization capability claims. This context, and the act of specifying the organization (below) conducting the task, differentiates these claims from *General Organization Capability* claims, defined below.

Organization – The unit conducting the task is the 'organization' element in a specific capability claim.

Effect – this is the intent of the tactical task, or the military effect it was intended to achieve. It is the 'why' in a mission statement – for example, [this organization] attacks (the task) [this location at this time] in order to destroy [this enemy] (the effect). Army doctrine gives a list of military effects in FM 1-02 and FM 5-0 ((HQDA 2010) and (HQDA 2010), respectively). Note that the effect intended can influence either how the organization conducts the task or whether or not an organization is capable at all – an attack intended to fix an enemy in place (e.g., forcing them to take cover and preventing them from moving) is conducted differently than attack to destroy an enemy; and a sniper team is capable of disrupting an enemy infantry platoon (by causing them to deploy in combat formation early stop and treat casualties) but is unlikely to be able to destroy it.

Standards of Proof – We prove specific organization capability by monitored and evaluated exercises (in training), rehearsals (prior to a designated mission), mission performance, or after-action reviews. Validation exercises prior to deployment or assignment for a certain mission are the definitive example.

Implications –

Sensitivity to context: Specific organizational capability claims are highly sensitive to context. The same organization that is capable of conducting a task when rested or in good weather may not be able to do so while exhausted or in poor weather. For this reason, there is a certain irreducible amount of uncertainty in this type of capability claim. Policies that increase the realism of training exercises or add the judgment of unit commanders to status assessments attempt to mitigate this uncertainty.

Differences in peace- and wartime: Specific organization capability claims have slightly differing meanings in peacetime and wartime. In war, we determine whether organization can do something in order to use it. In peace, we say an organization can do something in order to label it as 'ready' – or available for – a mission. The 'readiness' sense of the term is relevant to policy, as the readiness requirements of the force determine training budgets. This sense of the term is compatible with the elements of *general organization capability*, below – in fact, for readiness reporting (AR 220-1 (HQDA

2010)) purposes, the elements of general organization capability plus validation in a training exercise equals specific organization capability.

2. Technical Capability

The force development policy problem and the definition of general organization capability, both mentioned above, refer to this third sense of the term 'capability.' Claims of technical capability refer to the performance or abilities of specific systems. Examples of technical capabilities include the ability of a system to penetrate armor, hit a certain type of target, resist a certain type of attack, detect something, or communicate. Claims of the form 'the Javelin can destroy [armored] targets from medium ranges (65 to 2,000 meters), including helicopters and fortified positions' (HQDA 2008) are claims of the technical capabilities of the military system – in this case, the Javelin close combat missile. Technical capability claims have the following elements:

Requirements for technical capabilities – Technical capabilities are required when present systems cannot address a current operational need, capability gap in an approved plan, or element of a future force concept. Operational needs and gaps in approved plans are determined by the COCOMs and passed down from the Secretary of Defense (top-down); gaps in future force concepts are identified by the services and approved by the JROC (bottom-up). The top-down system identifies gaps in current organizational capabilities given the context of an OPLAN or ongoing operations. The bottom-up system identifies gaps in proposed future means of force employment. Because the bottom-up system is primarily responsible for identifying large procurement projects with long lead times, some commentators (GAO 2008, Lamb, Schmidt and Fitzsimmons 2009) believe it exerts disproportionate influence on the decisions of the JCIDS system.

Task – The technical ability of the system, or what it does. This can be defined very specifically – in terms of range, engagement areas, capacity, etc.[14] or more generally, in terms of a specific technical task. The Joint Capability Area framework provides a list of appropriate technical task categories. Using the Javelin example, the Javelin addresses JCA 3.2.1.1.1.1.1 - 'the ability to kinetically engage targets reinforced (with armor, concrete, dirt, etc.) to protect against blast, heat, or radiation' (CJCS 2012).

Context - The operating circumstances of the system, its limitations, and appropriate environments. For example, the cool-down time of the night-vision sight on the Javelin missile is 2.5 – 3 minutes. The ability to mitigate contextual variables may require other technical capabilities in the system. Estimating the effects of contextual variables can help determine the probability of achieving effect (or risk of failing to produce the desired effect).

Organization – The organization, process, or system used to employ the technical capability. Using the examples given above, employment of the Javelin missile system requires a trained gunner at minimum, and successful combat employment requires an organization to maneuver, identify targets, and protect the gunner(s). This 'organization' element corresponds with the task element of a general organization capability claim.

Effect – The effect element of a technical capability claim asserts what the system is likely to do when employed successful – for example, the ability to detect or destroy a certain type of target. The effects of technical capabilities do not usually correspond to the doctrinal military effects, except in the case of 'destroy'. Claims of technical effects may be probabilistic – like the probability of successfully hitting or destroying a target, or the probability a false negative or false positive on a sensor reading; deterministic – such as the troop-carrying capacity of a vehicle; or 'arbitrarily deterministic' (*i.e.,* probabilistically defined according to certain parameters, but set to a certain standard for planning purposes) – such as the weight capacity of a vehicle or the sustainable rate of fire of a weapon system.

Standards of Proof: Robust, bureaucratic systems for evaluating the technical capabilities of new military acquisitions were put in place after the scandals involved in the development and fielding of the Bradley Fighting Vehicle (Burton 1993) and F-18 and F-22 fighters (Coram 2002). Technical capabilities can be measured relatively objectively using controlled experiments and demonstrations, and there are mandatory tests for new materiel capabilities as they move through the JCIDS system.

Implications –

Minor technical changes with emergent effects: Any given history of the U.S. Civil War will point out that the emergence of the rifled musket with an effective range of greater than 300 meters, combined with Napoleonic tactics developed for the 100-meter smoothbore musket, led to disproportionate casualties; a situation that common tactics, techniques and procedures would not change to account for until late in the war. Even incremental improvements to systems with little organizational cost (see above) may require substantial reorganization to accommodate, after the implications of that improvement are identified.

This behavior can be articulated by the curious similarity between the *task* and *context* elements of technical capability claims. The armor penetrating capability of a missile, for example, can be articulated as a positive task (penetrate more than a given amount of armor) or a negative limitation (ineffective against more than a given amount of armor). If the removal of a contextual limitation enables the system to achieve a new type of effect (either the capability gap it was meant to address, or a change in the relative capability (see below) of the unit that employs it), then that change creates a new technical capability, which also requires its own general capability to employ.

Validation of new general capability by successful employment of a technical capability: Technology changes faster than doctrine (Singer 2009). Some systems (e.g., MRAPs) are fielded without a complete understanding of the organization required to employ them. Successful employment of such a system by a unit – usually in combat – then validates the *specific organization capability* of that unit to employ it. That specific capability can then be extrapolated into the *general organization capability* of units with similar systems; validated either by successful adoption of the new system or tactic by other organizations, or by exercise and review.

3. General Organization Capability

We can generalize from the specific capabilities of individual organizations to the general capabilities of all organizations of the same type. Claims of general organization capability assert that all units of a certain type can conduct all tasks of a certain type. Claims of the form 'the HBCT's capabilities include accomplishing very rapid movement and deep penetrations and performing company-sized air assaults', or 'the IBCT's capabilities include the ability to conduct forced-or early- entry operations and taking part in amphibious operations' (both summarized from (HQDA 2010)) are examples of claims of general organization capability.

The major force structure changes described in the introduction to this research are driven by the Army's efforts to improve its capabilities through reorganization (CSI 1999), but they are not primarily technical or specific organization capabilities. Rather, the Army argued that the reorganized units are more or less capable based on how they function and doctrine for the tasks they perform.

There are two main elements of a general organization capability claim – the *task*, which the claim asserts the capability of, and the *organization* which can conduct it. They put less emphasis on context and effect – the former verges into the realm of a specific organization claim, and the latter varies according to the tactical use of the task.

Requirements for general organizational capabilities – As mentioned above, while executing an operation requires specifically-capable organizations, these requirements can be met by generally-capable organizations trained and validated for that operation unless the requirements are so time-constrained that capable organizations must be on-hand immediately. Since the Army does not generally assign forces to specific Combatant Commands,[15] force structure requirements are articulated in terms of general organization capabilities.

Task – Tasks in generic organization capability claims are defined in terms of how an organization employs its constituent elements – what its members do, which of the organization's resources they use, and how they organize to perform the task. These tasks can run the gamut from tactical tasks – *e.g.,* 'conduct an anti-armor ambush' – to staff tasks – 'conduct intelligence preparation of the battlefield' – to supporting tasks – 'process and handle detainees.' The descriptions in doctrine for the above tasks[16] describe how the force organizes, identify subordinate tasks, and identify the likely effects it can achieve. The Army lists types of tasks in the Army Universal Task List (HQDA 2009), and describes how organizations conduct them in unit-specific doctrine.

Context – Claims of generic organization capability are inherently separated from operational context. In general, these claims offer guidelines on the circumstances and limitations in which they are appropriate or inappropriate. For example, 'the HBCT has limited mobility and speed in restricted or mountainous terrain (HQDA 2010)'. For lower-level tasks, some organizational context can be assumed away by assuming the availability of support organizations (someone at the other end of a radio to receive a report, for example); otherwise, support becomes part of the task.[17]

Organization – General organizational capability claims abstract the organization of the unit from the organization of the task, since the essence of these claims are assertions that organizations can perform the tasks. The generic organization for a unit, in the Army, is given by its Table of Organization and

Equipment (TOE) (HQDA 1997). This document describes the structure and equipment inherent in the organization and its hierarchical composition. The task-organization, or the method of employment of the organization, is the definition of the task itself.

Effect – because claims of generic organization capability are abstracted from specific context, they are also not tied to specific effects. In general, there are certain types of effects that certain types of tasks can achieve – FM 3-90: *Tactics* and ADRP 3-90 – *Offense and Defense* (HQDA 2001, HQDA 2012) enumerate lists of generic military effects on enemy forces,[18] but the employment of tactical tasks to achieve effect is the discretion of the commander or planner. To the extent that organization capability claims are linked to the employment of technical systems, their effects are related to the capabilities of that system – see relative military capability, below.

Standards of Proof – Claims of generic organization capability are difficult to prove; but can be validated by either extrapolation from specific organization capabilities or consistency with other doctrine.

Extrapolation from specific capability: The definitive method of validating a claim of organizational capability is to test it through the training, exercise, wargames, or combat employment of various organizations of the given type (see (CSI 1999) for examples of this on previous Army division structures). We can assume an organization type has a certain capability if enough specific organizations of that type have demonstrated that capability before. In times of peace, this can be done by realistic exercises and rehearsals. In times of war, tactics, techniques and procedures may be disseminated to other organizations without testing, and become institutionalized in doctrine if they are consistently successful.

Consistency with doctrine: Another method for validating generic organization capability claims is to compare them with approved doctrine. If a new organization is like an organization for which there is well-developed doctrine, we state that the new organization will have similar capabilities among those dimensions that are similar. An excellent example of this is the doctrine for the Stryker Mobile Gun System, which was written before the system was fielded and draws heavily on comparison with armored doctrine (so much so that the illustrations in FM 3-20.151 depict Abrams tanks, not Stryker MGSs (HQDA 2005)).

Implications –

Validating Organizational Change: Generic organization capability claims are the only way to reflect the benefit of decisions such as force reorganization or other non-materiel (in the JCIDS system, 'Doctrinal Change Recommendation' (DCR) (CJCS 2012) changes to forces. However, the two standards of proof for general organization capability claims have fundamental limitations for force development.

Extrapolating general organization capabilities from the observed capability of specific units requires that the new system or organization be fielded in large numbers, which spends a significant portion of the decision costs before the decision is validated. The failure in fielding the Pentomic division, cited above (CSI 1999), is an example of this – the Army reorganized its entire force to the new structure, but then found that the force did not have enough communications or artillery available to achieve its designed effect.

Arguing for capability by consistency with doctrine does not require fielding or equipping expense, but is only as accurate as the fundamental analogy.[19] While an SBCT can conduct some tasks like ABCTs, it lacks the same amount of protection or firepower. At the time the BCT was fielded, there were substantial arguments over which tasks that meant the SBCT would be incapable of, (see (O'Reilly 2003)).

Employment of Technical Capability: Technical and general organization capability claims are related, as the general organization capability is the means by which a specific technical capability (described below) is employed.

In the case of an incremental improvement to an existing program – such as building a better rifle –the argument of organization capability by analogy applies perfectly. The tasks and organization (aside from the new system, which occupies a similar role) are identical; therefore the essential element of the original organizational capability claim remains valid. New technological capabilities add value insofar as they affect the context of the original capability claim by removing or changing limitations (for example, an all-weather capable optic), or by changing the achievable effects (for example, a more lethal or accurate weapon).

However, in the case of capabilities that require a new type of organization or a current organization to function differently in order to be employed, the link between the new system's capabilities and its effects depends on how it is organized. The changes to the organization required to use the new system is its 'organizational cost'. If a specialized organization uses the system – for example, the Unmanned Aerial System (UAS) platoon in Military Intelligence Companies – the cost is the new organization. Even in the case of specialized organizations, how they fit into their higher organization can shape the effects they provide.[20] If an organization reorganizes, or changes the way it fights, to implement the new system – for example, the change from the M113 Gavin to the M2 Bradley in Mechanized Infantry Platoons – the cost is the reorganization required to employ the system.

Tasks are separate from organizations: If an organization has sufficient resources – in terms of trained personnel and technically-capable systems – it has the general organization capability to task-organize for a specific task. A tank platoon with additional infantry equipment has enough personnel to form a rifle squad and a weapons squad from a standard infantry section, and a tank company can dismount and reorganize as an overstrength infantry platoon. Specific platoons or companies may require additional training to do so effectively; but the organizations are generally capable.

During Operations Iraqi and Enduring freedom, Army units demonstrated this by reorganizing field artillery battalions and reconnaissance squadrons to fight as infantry, in order to expand the amount of area the parent BCT could control (see (Taylor and Krivitsky 2005), for example). Army readiness reporting systems allow for organizations to be reported for both their designed and assigned tasks (HQDA 2010).

4. Aggregate Organization Capacity

The 2010 QDR distinguishes 'capacity' from 'capability' – "…not only considerations on the *capabilities* our Armed Forces need but also their aggregate *capacity* to accomplish their missions now and in the future (OSD 2010)." This term is new to the capabilities-based planning lexicon, and used almost exclusively to refer to force structure decisions writ large. Claims of aggregate organization capacity assert that an organization can accomplish multiple, discrete tasks simultaneously (or nearly simultaneously).

Requirements for aggregate capacity – Requirements for aggregate capacity are the sum of the general organization capability requirements from OPLANs or CONPLANs, modified by contextual variables (see below). For example, under the 'two major regional contingency' paradigm, mentioned above, the aggregate capacity requirement is sufficient forces to address both contingencies. Under the 'disrupt in one theater, defeat in another' paradigm (OSD, The White House 2012), the aggregate capacity requirement is the disrupting force plus the defeating force.

Task – The task element of a claim of aggregate organizational capacity involves a set of smaller general organization capability tasks, each defined as above for general organization capability claims.

Context –The time frames in which the forces are required, their locations, the types of operations that drive the requirement, and the command relationships between the forces provide context for claims of aggregate capacity. Some of these contextual variables may be mitigated by additional subtasks within the aggregate capacity claim – for example, the ability to deploy within a certain timeframe may be a limiting contextual variable or a task to be provided by a designated transportation organization. Other contextual variables may be readiness requirements (see specific capability, above).

Organization –The force that will provide the set of capabilities is the organizational portion of the aggregate capacity claim. This is usually defined as the entire force structure, but it may be limited to the 'available pool' for certain planning purposes.

Effect – The effect of an aggregate capacity claim is implied by the task – all forces are provided, satisfying the requirement. Debates about aggregate capacity claims do not focus on the effect desired, by rather the risk of failing to satisfy the capacity requirement, either because of insufficient forces or inadequately ready forces. This is the 'force management risk' construct identified in the 2010 QDR.

Standards of Proof – There are few standards for proving or validating aggregate capacity claims at the 'total force' level prior to actually providing those forces for an operation or contingency. This is in part due to the novelty of the term and in part due to the identification of the capacity problem in the challenges faced by the Army during operations IRAQI FREEDOM, ENDURING FREEDOM, and NEW DAWN.

The Army validates the aggregate capacity of its force via both participation in the Joint Global Force Management process and the Total Army Analysis process. The former assigns Army units to military requirements within the current budget timeline (current year to two years out); the latter tests the Army's planned force structure against possible scenarios within the defense program year (three to seven years from the current year).

Implications –

Aggregate capacity claims are types of general organization capability claims: It is possible to articulate aggregate capacity requirements as a single capability requirement posed to the force structure as a whole. Indeed, during the Cold War, this was precisely the dominant OPLAN model of force structure design. Doing so has certain advantages, as it includes higher-echelon enablers and generating force support requirements in the force planning criteria, in addition to capturing the basic building blocks of the force.

However, the distinction between aggregate capacity and a higher level 'total force' capability remains useful, both because ti is how the actual Global Force Management and Total Army Analysis processes work, and because the higher order support requirements (especially theater-level Joint Command and Control requirements and multi-service enabling requirements) may not be well-defined enough to articulate as a in the capability requirement, especially for less-detailed CONPLANs (CJCS 2011).[21]

Aggregate capacity at the tactical level: Requirements for force capacity are not generally articulated at the tactical level, in part because generic organization capabilities are already articulated in doctrine at the tactical level, and claims of capacity are subsets of these organizational capability claims. However, the notion of capacity as articulated above holds equally well for tactical organizations as it does for the force structure as a whole. If an organization must be employed differently from its doctrinally described tasks, such as the practice of conducting section- or platoon-level patrols from semi-permanent combat outposts in Iraq and Afghanistan, there is value in determining the number of different subtasks it can execute. The elements of capacity claims described above hold for 'tactical capacity claims,' but they can be proven with the standards for general organization capability claims. In this sense, as well, specific capability implies aggregate capacity for related tasks validated under the specific capability claim.

5. Relative Military Capability

Relative capability claims assert the ability of one military force to achieve effect against another – in colloquial language, "my tank division can beat your tank division." Because these claims depend on an identified enemy, there are often made either in the context of validating OPLANs, in discussions of foreign policy, or in discussions of future threats and concepts to address them (*e.g.,* if the enemy fields this new system, we will no longer be able to defeat them).

Requirements for relative military capability – Relative military capability is the output of general organization capabilities and technical capabilities created by force development. Requirements for relative military capability most closely correspond with 'capability gaps' identified in the JCIDS system, though the JCIDS system quickly identifies them for either materiel or non-materiel solutions (i.e., requirements for technical capability or general organization capabilities). These claims are used to validate plans, assess attrition or resource expenditure, or inform assessments of foreign policy.

Task – The task element of a claim of relative military capability identifies the type of enemy and the military effect[22] intended. The effect, here, specifies one of the effects that general organization capability claims are linked to.

Context – Context for relative capability claims includes the circumstances of the engagement, including both the contextual variables that affect the general capability of the organization conducting the task, the technical capabilities of the systems it employs, and the enemy.

Organization – The organization element of a relative military capability claim is a friendly organization or unit, task-organized as per the 'task' element of general organization capability claims, described above.

Effect – The effect element and the task element of relative military capability claims are described in terms of each other – indeed, the task *is to achieve* the intended effect. For combat modeling, effects may be modeled probabilistically (*e.g.,* the chance of success of an operation) or in terms of cost (*e.g.,* the number of casualties on both sides of an engagement).

Standards of Proof – Claims of relative military capability are even more difficult to prove than claims of general organization capability. The only definitive proof of relative capability is success in combat – to quote Musashi, "the only real measure of [the warrior's] ability lies in being able to beat men in fights regardless of their nature (Musashi 1645/1994)."

For policy purposes, evidence for claims of relative capability derive from a combination of the *consistency with doctrine* standard for general organization capability, and the standards for evaluating technical capability.

After fielding, but in lieu of combat, evidence for relative capability can be derived from observing similarly-equipped forces in combat. Indeed, the impetus for AirLand[23] battle came from observing the limitations and capabilities of Russian arms versus American arms, wielded by both sides in the 1973 Arab-Israeli war (Johnson 2006)

Implications –

Relative Capability is a function of both technical and general capability. A history of American operational art prior to and during World War II articulated this same claim, at the tactical level: "Tactics, in fact, is how technology in the form of weapons can best be employed on the battlefield (Matheny 2011)." The essential elements of this implication are already mentioned above – general capability reflects the ability to employ a technical system, technical capabilities describe the effect of a system, and relative capability depends on the two.

At the tactical level of war, this holds very clearly. The ability of an infantry platoon to destroy enemy armor depends on both the method of engagement (close ambush, far ambush, prepared defense, etc.), and the capability of a weapon system (AT-4s can work in a close ambush against lighter tanks; Javelins are capable against larger tanks at longer ranges). At the operational and strategic level, the relative importance of the general capability claim becomes more important. At these levels of war, large organizations employ more specialized systems (technical capabilities with specific organizations developed to employ them), and the effects of widely-fielded tactical systems are generalized across the entire force.

Relative Capability can be defined both specifically and generally. In its general sense, relative capability implies the ability of one type of force to cause an effect on another type of force. However, the observed results of combat are validated relative capability claims. In this case, we have captured the specific instance of a unit performing the task, and the specific effect it achieved on the enemy. This process of evidence works the same way as the validation of general organization capability through the observation of specific capability, mentioned above.

Section 4: Logic of Capability Claims

The foregoing sections have discussed the policy problems articulated by capability claims, the elements of capability claims, and the different types of capability claims; this chapter shows how these capability claims relate to each other and the policy problems they address, and how to logically address fallacies in reasoning about capability.

1. Context in the logic of capability

ADRP 3-0: *Unified Land Operations* (HQDA 2012) defines 'mission variables', or relevant context for conditions that pertain to the task, described by mission, enemy, terrain and weather, troops and support available, time available, and civil considerations (METT-TC). We can base a notation for contextual variables of capability claims on these mission variables.

- Let *o* indicate a specific organization, and *O* indicate all organizations of a type (therefore, $o \in O$).
- Let *T* indicate a type of task. Specific tasks are defined by type and context.
- Mission variables: Similarly, let *M, E, Te, Tr, Ti,* and *C* indicate all mission variables of a type, and let *m, e, te, tr, ti,* and c represent specific instances of that type. For example, the statement "ABCTs have limited mobility in mountainous terrain" is an example of *O* and *Te,* while the statement "2nd BCT, 1st Armored Division had limited mobility in Afghanistan" is an example of *o* and *te*.
- For most cases, the definition of the mission variables is self-evident. For our purposes, we define 'Mission' specifically as the military effect to be achieved

This notation allows us to note capability claims as binary functions of an organization, type of task, and limiting context. Let *S, T, G, A, R* stand for specific, technical, general, aggregate capacity, and relative capability claims, respectively. We can assert each time of capability claim, given context, as:

- *Specific organization capability:* $S(o,T|te,tr,ti, c) = \{1,0\}$, reads as "the specific capability of organization *o,* given specific terrain, troops, time and/or civil considerations" and is defined as one or zero if validated or invalidated.

- *Technical Capability: T(T|M, E, Te,Ti) = {1,0}* reads as "the Technical Capability of a system and employment method (*T)*, given a type of desired effect proper to the system (*M)*, and specific terrain/weather/time constraints. Technical capabilities may also be defined with a given enemy as context. Note that technical capabilities are not defined as functions of organizations and tasks; rather they are defined for tasks alone. This is consistent with the definition of technical claims given before – the organizational element is the method of employment (*T,* here) and the task element is the military effect (*M,* and/or *E,* here) to be achieved.
- *General organization capability: G(O,T|Te,Ti,C) = {1,0}*. General organization capability is defined for all units of a type, and all applicable troops. It may be nuanced by context of types of feasible terrain, time constraints, or types of civil considerations.
- *Aggregate organization capacity: G(O,T|Ti) = {1,0}.* Aggregate capacity shares the elements of its definition with general organization capability, as (described above) aggregate capacity claims are types of general organization capability claims.
- *Relative military capability:*
  - *In the general sense: R(O,T|M,E,Te,Ti,C) = {1,0}*
  - *In the specific sense: R(o,t|m,e,te,tr,ti,c) = {1,0}*

  Relative capability is defined similarly to general capability – for all units of a type – given the additional contextual variables of the effect to be achieved and the type of enemy it is to be achieved on.

2. Axioms

Proving general organization capability by observing specific organization capability. By the conditional probability variation of the law of total probability (DeGroot and Schervish 2002),

$G(O,T|Te, Ti) = \sum_{j=1}^{k} S(o_j, T \mid te, ti, tr_j)$; provided that $o \in O$, $te \in Te$, $ti \in Ti$.

The claim of capability, here, functions like a probability distribution. As long as the supporting contextual variables (*te, ti*) are of the appropriate type, then observations of specific organization capability serve to provide observations across the potential field of troops available and organizations.

Specific organization capability = general organization capability + training. On the other hand, the act of validating units for employment involves testing a specific organization against a general organization capability of a type appropriate to it:

By the definition of conditional probability:

S(o,T|te,tr,ti, c) = G((O,T|Te,Ti,C)(te,tr,ti,c))/ G(O,T|Te,Ti).* Provided $o \in O$, $te \in Te$, $ti \in Ti$, etc.

Conditional probability is defined as the probability of an event, given that another event has already occurred. In the case of specific capability, this is precisely the general form of the mechanism that validates capability by sending an organization of a type with a given general capability to a training center. That is, the general organization capability claim gives broad limits for the type of terrain and time constraints. The specific organization being trained provides the context of the troops available and the specific organization. For policy purposes, if we tend to treat the specific instances of the terrain and time constraints at the training centers as validating the organization for all appropriate terrain types.

Relative military capability = general organization capability + technical capability. By a similar logic to the validation of specific capability against general organization capability, we can consider relative capability as a function of general capability and technical capability:

$R(O,T|M,E,Te,Ti, c) = G((O,T|Te,Ti,C)*T(T|M,E, Te, Ti))/ G(O,T|Te,Ti)$ Such that the type of task, terrain and time considerations are the same for both the general and technical capability claims.

This axiom merely formalizes the assertions that general organization capability represents the employment of a technical system, that those technical capabilities represent the ability to achieve effects given terrain and enemy, and that relative capability relates organization, tasks, and enemies.

3. Fallacies of reasoning about capabilities

The development of a logical structure for capability allows us to identify fallacies in capability claims. Two examples follow:

Extrapolating Technical Capability into Generic Organizational Capability. Claims of the form 'the Q-47 is capable of adjusting friendly indirect fire' (HQDA 2002) or 'the [Stryker Infantry Platoon is capable of destroying tanks and fighting vehicles with long range antitank guided missile (ATGM) fires out to 2,000 meters (Javelin)' (HQDA 2002) are based on the technical capabilities of specific systems - the Q-47 and Javelin ATGM, respectively.

The first capability – the Q-47 – implies an organization. Adjusting indirect fire requires a sensor that can observe where the round impacts (in this case, the Q-47), communication between that sensor and the fire direction center, a fire direction center to adjust the instructions to the gun battery, communication with the gun battery, and a set of guns to fire the adjusted rounds. The second capability – the ability to destroy tanks, implies both a weapon and a means of employment. In order to destroy tanks with the Javelin ATGM, the Stryker platoon must have dismounted its infantry and task-organized its squads as anti-tank teams.

Assuming the presence of enabling capabilities. Claims of the form 'The HBCT can conduct company-sized Air Assault operations' imply an organizational structure outside of the capable organization. The HBCT is capable task-organizing its infantry into an air assault, but requires helicopters and crews, and a higher organization that provides the C2 necessary to organize an air operation (*e.g.*, airspace control and other functions). In this case, the general organization capability to conduct the air assault is resident in the Division (or higher) task force that controls the operation. For operational planning and force structure purposes, this fallacy becomes important if the supply of enabling forces is constricted - the definition of 'high-demand, low-density' forces.

Section 5: Conclusion and Findings

This chapter discussed the policy decisions that are informed by military capability, analyzed how the capabilities-based planning paradigm articulates them, developed a taxonomy of capability claims, and examined the logical relations between types of capability claims. This chapter presents the following key findings:

- *There are five different types of capability claims, and they are each related to different policy problems.*
- *One type of capability claim, claims of general organization capability, brings together force structure and force development decisions.*
- *Assessment of general organization capability by doctrinal analogy is the only way to assess claims of organization capability prior to initial fielding and experimentation.*

1. Findings

Finding 1: There are 5 Different types of Capability Claims.

This chapter identifies 5 distinct types of capability claims – (1) specific organization capability claims, (2) technical capability claims, (3) general organization capability claims, (4) claims of aggregate organization capacity, and (5) relative military capability claims. These capability claims are used to justify four different kinds of policies, and not all capability claims are applicable to each sort of policy. Figure 3 in this chapter depicts the relationships between the various types of capability claims.

Sub-Finding – We can express capability claims as formal logical propositions and analyze them as such.

The insight in section 2, that capability claims are composed of an organization and task element and assert a relationship between those elements subject to limiting context is a logical proposition. Section 4 articulates the five different types of capability claims as logical propositions, provides examples of how some of the intricacies of capability claims can be considered logically, and identifies some fallacies of reasoning about capability.

Sub-Finding - The mission variables of METT-TC articulate the contextual differences between types of capability claims.

The specific context for the logical propositions of capability can be consistently expressed in terms of instances and types of mission variables. Expressing these contextual elements as mission variables allows us to show how the types of capability assertions, given contexts, relate to each other. In addition, several laws of both logic and probability, including the law of conditional probability, can be applied to demonstrate nuances of reasoning about capability.

Finding 2: General organization capability claims bring together elements of military policy.

Both plans and future concepts articulate requirements for general organization capabilities – plans, because we cannot predict which forces will be available in the future at any given time; concepts, because we must design both the organizations and systems that will fight according to the new concept. The military policy elements of force structure revolve around providing an inventory of actual organizations that both possess the required capabilities (aggregate capacity) and are ready to employ them (specific capability). Force development requires us to consider the general capability of the organizations that will employ the new system or concept – even if the new system represents only an incremental improvement in technical capability, the improvement in the relative capability is a function of both the general organization capability and the technical capability.

Sub-Finding – Aggregate organization capacity is a subset of general organization capability

Section 3, in the description of aggregate organization capacity claims, pointed out that we can always articulate the capacity of an organization to perform a set of lower-echelon tasks as either a set of tasks or a single higher-echelon task that decomposes into the lower-echelon requirements. Both ways of articulating the problem have value for considering different problems.

Finding 3: Evaluation of general organization capability by comparison with doctrine allows force development decisions to evaluated prior to fielding

General organization capability claims, for force development purposes, are used to justify new organizations and systems. Unfortunately, the most reliable method of validating these claims requires fielding the new organizations and testing it – resulting most of the expense of the force development decision. The development of detailed concepts for the new capability – as was done in the SBCT, to the extent of publishing field manuals for the various components of the BCT before their Strykers were fielded – allows us to evaluate the capability.

This argument for capability by analogy is only as good as the underlying analogy. Providing a more robust description of the organization and more explicitly stating the comparisons with previous doctrine allows us to produce a more reliable assessment of the capability of the new concept or forces being developed.

2. Conclusion

This chapter addresses ambiguity in the definition of capability by identifying important types of capability claims and developing the taxonomy of distinct definition and logical implications for them. This method is different from the general approach taken since the inception of Capabilities-Based planning, of attempting to develop a single, unifying concept of capability and means to then 'optimize' military policy by providing the most capability according to requirements and constraints that necessitate choice. The attempts to develop such a unifying theme of capability - 'the ability to achieve a desired effect under specified standards and conditions through combinations of means and ways to perform a set of tasks (CJCS 2010)' or 'the ability to execute a specified course of action (CJCS 2013)' – either make the concept so broad as to be nearly useless[24] or return it to the threat-based planning paradigm it was meant to supplant.

The definitions and logical structure for capability given in this chapter promise to be more useful, as they specify the meaning of the types of capability claims, the contexts for which they are defined, and the standards of proof generally used for their validation. This approach allows the various aspects of capability to compared according to specifically relevant criteria and across systems and policy decisions, rather than specifying different policy systems (such as the Joint Operational Planning and Execution System and the JCIDS system) that focus on certain types of capability decisions and ignore others.

The remainder of this research, presented in Chapters 3 and 4, further develops finding 3 to create a network-science based method for evaluating general organization capability by analogy with doctrine. Chapter 3 shows how to represent both doctrinal organizations and tasks as meta-networks, and chapter 4 shows how to measure the general organization capability consistently based on the meta-network representation.

Notes for Chapter 2

[1] The same emphasis is given in the original text.

[2] The current strategic guidance is President Obama's 2010 National Security Strategy (The White House 2010); the 2010 Quadrennial Defense Review (OSD 2010), and the special sequestration-driven priority documents "Priorities for 21st Century Defense" (OSD, The White House 2012) and "Defense Budget Priorities and Choices" (OSD 2012).

[3] While Korea is part of the Pacific Command area of operations, and United States Forces – Korea (USFK) are subordinate to the Commander of Pacific Command, USFK is a standing Joint Task Force with a mission dominated by requirements for ground forces, hence its traditional Army command.

[4] These methods are discussed in section 3, paragraph 5 – relative capability claims, as they involve the assessment of a force's ability to achieve effect against an enemy.

[5] Deployment is the process of moving a unit to a theater of operation; or, in common usage, sending a unit to an operation. Mobilization, in the sense of ARFORGEN, refers to bringing a reserve component unit to a state of readiness for war or other national use – including bringing that unit on to active duty and/or deploying it to an operation. (CJCS 2013)

[6] 'Nor ought such a force ever to be thrown into one hand, as to incapacitate the neighboring states from defending their rights against it.'

[7] "If we desire to defeat the enemy, we must proportion our efforts to his powers of resistance. This is expressed by the product of two factors which cannot be separated, namely, *the sum of available means* and *the strength of the will*." Chapter 1, Section 5

[8] There are several of these, including Rapid Fielding Initiatives, Operational Need Statements, and Urgent Operational Needs Statements.

[9] For example, the Joint Operational Access Concept – ability to operate in an area where the enemy attempts to deny air or maritime access (Anti-Access, Area Denial) is a current concept driving some force development activities. (CJCS 2012). Of the 30 capabilities identified in this concept, at least 20 urge the development of new technical capabilities.

[10] The rows refer to the method of defense planning; the columns refer to military requirements, organizations, and the relationships between them.

[11] This requirement is the foundation of 'cadre units' – units manned with professional officers and NCOs, but few-to-no junior Soldiers and leaders. The Army operationalized this requirement before the Korean War in the form of Army Reserve training divisions (Currie and Crossland 1997).

[12] Validation is the process by which generically capable organization types are assessed as specifically capable; validation is explained under *generic organization capability.*

[13] The Army specifies these training tasks in the Army Training and Evaluation Plan (ARTEP) for unit types.

[14] For example, see p. B-10, FM 3-21.8: The Infantry Rifle Platoon and Squad, (HQDA 2007), which describes some of the technical capabilities of the Javelin missile.

[15] Except for those forces that are forward-stationed and allocated to combatant commands, such as the forces in Germany, Korea, and those Continental United States-based forces allocated to United States Pacific Command.

[16] See FM 3-21.91: Tactical Employment of Antiarmor Platoons and Companies (HQDA 2002); FM 2-01.3: Intelligence Preparation of the Battlefield (distribution restricted) (HQDA 2009); and FM 3-39: Military Police Operations (HQDA 2013) for descriptions of each.

[17]For example, the Army formalizes the higher-level support requirements for large operations in its rules of allocation (HQDA 1995), which list the additional support forces that must be available for the operation.

[18] For reference, these are: *Block, Canalize, Contain, Defeat, Destroy, Disrupt, Fix, Interdict, Isolate, Neutralize, Suppress,* and *Turn.*

[19] The remainder of this research, outside of this chapter, focuses on what is fundamentally a way to make this analogy more robust and provide methods to rigorously test new capability claims against them.

[20]Using the UAS platoon example, UAS in BCTs are organized as a brigade asset, in the BSTB. In Battlefield Surveillance Brigades (BfSBs), the UAS are organized into the line cavalry squadrons as battalion assets.

[21] There are four levels of detail for contingency planning – from least to most, a 'commander's estimate', a base plan, a concept plan, or an OPLAN. Only the OPLAN level has specified forces and deployment schedules.

[22] See endnote 15, above.

[23] A U.S. Army operational concept during the 80s that led to the development of the Abrams tank, Apache and Blackhawk helicopters, the Bradley fighting vehicle, and the Multiple Launch Rocket System. (HQDA 1982)

[24] "The linguistic equivalent of burning down a village to save it." (Fitzsimmons 2007)

Army Doctrine as Meta-Networks

CHAPTER 3

Army doctrine gives us tools to represent both organizations and task-organizations in similar language. This chapter discusses how to use the meta-network model of structure in organizations to represent these. It proceeds by identifying relevant sources of doctrinal data for unit and tasks, and general comments on the use of these data and where interpretation is required. The bulk of the chapter describes meta-network models for units, tasks, and common resource and knowledge information; and the entities and relationships in these networks. Finally, the chapter shows meta-network statistics of a sample of Army tactical organizations.

Section 1: Sources of network data of military organizations

The term 'doctrine' up to this point has been used in the academic sense to describe various concepts – from the overall concept of how a nation intends to employ forces within the context of a grand strategy (Posen 1984). From this point on, we will use it in a more limited sense, to refer specifically to Army Doctrinal Publications (ADPs), Army Doctrine Reference Publications (ADRPs), Field Manuals (FMs), and other publications[1] of Army Training and Doctrine Command (TRADOC).

This doctrine is important to the way the Army makes both force development and force structure decisions. For force development, the process of generating and documenting new force structure decisions requires doctrinal review and approval (USAWC 2013); for force structure and operation planning, the process of developing a force for an operation or the overall force structure involves rules of allocation developed by TRADOC and functional area proponents (HQDA 1995, USAWC 2013).

Unit-specific FMs and ADRPs, such as FM 3-21.8 *The Infantry Rifle Platoon and Squad* (HQDA 2007), provide most of the network data for both units and tasks. These FMs, especially at lower echelons, are primarily for the members and leaders of such units, and cover their organization and employment in specific types of operations. Higher-echelon unit specific FMs provide information on larger and more complicated tasks, discuss task-organization of subordinate units, provide information on enabling forces, and discuss communication and command and control arrangements.

Other FMs detail procedures common across various organizations, from higher level staffing processes described in ADP 5-0 *The Operations Process* and its associated ADRP and FM (HQDA 2012), to common military tactics described in FM 3-90 *Tactics* (HQDA 2001). These FMs can describe both higher- and lower-echelon tasks, and can clarify or expand upon task information contained in the unit-specific field manuals.

When necessary, other doctrinal publications such as Technical Manuals (which describe specific systems) and Army Training and Evaluation Program documents (which describe evaluation standards for units conducting tactical training exercises) are used to provide confirming or clarifying information. Technical Manuals are especially employment for determining the doctrinal methods of employment for systems that are not mentioned in the FM or used in other types of organizations.

BCTs and their subordinate organizations, as the primary maneuver formations in the U.S. Army, have the advantage of well-described, coherent, and consistent doctrine. In the cases where the FMs and other publications provide inconsistent or incomplete information, we refer to other Army publications, military journals, Jane's Defense Weekly publications, other internet sources, or military subject matter experts (including the author's personal experience).

Section 2: The Meta-Network Model

These sources of data are used to create a data set of U.S. Army unit types, tactical tasks and procedures, and common resources and knowledge. Each of these can be represented as an individual meta-network – a set of node classes that represent distinct kinds of entities within the organization and networks of relationships between them expressed as graphs.

Throughout this analysis, we focus on those elements of tactical organizations that represent budgetary or capital expenditure on the part of the Army or decisions about individual or organization authority. Personnel positions and equipment authorizations are policy decisions to spend money; responsibility for organizational knowledge and the structure of organizations are policy decisions regarding authority. Table 2, below, shows the policy elements considered in the meta-networks.

Units/Organizations	**Tasks**
Entities • Personnel – *Agents* • Materiel – *Resources* • Organizational *Knowledge* • Distinct Elements – *Organizations*	**Entities** • Personnel Functions – *Roles* • Materiel Requirements – *Resources* • Utilization of Organizational *Knowledge* • Distinct Elements – *Tasks*
Networks • Command Relationships *(Agents to Agents)* • Equipment Specific Training *(Agents to Resources)* • Training and authority to handle certain types of information *(Agents to Knowledge)*	**Networks** • Tactical Control *(Role to Role)* • Employment of Equipment *(Role to Resource)* • Contribution of Knowledge *(Role to Knowledge)* • Knowledge handling function of the task *(Task to Knowledge)*

• Organizational Authorizations
  • Personnel *(Organizations to Agents)*
  • Equipment *(Organizations to Resources)*
• Information handling functions *(Organizations to Knowledge)*
• Organization structure (*Organizations to Organizations)*
	• Requirements:
	  • Personnel *(Task to Roles)*
	  • Equipment *(Task to Resource)*
	• Subordinate Tasks *(Task to Task)*

<u>Other Networks:</u> • Communication Networks (*Resource by Resource*) • System access and information management (*Resource by Knowledge*) • Knowledge management (*Knowledge by Knowledge*)	

Table 2 - Military policy elements modeled in organization and task meta-networks

The unit/organization data represents the policy decisions based on expenditure and resources – the money spent on people, systems, and communications. The task elements represent how these assets are organized in order to perform functions. Each of these types of entities becomes a distinct node class in the meta-network model, and the relationships are modeled as graphs. Meta networks for units are described in the next section, and meta-networks for tasks are described in section 4. Note that both units/organizations and tasks share 'resources' and 'knowledge' in common – these two entity types share relationships that exist regardless of the type of task, described following in section 5.

Graph Notation

This is an appropriate point to introduce the matrix notation that will be used throughout this work. Each network between a source entity class with *m* elements and a target entity class with *n* elements is described in a matrix of either binary or integer values, of dimension *m* by *n,* as shown below. We note matrices in **bold** type. In order to avoid a proliferation of names and abbreviations for specific matrices, we note specific matrix relationships by a **<u>bold, underlined</u>** two-letter abbreviation of the source and target node classes - for example, the Agent by Agent command network is noted **<u>AA</u>**, and the Resource by Task requirement network is given by **<u>RT</u>.** If we define or derive multiple node relationships for the same source and target node-classes, we indicate the distinct relationships by a subscript abbreviation of the relationship names. For most networks of relationships between entities of the same class, we set the diagonal to one (indicating that the entity has a link to itself) for mathematical convenience - theoretically, we are not concerned with whether an agent commands itself (and neither, in our experience, is that agent's boss). In cases where a specific computation requires a certain value for the diagonal, or in the off chance we have a theoretical concern for the value of a self-link, we indicate so in the description of the network. These matrices also define directed graphs of dyadic links; if relevant, we will note if a specific mathematical operation is defined on a set of links instead of a matrix. We note the transpose of a matrix with an apostrophe.

	A	R	K	T	L	O
A - AGENTS	AA_{cmd}	AR_{skl}	AK_{acc}			AO_{mbr}
R - RESOURCES		RR_{commo}	RK_{hnd}	RT_{req}	RL_{use}	RO_{asg}
K - KNOWLEDGE			KK_{rel}	KT_{upd}	KL_{con}	KO_{resp}
T - TASKS				TT_{dec}	TL_{per}	
L - ROLES					LL_{ctrl}	
O - ORGANIZATIONS						OO_{comp}

Table 3 - Entity class and network abbreviations

Table 3 shows the abbreviations for node-classes and common relationships. Networks identified in green cells are described in unit information, those in yellow are described in task information, and those in blue are described in the common resource and knowledge information.

The meta-network model of organizations is cumbersome when defining multiple types of similar organizations. The number of possible connections between entities in the organizations expands rapidly as the number of entities and kinds of entities increases, since each new entity can be connected to every other entity in the organization. Since the objective of this thesis is to compare large numbers of possible military organizations, the doctrinal data is stored in an intermediate data form – OrgChart - and translated into the meta-network format by a rules based parser. The OrgChart data records information about component parts of organizations, the overall structure of the organizations, and how the separate components of the organization are linked to each other. For the details of this data form, see Appendix B.

Section 3: Unit Information

Network data of a military unit[2] describes the personnel and equipment it is authorized (agents and resources), the information it maintains or processes (if any), and its named components (organizations). For the purposes of this research, the unit-based field manuals provide most of this information - actual acquisition and resource decisions use the structure given by unit TO&Es and M-TOEs, which is far more detailed.[3] This section describes how the doctrinal description of a unit is translated into meta-network data, which entities and relationships were modeled, and what kinds of assumptions and judgment were used to develop the data representation. It covers each node class in turn, and the relationships specific to that node class and those that have been described before.

Table 4, below, describes the meta-network representation of a unit.

	AGENTS	RESOURCES	KNOWLEDGE	ORGANIZATION
AGENTS	Command	Skill	Access	Membership
RESOURCES		Communication	Handling	Assignment
KNOWLEDGE			Relevance	Responsibility
ORGANIZATIONS				Composition

Table 4 - Meta-Network model of a Unit[4]

Throughout this section we will use two standard organizations – 'leg' infantry platoons and M1 Abrams tank platoons; perhaps the two organizations most representative of the U.S. Army – to show the modeling practices at work.[5] These organizations are particularly interesting, both due to their importance and the major structural differences between them –the tank platoon consists of 4 identical tanks, while the Infantry Platoon has one special squad (the weapons squad) and a platoon headquarters element.

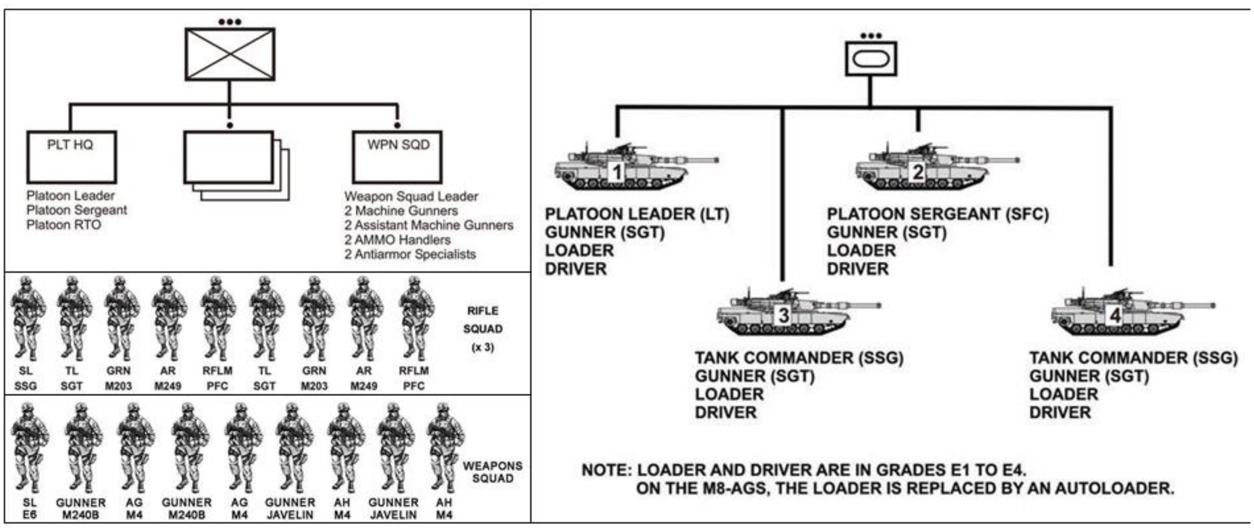


Figure 4 - The Infantry Platoon and Tank Platoon

1. Agents[6]

The Agents node class describes the personnel in the organization. We model every Soldier position in a doctrinal organization with an individual agent node. Each agent node has two properties – a title, which gives its duty position (*e.g.*, 'Rifleman'); and an ID, which is unique to the agent and coded by duty position and subunit of assignment (*e.g.*, '1 Bn - A Co - 1 PLT - 1 Squad - A Tm - Rifleman'). Within the intermediate data, agents are also described with a Boolean variable that indicates whether or not they command their unit of assignment. This 'command' variable is used to compute the Agent by Agent (command) network.

In the case of the example organizations, there are 39 agents in an infantry platoon and 16 agents in a tank platoon. We define relationships between agent nodes and other agents, resources, knowledge, and organizations.

Agent by Agent Command Network

Matrix **AA** is the agent by agent 'command' network. Agent *i* has a link to agent *j* in **AA** if agent *i* commands agent *j*[7]. We interpret the command relationship to the lowest level possible - in these data, for example, a machine gunner commands his assistant gunner. Unless otherwise noted for a specific operation, we define the diagonal of **AA** as one (indicating that each agent commands itself) for mathematical convenience. In the organization templates, commanders of organizations command the immediate personnel in that organization and the commanders of each subunit, unless otherwise indicated.[8]

In the example organizations, the Infantry platoon leader commands the individuals in his headquarters (the platoon sergeant and radio operator) and each of his squad leaders. Tank platoons organize differently – the platoon leader commands his tank and his wingman, and directs the platoon sergeant's section. Figure 4 shows the command network for each of the example organizations.

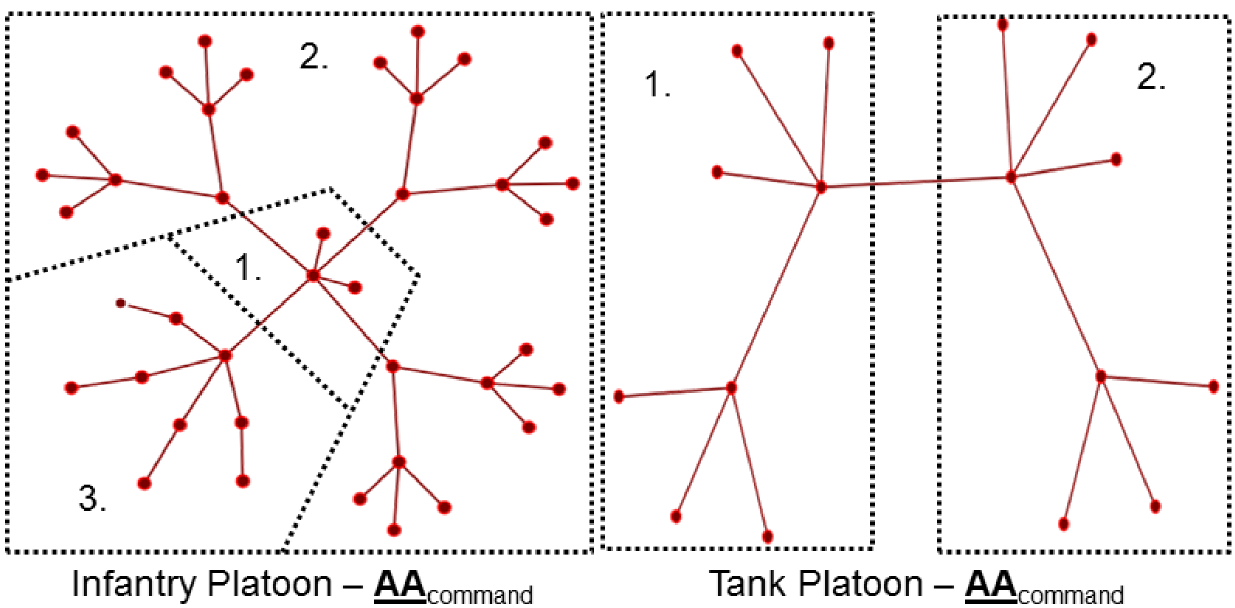


Figure 5 - The command network in the Infantry and Tank platoons

The two organizations reveal distinct structures:

Infantry Platoon –
1. Platoon headquarters;
2. Three rifle squads;
3. Weapons squad.

Tank Platoon –
1. Platoon leader's section;
2. Platoon sergeant's section.

2. Resources[9]

The Resources node class represents the equipment and materiel in the organization. We model relevant items of equipment in the organization as resources. Resource nodes have similar properties to agents – a title that indicates its type, and ID that specifies it individually by its organizational position (*e.g.,* "1 Bn - A Co - 1PLT - A Tm - Tank" or "1 Bn - HHC - BFV[10] 2").

Choosing which entities to model in this node class requires substantially more interpretation than the Agents node class, since there are literally thousands of discrete pieces of equipment in even company level units. In order to limit the node class to a reasonable size, we model a type of equipment as a Resource node if:

- It is required for a task. For example, we model tanks as resources because they are required to 'conduct a patrol in tanks.' This sense of the term generally comports with 'Pacing Items', or those items of equipment that have reporting requirements on a Unit Status Report because they are critical to a unit's wartime mission.
- It can communicate with other resources, *i.e.,* it is a communication or information system.
- It is not individual equipment or equipment issued to everyone in the organization, such as personal weapons (M16 or M4 rifle and/or M9 pistol) or uniforms and load-bearing equipment. These resources can be considered part of the 'agent' node that refers to a soldier.

In the case of the example organizations, we model 28 resources in the Infantry Platoon and 32 in the Tank Platoon, broken down by type on the following table:

Infantry Platoon		**Tank Platoon**	
Resource	**Quantity**	**Resource**	**Quantity**
Global Positioning System	4	M1 Tank	4
Javelin Anti-Tank Missile	2	120mm Main Gun	4
(Grenade Launcher) M203	6	(Machine Gun) Coaxial M2	4
(Medium Machine Gun) M240B	2	(Machine Gun) M2	4
(Light Machine Gun) M249	6	(Radio) - Amplified SINCGARS	4
(Radio) Manpack SINCGARS	5	(Computer) – FBCB2	4
Squad Marksman Rifle	3	Global Positioning System	4
Total	**28**	**Total**	**32**

Table 5 - Resources in the IN PLT and Tank PLT

Agent by Resource Skill Network

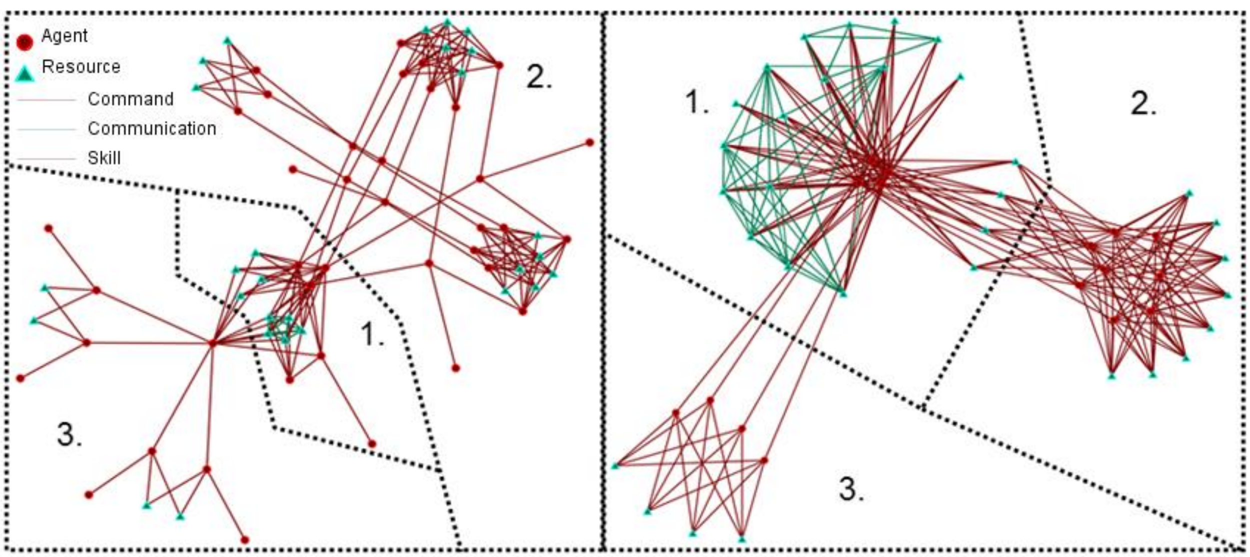
The agent by resource network **AR** indicates the skills of each agent to operate the indicated resource. Agent *i* has a link to resource *j* if agent *i* has the skills or qualifications to use that resource. In a real unit, agent skills are determined and tracked in a number of different ways depending on the type of resource; doctrinally, the agent's Military Operational Specialty (MOS) determines the base skills an agent is expected to possess, and the rest is the organization's responsibility to train. In these data, we use a relatively parsimonious assumption of agent skills. Unless mentioned otherwise in an agent or organization's description, we assume that each agent only has the skills for equipment assigned to it in doctrine.[11]

Resource by Resource Communication Network

The resource by resource communication **RR** indicates the technical ability of resources and systems to communicate with each other. We define a link **RR***ij* in the **RR** communication network if any resource type *i* can communicate with resources type *j*. The diagonal of **RR** is explicitly modeled – while virtually all communications systems are able to communicate with similar devices, things such as transmit-only radios cannot.

We model communication links specifically - a resource can communicate with another resource if it meets any of three criteria: 1. Computer systems that share a common network, such as the Secure or Non-secure Internet Protocol Routing Network (SIPRNET or NIPRNET), can communicate with other computer systems on the same network, 2. Radio systems can communicate with other radios that can transmit and receive on the same or similar frequency bands, or 3. Any resource can communicate with other resources that doctrine says it is specifically compatible with (*e.g.,* the Advanced Field Artillery Target Acquisition Data System is specifically mentioned as capable of communicating with the All Source Analysis System).

Figure 5, below, gives a depiction of the example organizations with both agents and resources modeled.



Infantry Platoon – $\underline{\mathbf{AA}}_{command}$ and $\underline{\mathbf{AR}}_{skill}$ overlay

Tank Platoon – $\underline{\mathbf{AA}}_{command}$ and $\underline{\mathbf{AR}}_{skill}$ overlay

Figure 6 - Agent and Resource networks in example platoons

The numbered areas on the network diagrams depict distinct portion of the organization:

Infantry Platoon – 1. Platoon & Squad Leadership;

2. Rifle Squads (grouped left-right by DRM, M249, and M203);
3. Weapons squad (grouped by M240B and Javelin).

Tank Platoon –
1. Tank Commanders (differentiated by radios & computers);
2. Gunners and Loaders;
3. Drivers.

3. Knowledge

The Knowledge node class describes common information products managed by organizations and unit staffs.[12] We model organization knowledge in order to analyze the organization's ability to collect, process, and disseminate it. The organizational elements that we gather together under the blanket heading 'knowledge' are the results of policy decisions on both authorities and expenditure – authority, in that access to knowledge is an important part of rank and duty position, and expense in the acquisition of information systems and staffs to manage information.

We use the term 'content' to refer to an individual knowledge entity, and 'knowledge' as the plural for content entities, when necessary. The knowledge entity class and networks are particularly difficult to model, as doctrine is not always explicit about what knowledge is available, who is responsible for handling it, and who is trained in its creation and interpretation. We create a content node if:

- There is a doctrinally named analytical product that is related to the organization,
- Or if there is a type of report or communication described as related to a named analytical product and associated with that organization.

We do not represent other types of general or agent-specific knowledge, such as an agent's Military Occupational Specialty that represent information proper to the agent rather than the organization.[13]

For an example of organizational knowledge, consider the BCT's 'friendly situation template'[14] – a named product that records the locations and status of all of the units in the Brigade Combat Team. This product is doctrinally defined, and assembled from either verbal or automated reports from each of the BCT's units operating in the battlefield.[15] We model both the template itself as a content node, and the situation of each of the subordinate units as a unique content node respective to those units. In the example organizations, both the infantry platoon and the tank platoon have their individual situation content nodes, and access to both the higher organization's situation and the friendly situation template.

Knowledge entities have the following relationships:

Agent by Knowledge Access Network

The agent by knowledge network **AK** indicates access of each agent to the indicated knowledge. Access, here, is defined if the agent *i* has the training, security clearance, and 'need-to-know' required to handle knowledge *j.* In these data, we assume access to knowledge if the agent is a member of an organization that is responsible for knowledge of that type (for example, a brigade-level intelligence analyst has access to intelligence information), or if the agent is specifically described as knowing a certain type of information (for example, Platoon Leaders are expected to understand the mission 'two levels up' – the company and battalion missions (HQDA 2007)).

Resource by Knowledge Handling Network

We define a link **RK**ij in the **RK** handling network if resources of the same type as resource i are specifically suitable to store or convey knowledge j. We restrict this definition to systems uniquely appropriate to the codified knowledge product - for example, the Integrated Meteorological System (IMETS) is specifically designed to handle weather knowledge. While most computer systems can carry and communicate codified knowledge products, this activity is modeled by the **RR** communication network. Doctrine details specific systems for the collection, storage, communication, or analysis of specific information types, and we model this specific ability in the storage network.

Knowledge by Knowledge Relevance Network

A link **KK**ij in the **KK** relevance network indicates that content i is relevant to, contributes to, or used in the creation of content j. The diagonal of **KK** is set to one. We model a relevance link if a content element is used by or in another content element - the classic example is a brigade analytical product that is derived from other units' information or analytical products.

4. Organizations

The organization node class names units and defined parts of units. If doctrine mentions the organization as a distinct element – or, better, if there is doctrine written specifically for that organization type – we represent it as a distinct knowledge node. Practically, organization nodes represent the documents and paragraphs in a TO&E, which identify the specific parts and hierarchical composition of a unit.

In both of the examples given, the platoons are a specific organization node. In addition, in the infantry platoon, the squads, fire teams, weapons teams, and platoon headquarters are additional organization nodes. In the tank platoon, the 4 tank crews are individual organization nodes. In the developed data set, we define organization nodes to the lowest level that may be moved or independently employed – usually the fire team level. This is a matter of data and computational convenience, as it allows us to experiment with many different types of organization structures by moving parts at various echelons.[16] Organization entities have the following relationships:

Agent by Organization Membership Network

The agent by organization network **AO** indicates which organizations an agent is a member of. Agent i has a link to organization j if agent i is a member of organization j, where membership indicates either assignment to a unit or presence in a specific named organization (such as a unit staff). Links in **AO** are defined to the lowest level - for example, in a platoon, a rifleman is considered a member of one of the fire teams and not the platoon itself. His link to the platoon is derived from the **OO** composition network, defined in paragraph 4.*f*, below. Agents only have links to one organization - in the case where the agent specifically wears 'two hats', the agent is assigned to the lower-level organization. For example, in the tank platoon, the platoon leader is also the vehicle commander of his own tank, which can act as an independent tank crew should it be separated from the platoon. In this case, the platoon leader is assigned to his individual tank crew, though his other networks (including $\underline{\mathbf{AA}}_{command}$) are computed from his position as platoon leader.

Resource by Organization Assignment Network

A link **<u>RO</u>***ij* in the **<u>RO</u>** assignment network indicates that resource *i* is assigned to organization *j.* In a completed meta-network a resource is linked to the lowest-level organization that it is assigned to. This network reflects one of the more fundamental concepts in doctrine, and tracks closely to the organization's Table of Organization and Equipment (TO&E).

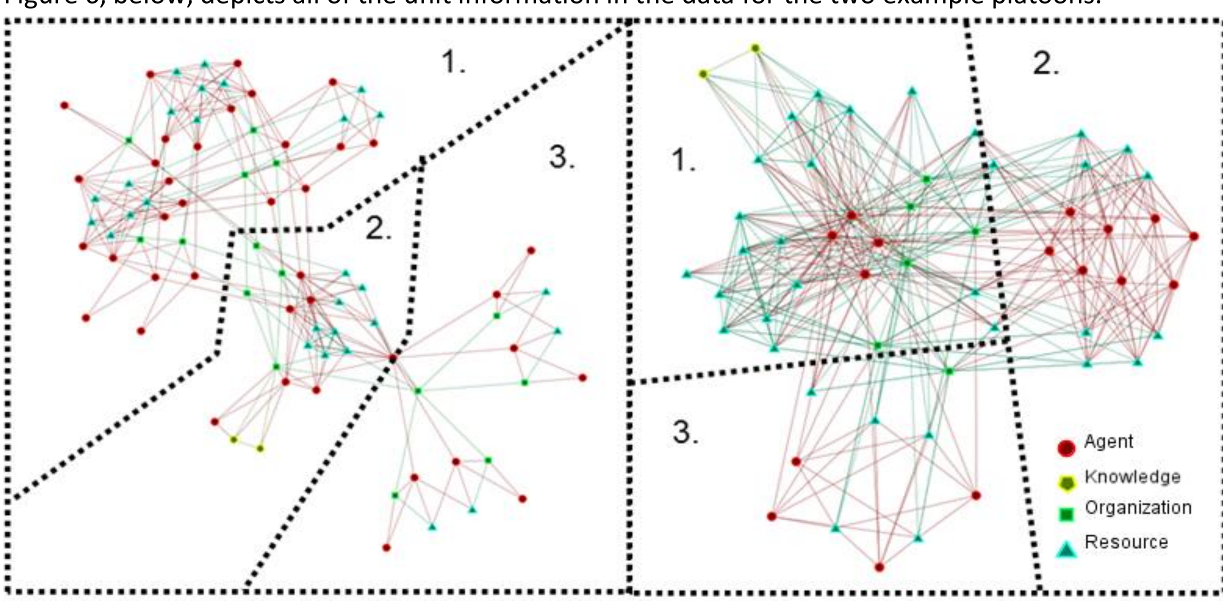
Knowledge by Organization Responsibility Network

A link **<u>KO</u>***ij* in the **<u>KO</u>** responsibility network indicates that knowledge *i* is the responsibility of organization *j*. We call an organization responsible for a specific content node if the content is something proper to the organization's function, even if that content depends (*i.e.*, other knowledge has links to it in the **<u>KK</u>** network) on knowledge outside its scope. The classic example is a staff section, which is responsible for the management of named categories of information. This network and the **<u>KT</u>** update network imply the coordinating functions of staffs.

Organization by Organization Composition Network

A link **<u>OO</u>***ij* in the organization by organization **<u>OO</u>** composition network indicates that organization *i* is composed of organization j. An alternate, and equally viable reading of a link is that organization *j* is a subordinate element, or part, of organization *i.* This network is used to indicate both the hierarchical links between organizations and allow for the modeling of distinct elements that are distributed throughout the overall organization.

Figure 6, below, depicts all of the unit information in the data for the two example platoons.



Infantry Platoon – All Unit Information **Tank Platoon – All Unit Information**

Figure 7 – All entities and relationships in example platoons.

As above, the numbered sections depict distinct portions of the organization:

Infantry Platoon –
1. Rifle Squads;
2. Platoon Leadership;
3. Weapons squad.

Tank Platoon –
1. Tank Commanders;
2. Gunners and Loaders;
3. Drivers.

The consolidated network clearly shows the differences in organization and structure both between the two platoons and between the various parts of the organization. In general, the $\underline{\textbf{AA}}_{command}$ network closely tracks the $\underline{\textbf{OO}}_{composition}$ network, and the non-leadership jobs in the organization are differentiated primarily by which resources they employ.

Section 4: Task Information

The network model of a military task focuses on the various duties within the task and the subordinate tasks that compose it. At the lowest level, a single task with no subordinate tasks is just something one or more people do. At higher levels, tasks are composed of various elements with personnel and resources performing different roles, and affecting the knowledge of the organization. The resources and knowledge elements in tasks are the same as those in organizations. Tasks also introduce the concepts of roles- functions that people perform in tasks; subordinate tasks, which are tasks in themselves.

Unit field manuals provide some data for tactical tasks. Other data comes from technical manuals, the Center for Army Lessons Learned, the Army Training and Evaluation Program, interviews with subject matter experts, and the author's own training and experience. This section describes the meta-network model of a task and the assumptions and judgments used to develop it.

	RESOURCES	**KNOWLEDGE**	**TASKS**	**ROLES**
RESOURCES	Communication	Handling	Requirement	Utilization
KNOWLEDGE		Relevance	Update	Contribution
TASKS			Decomposition	Personnel
ROLES				Control

Table 6 - Meta-Network model of a Task

Throughout this section, we use two tasks, "Fight as an infantry rifle platoon" and "Fight as a tank platoon" to illustrate task data and modeling practices. These tasks illustrate the standard operation of the tank and rifle platoon.

5. Tasks

The tasks node class identifies named task-organizations for conducting common procedures and tactical operations. We model tasks both as the 'output' of organization capabilities (or the asserted element of organizational capability claims) and as a component of organizations. In these data, a task is a specific, named activity; and the organization elements involved in it are defined by that task node's relationships with other entities. For example, the task 'Operate an M1 Tank' represents an organization crewing a tank, and the task 'Fight as a Rifle Team' represents a four-man element fighting dismounted.

In many cases within these data, especially for lower level organizations, the structure of a task matches the structure of an organization designed to do it. For example, the task of how to crew a tank and the organization of a tank crew are defined in tandem. Similarly, an infantry rifle team is built along the standard for fighting as a dismounted team, often with additional capabilities organic to it.

Task entities are defined by the following relationships:

Resource by Task Requirement Network

A link between a resource and a task **RT***ij* = *v* in the **RT** requirement network exists if one or more resources of the same type as resource *i* are required to complete task *j.* For example, one has to have anti-tank missiles to conduct an anti-armor ambush; therefore there is a link between a 'Javelin anti-tank missile' resource and the task 'conduct an anti-armor ambush'. Links in the **RT** requirement network are valued – where the value of a link **RT***ij* indicates the number of resources of type *i* required to perform task *j.*

Knowledge by Task Update Network

A link **KT***ij* in the **KT** update network indicates that knowledge *i* is processed or updated in task *j.* 'Update' is loosely defined in this sense, since tasks can interact with knowledge in a number of ways. We model an update link if the content is either one of the types of content considered in a staff process or the target of a task designed to collect information. In general, we are not concerned with the actual knowledge updated or gained, rather the position of the knowledge in the working organization.

Task by Task Decomposition Network

A link **TT***ij* = *v* in the **TT** composition network indicates that task *i* is composed *v* instances of task *j*. The diagonal of this network is set explicitly to zero - a task is not composed of itself. The **TT** composition network has integer values. For example, the task 'fight as an infantry platoon' is composed of 3 'fight as a rifle squad' tasks and one 'fight as a machine gun squad' task; therefore, it has a link of value 3 with 'fight as a rifle squad' and a link of value 1 with 'fight as a weapons squad'.

6. Roles

The roles node class represents the activities of agents conducting a task. A role node reflects a name activity in a doctrinal task. For example, the roles 'driver' and 'vehicle commander' are named in the information for the task 'Operate a Stryker.' As with tasks, for organizations at lower echelons, roles often map directly to the agents in the organization. Each role node represents a distinct thing that a person does in the conduct of a tactical task. The roles node class can be thought of as tasks appropriate to only one person. It is not modeled as such because the role node class also has the control relationship, distinct from the $\underline{\mathbf{TT}}_{decomposition}$ network. Figure 7, below, depicts the task and role node classes for the example tasks.

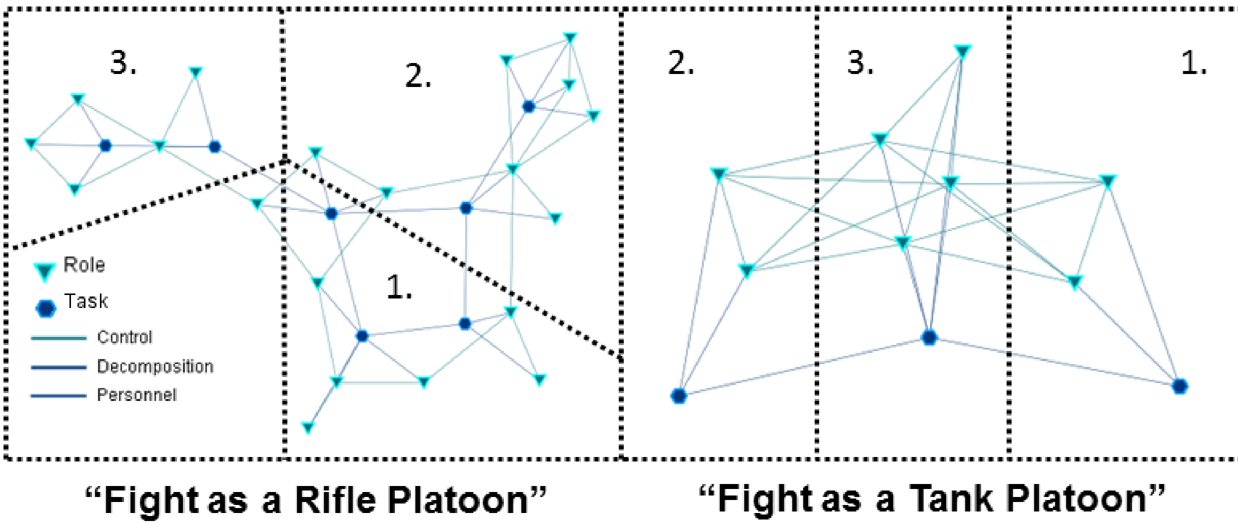


Figure 8 – the $\underline{\mathbf{TT}}_{decomposition}$, $\underline{\mathbf{TL}}_{personnel}$, and $\underline{\mathbf{LL}}_{control}$ networks in the example tasks.

The numbered areas depict:

Infantry Platoon –
1. Platoon and Section tasks
2. Rifle squad and rifle team tasks;
3. Weapons squad and machine gun team tasks.

Tank Platoon –
1. Platoon task;
2. Section task;
3. Vehicle operation task.

Role entities are defined by the following relationships:

Resource by Role Utilization Network

A link $\underline{\mathbf{RL}}_{ij}$ in the $\underline{\mathbf{RL}}$ utilization network indicates that resource *i* is used by role *j* in the performance of a task. Often, the utilization of a particular resource is the definitive element of the role – e.g., 'gunner.'

Knowledge by Role Contribution Network

A link **KL**_ij_ in the **KL** contribution network indicates that knowledge *i* is contributed to a task by role *j;* for example, the role of S3 representative contributes the operations knowledge to a specific staff meeting task. This functions similarly to the **RL** utilization network in that this link may define a role – e.g., the primary contribution of a Company Intelligence Support Team is to contribute access to higher-level intelligence information to the company commander.

Task by Role Personnel Network

A link **TL**_ij = v_ in the **TL** personnel network indicates that task *i* requires *v* instances of role *j*. The various positions or activities of people in tasks are identified in the role node class, and a link between a task node and a role node indicates that the task involves *v* people conducting that activity.

Role by Role Control Network

The remaining defined role relationship, the **LL** control network, indicates which roles control the activity of other roles in the conduct of a task. A link **LL**_ij = v_ in the role by role control network indicates that role *i* controls *v* instances of role *j* in the conduct of a task. The diagonal is set to one. This network is used to model the hierarchical relationships of people in the performance of specific duties (roles), and is comparable with the **AA** command network.

Figure 8, below, depicts all of the entities in the task data for the two example platoon-level tasks.

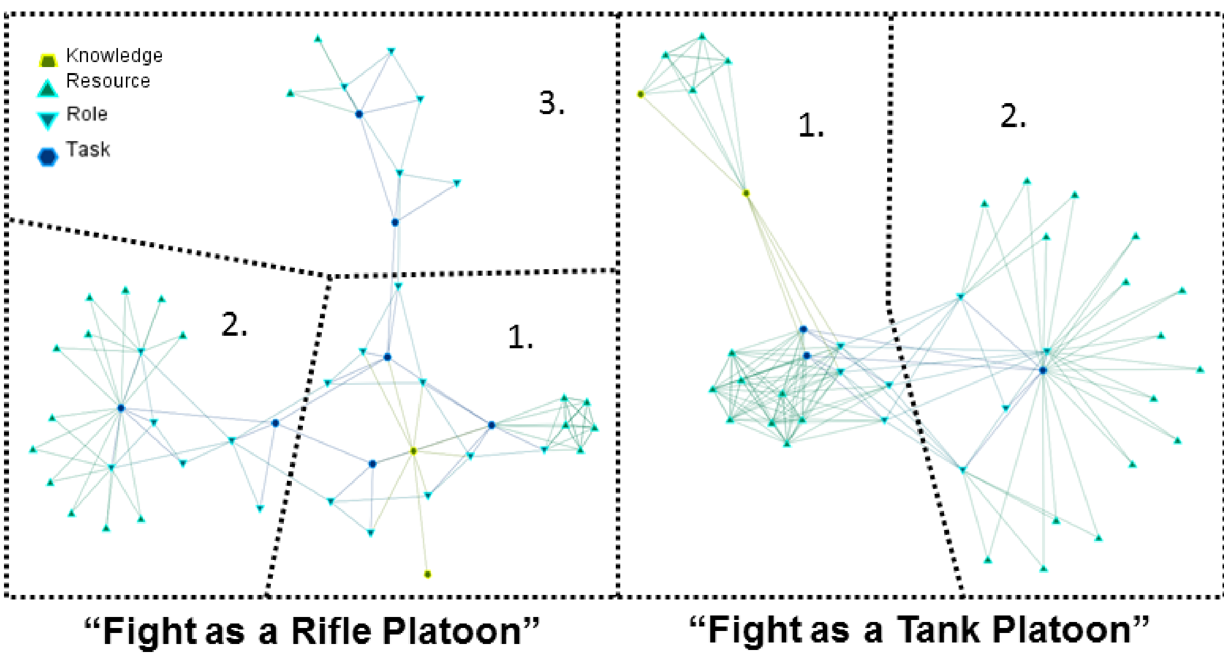


Figure 9 – All entities and relationships in the example tasks.

The numbered areas depict:

Infantry Platoon – 1. Platoon and Section tasks
2. Rifle squad and rifle team tasks;
3. Weapons squad and machine gun team tasks.

Tank Platoon – 1. Platoon & Section tasks;
2. Vehicle operation task.

As before, the consolidated structure shows clear differences between the two methods of employing forces. The infantry task, as befits a larger organization, has more subcomponents and more different types of subcomponent; the Armor task employs more resources across the organization. Note that both of the tasks share C2 structures that are distinctly different from the 'lower-echelon' tasks.

Section 5: Resource and Knowledge Information

	RESOURCES	**KNOWLEDGE**
RESOURCES	Communication	Handling
KNOWLEDGE		Relevance

Table 7 - Resource and Knowledge data

The ability of communication systems to interoperate, the types of information that information systems are designed and accredited to store, and what kinds of knowledge are relevant to other knowledge remain consistent regardless of the particular unit or task. For example, the ability of communication systems to talk to each other is a function of the particular system and constant throughout the Army inventory.

The resource by resource communication network **RR** and resource by knowledge storage network **RK** refer to specific technical capabilities of types of resources. We code these data, along with the knowledge by knowledge composition network **KK,** separately from the organization and task data because they do not vary by the type of organization involved or task they're being used for.

Figure 9, below, shows the resource and knowledge data for types of resources and knowledge in the examples given above:

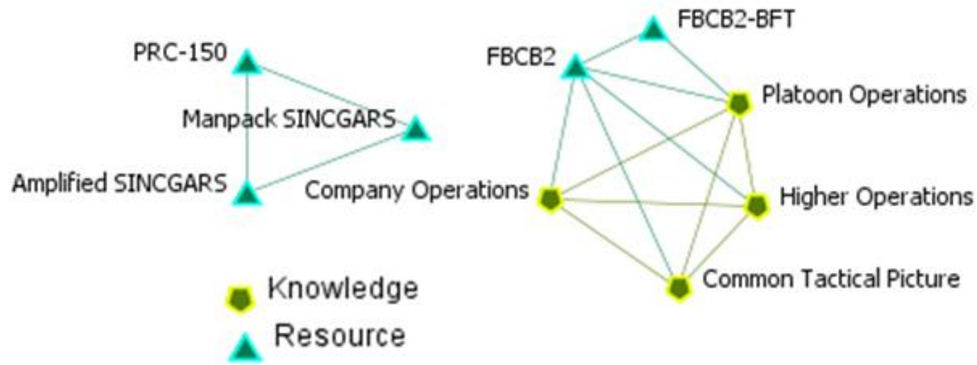


Figure 10 – Resource and knowledge information in the meta-network.

Note the connected relationships between the voice-type radio systems (the PRC-150 and Single-Channel Ground to Air Radio System (SINCGARS)), which can communicate on similar frequencies. Note also the network in 'operations' type knowledge. These types of knowledge relate to each other, and can be stored on the Force XXI Brigade and Below (FBCB2) computer (which is accredited for sufficient classification). The FBCB2-Blue Force Tracker (BFT) does not use as secure a communication system, and so while it has limited communication with FBCB2 it cannot handle higher-level operational information.

The decision to model the $\mathbf{\underline{KK}}_{Relevance}$ network as exogenous to any specific task or organization is based on the decision to use content entities as generalized types of information. The 'staff oriented' doctrinal publications and FMs, especially the 5-0 series (the Operations Process (HQDA 2010, HQDA 2012, HQDA 2012)) describe staff products and the types of information that go into their development. While a specific type of knowledge may not be relevant to a specific staff product, *in general* that type of knowledge may be relevant to that type of staff product.

Section 6: Characteristics of Represented Organizations

1. Combining the Meta-Networks

We can also represent the unit, task, and resource and knowledge information as a single meta-network. An essential aspect of social network theory is that the formal organization that an agent works in – the 'organization chart' elements conveyed by the unit data – and the structure of relationships and mutual work that exists in the task data –exist in the same organization at the same time and affect agent's behavior and cognition of their place in the network (Blau and Scott 1962/2001, Krackhardt 1994). We represent this combined structure as a meta-network that shares the entities from both the task and organization data, as shown in the table below.

	AGENTS	RESOURCES	KNOWLEDGE	TASK	ROLES	ORGANIZATION
AGENTS	Command	Skill	Access	***Derived***	***Derived***	Membership
RESOURCES		Communication	Handling	Requirement	Utilization	Assignment
KNOWLEDGE			Relevance	Update	Contribution	Responsibility
TASKS				Decomposition	Personnel	***Derived***
ROLES					Control	***Derived***
ORGANIZATIONS						Composition

Table 8 - Combined Meta-Network

This method of combining networks is useful, because the question of organization and task capability is further complicated by the fact that the organizations and tasks are hierarchically defined. The larger meta-network conveys the hierarchical structure of tasks, organizations, and their component parts, while conveying a separate set of relationships between the unique entities in each element. This combined meta-network has four new possible types of relationships (highlighted in grey in table 8):

1. Agents to Roles,
2. Agents to Tasks,
3. Organizations to Roles, and
4. Organizations to Tasks.

Of these, only the Agent to Role relationship and the Organization to Task relationship are relevant to the measurement of capability, described in the next chapter. However, the effect of the task information on Agents may be conveyed by the Agent to Task relationship.

Organization to Task Relationships

Since the essence of the type of generic organization capability claims we seek to measure is a relationship between organizations and tasks, the output of the model is the Organization by Task 'capability' network, **OT** $_{capable}$. General capability is a binary function; therefore links in the **OT** $_{capable}$ network are binary links, where the existence of a link **OT***ij* indicates that organization *i* is capable of task organizing to perform task *j.*

An organization is capable of a task if it has (1) sufficient resources to meet the resource requirements and (2) sufficient personnel to meet the role requirements.[17] Two of the relationships in the task data– the **TL** $_{personnel}$ and the **RT** $_{requirement}$ networks – list requirements (for personnel and resources, respectively) which must be satisfied by an organization conducting the task. Two corresponding relationships in the organization data list the assets available – the **AO** $_{membership}$ network and the **RO** $_{assignment}$ network.

Each of these criteria is a separate organization by task relationship – *i.e.,* there is an **OT** $_{resource\ capable}$ and an **OT** $_{personnel\ capable}$ network. This leads to a total of three **OT** networks – "personnel capability", "resource capability", and "capability." By the first condition above, the latter **OT** $_{capable}$ network is the conjunction of the former – *i.e.*, **OT** $_{resource}$ ∩ **OT** $_{personnel}$ = **OT** $_{capable}$.

Agent to Role Relationships

The most important Agent relationship is the relationship between Agents and Roles, or the relationship between the people in an organization and the functions people perform in the conduct of a task. This network, the **AL** $_{qualified}$ network, is a binary network where the existence of a link **AL***ij* indicates that Agent *i* is capable of task *j*.

The derivation of the **AL** $_{qualified}$ network is similar to that of the **OT** $_{capable}$ network – we say that an Agent is qualified to perform a role if it has (1) the skills to employ the resources that role employs and (2) access to the knowledge that role contributes. Similar to the **OT** network, as well, two relationships define the requirements for their respective entities – the **RL** $_{utilization}$ network for and the **KL** $_{contribution}$ network. The **AR** $_{skill}$ and **AK** $_{access}$ networks list the ability of the agents to satisfy these requirements. Finally, as in the **OT** network, the ability to satisfy each criterion is indicated in separate agent by role networks - **AL** $_{skill\ qualified}$ and **AL** $_{access\ qualified}$ - such that **AL** $_{skill\ qualified}$ ∩ **AL** $_{access\ qualified}$ = **AL** $_{qualified}$.[18]

Agent to Task Relationships

The traditional meta-network model of organizations articulates tasks as activities assigned to specific agents. It is unclear whether or not multiple agent relationships with the same task node indicate that all of the agents are working together on the same task, or working on independent instances of the same task.

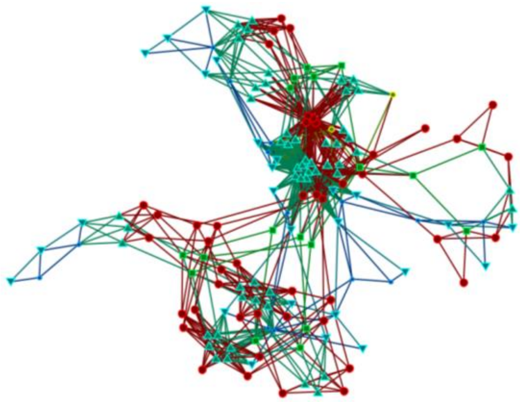
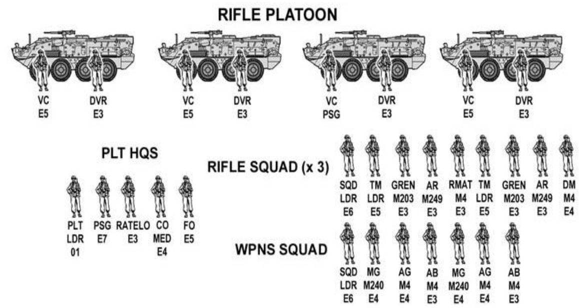
In the case of these data, because tasks are not modeled as instances we cannot model assignment. Instead, we consider an agent to task relationship based on whether or not the agent is available for – i.e., is qualified to conduct – a role within a task. That is, a link **AT***ij = v* in the **AT** $_{available}$ network means that Agent *i* is qualified to perform *v* roles in Task *j*. **AT** $_{available}$ is computed by **AL** $_{qualified}$ ● **LT** $_{personnel}$.

2. Represented Organizations

Organization	Primary Reference	BCT Type	WFF/Branch
Stryker Infantry Rifle Platoon	FM 3-21.8 (HQDA 2007)	SBCT	Maneuver/Infantry
Stryker MGS Platoon	*FM 3-20.151* (HQDA 2005)	SBCT	Maneuver/Armor
Tank Platoon	*FM 3-20.15* (HQDA 2007)	HBCT	Maneuver/Armor
Mechanized Infantry Platoon	FM 3-21.7 (HQDA 2002)	HBCT	Maneuver/Infantry
Heavy Recon Platoon	*FM 3-20.971* (HQDA 2009)	HBCT	ISR[19]/Armor
Light Infantry Platoon	FM 3-21.8 (HQDA 2007)	IBCT	Maneuver/Infantry
Infantry Assault Platoon	FM 3-21.12 (HQDA 2008)	IBCT	Maneuver/Infantry

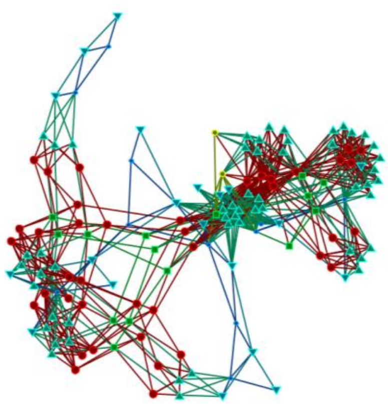
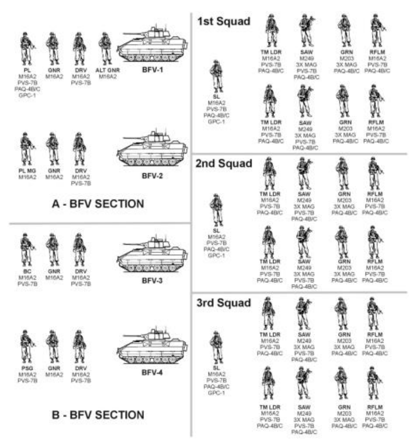
Table 9 - Organizations represented[20]

Table 9 identifies a set of 7 organizations coded as proof of concept of the methods in this dissertation. The figures below show four of them:

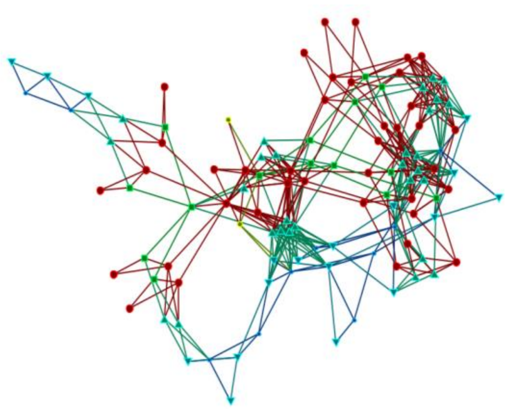
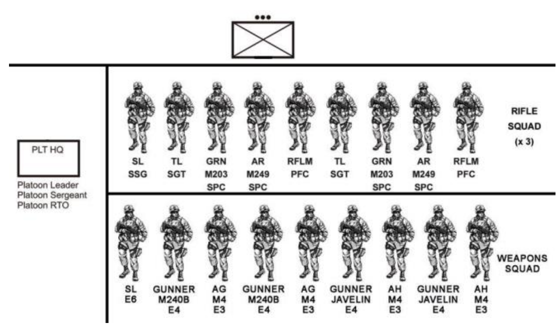
Agents	Resources	Organizations	Tasks	Roles
45	53	18	16	45

Figure 11 – The SBCT Rifle Platoon

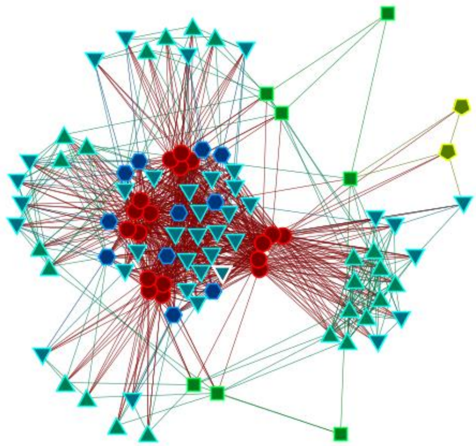
Agents	40
Resources	53
Organizations	15
Tasks	11
Roles	38

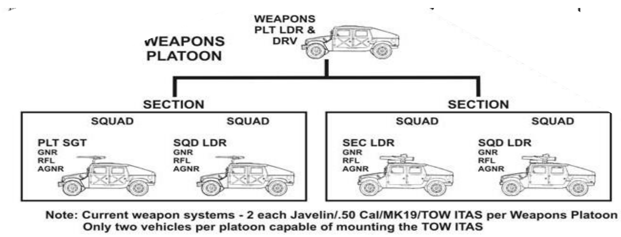
Figure 12 – The Mechanized Infantry Platoon

Agents	Resources	Organizations	Tasks	Roles
39	28	15	10	30

Figure 13 – The Infantry Platoon





Agents	Resources	Organizations	Tasks	Roles
18	23	7	11	37

Figure 14 – The Infantry Weapons Platoon

3. Statistics of Represented Organizations

Based on these network descriptions, we can compute descriptive statistics of the organization and its personnel positions. Table 10 considers the cognitive demand of leaders in the various organizations.

Organization	PL's Cognitive Demand	PSG[21]'s Cognitive Demand	Delta Cognitive Demand	Gini Coefficient – Cognitive Demand
Stryker Infantry Rifle Platoon	**.403**	.387	.016	.114
Stryker MGS Platoon	***.596***	**.484**	.112	.246
Tank Platoon	*.558*	.458	0.1	**.281**
Mechanized Infantry Platoon	.494	.389	.105	.104
Heavy Recon Platoon	.475	**.368**	.107	.132
Light Infantry Platoon	.449	.341	.108	**.076**
Infantry Weapons Platoon	.573	.479	.094	.109

Table 10 - Statistics of represented organizations

We consider cognitive demand primarily because it is a statistic that bases structural predictions across multiple networks (Carley, Reminga and Kamneva 2003, McCulloh, Armstrong and Johnson 2013). Cognitive demand indicates the need to communicate with others to perform tasks; and it performs generally as expected (indicating higher values for leaders).

More interesting, the distribution of values across the modeled organizations reveal that the nature of leaders' jobs and the distribution of workload in the various platoons are significantly different based on the type of organizations. The platoons modeled according to infantry doctrine tend to have lower key leader cognitive demand, except for the Infantry Weapons Platoon.

Section 7: Conclusion and Findings

This chapter focuses on applying the meta-network model of organizational structure to a different type of organization then usual – organizations in the ideal. The doctrinal description of organizations is an ideal structure; real organizations are always manned, trained, and equipped differently than the documented structure. However, the ideal structure – documented in doctrine and the various authorization documents is what public policy decisions about military organizations are based on.

The essential finding of this chapter is the models described in sections 3, 4, and 5, which are the result of analysis of the policy aspects of military organization structure and the tactical aspects of military tasks. The process of developing these models revealed the following findings:

- *The doctrinal structure of both Army organizations and tasks can be represented as meta-networks.*
- *Unit doctrine provides inconsistent Task-organization data for network modeling.*
- *The results of some network science methods defined to characterized observational data mean something different when applied to doctrinal data.*

1. Findings

Finding 1: Doctrinal organizations and tasks can be modeled as meta-networks.

The basic finding of this chapter is also its subject – that formal organization structures can be represented in meta-networks, similar to informal or observed organizations. The meta-networks of organizations and tasks accurate convey the policy decisions and technical/tactical decisions that go into the construction of military organizations and tasks, respectively. Doctrinal or authoritative sources of network data have no issues with observer bias or collection error, but they are prone to inconsistencies in interpretation where the doctrine is unclear or inconsistent, and arguments of authority when separate doctrinal sources deal with the same subject.

Finding 2: Unit doctrine provides inconsistent Task-organization data for network modeling.

For their purpose – providing unit commanders and members a comprehensive guide as to how their unit is designed to work – the unit-based FMs are an excellent reference. However, the task data they provide is designed explicitly for their unit, and does not convey how a similar organization or the same organization structured differently (for example, due to casualties) should conduct operations. For the purposes of this research, we need task data that conveys task organization, not the general spatial and temporal data conveyed by the unit field manuals. In general, the field manual data conveys as much task-organization data through its description of the composition of the unit as is does through the description of the tasks. At higher levels, unit field manuals tend to convey task organization more explicitly, but do not convey organization tasks down to the individual agent/resource level.

Finding 3: Some network science methods perform differently when applied to doctrinal data.

The essential relationship considered in Social Network Analysis is observed interactions between people or agents. These are not modeled in these data. Network statistics of observed interactions are generally focused on identifying powerful and influential actors, clusters of similar agents, or characterizations of the properties of the network.

We are not concerned with these interactions at the policy level, because those decisions do not represent the allocation of resources or authority, and we expect subordinate organization members to organize themselves appropriately. We assume that agents will communicate with each other based on other factors, such as being in the same organization, having radio combat, working together on tasks, having the same boss, etc. Unit doctrine often gives examples of appropriate interactions,[22] but these are suggestions, not authoritative.

Because we don't model observed interaction, many network statistics designed to measure or characterize interactions are irrelevant. Some of these statistics are relevant to distinguishing the difference between elements in similar positions across multiple organizations – for example, assessing the difference in job requirements for the leaders of different types of platoons. However, because we do not model **AT** relationships explicitly, we have to compute these meta-network statistics based on derived networks, which are partially autocorrelated with other independent variables.

2. Conclusion

Military units are the stereotype that conveys the idea of formal organization. There has been published, written tactical doctrine for military organizations for the entire span of western history. The United States Army publishes extensive doctrine for each of its component parts, including doctrine for both specific units and specific tasks. This chapter establishes a model by which the policy decisions in Army doctrine – decisions on resources and authority –can be represented as networks. In doing so, it applies the same structures to formal organization data that the social network analysis and network science disciplines use to analyze informal and non-social networks. The next chapter applies some of the methods developed in these disciplines to develop a network model of organization capability.

Notes for Chapter 3

[1] A comprehensive list of doctrinal sources is included in Appendix A.

[2] The relevant definition from Joint Publication 1-02 (Department of Defense Dictionary) is "any military element whose structure is prescribed by competent authority (CJCS 2013)." This usage is consistent with that definition, but we will discuss the use of authoritative data in chapter 5, future work.

[3] Unit TOEs and M-TOEs are For Official Use Only, and are not used here in a widely-published document.

[4] As above, entity types are indicated in the row and column headings, and the relationships between them are indicated in the cells. The green cells are particular to the unit being modeled, while the blue cells are common between all units.

[5] Both Infantry Platoons and Tank Platoons are described in FM 3-21.8, *The Infantry Rifle Platoon and Squad* (HQDA 2007). Data and figures are drawn from there. We refer to FM 3-20.15 *The Tank Platoon* (HQDA 2007) for clarification as needed, but do not present information due to distribution restrictions.

[6] We use the term 'Agents', rather than the more common military term 'personnel', for similarity with the network science literature. For our purposes, the terms are interchangeable.

[7] The relationship of command is clearly defined in doctrine for officers at the level of platoon leader and above; at the lower levels, some elements of the doctrinal relationship of command are exercised by a soldier's immediate supervisor and some elements are exercised by the nearest officer of the chain of command. We interpret this command relationship to the lowest level - a command relationship here indicates the immediate supervisory aspects of commands.

[8] A note about headquarters: all soldiers in BCTs are assigned to companies - indicated in the agent by organization 'membership' network **AO**. The brigade commander and his staff in a maneuver BCT are assigned to the BCT Headquarters and Headquarters Company (HHC), which has its own commander, for administrative purposes. However, the administrative control that an organization - in this case, HHC - commander has over the BCT commander does not extend to the relationship of command. In this case, the command network does not mirror the organization network.

[9] For all practical purposes, in these data 'resources' is synonymous with equipment. As with 'agents', the term 'resources' is used for similarity with the network science literature. In future development, resource nodes can model access to other, non-equipment assets, such as access to Commander's Emergency Response Funds.

[10] HHC = Headquarters and Headquarters Company. BFV = Bradley Fighting Vehicle

[11] Note that while in many cases doctrine lists specific personnel with specific equipment, we do not model an agent by resource 'assignment' network in these data. Since we do not include individual equipment, all of the equipment we model is organizational property and is assigned to the owning unit.

[12] The official definition of 'knowledge' – 'information that has been analyzed to provide meaning or value or evaluated as to implications for the operation' (HQDA 2012)is consistent with the given usage, but far too broad for modeling purposes.

[13] MOS - the skills a soldier is trained in - can be interpreted as the 'skill' links an agent has with specific resources (*e.g.*, a 'Mortar Gunner' agent has links with 'Mortar' resources because he is MOS 11C) and access to specific types of knowledge based on security clearance. However, we choose to model the links directly, rather than through an MOS.

[14] This product goes by various names in given doctrine. We use 'friendly situation template' to refer to the friendly portion of the Common Operating Picture, usually displayed on the Maneuver Control System in the BCT Tactical Operations Center.

[15] We choose the platoon level somewhat arbitrarily, based on the assertion in the infantry platoon FM that the Infantry Platoon is the smallest independently employed unit.

[16] In general, it is convenient to define one or more organization nodes for each level of sub-task in the types of tasks being analyzed. This allows for a 1-for-1 matching of organizations to tasks in the structural capability measurement, defined in the next chapter.

[17] Note that we do not impose a knowledge constraint - if an organization is given a task that requires certain knowledge, we consider it responsible for that knowledge by fiat

[18] The $\underline{\mathbf{AO}}_{membership}$ and $\underline{\mathbf{AA}}_{command}$ networks are not used to determine role availability. Because the task is defined separately from the organization, there is no requirement to be in a particular organization in order to qualify for a specific function in a particular task. Theoretically, constraints could be developed based on the $\underline{\mathbf{AA}}_{command}$ network; in order to indicate such policies as "agents cannot be in a role that controls agents that outrank them." Doing so is unnecessary from a capability-modeling perspective, and may degrade accuracy – there are certain circumstances when lower ranking personnel do control the activities of higher ranking personnel, such as the commander of a vehicle carrying senior officer.

[19] Intelligence, Surveillance, and Reconnaissance.

[20] Note that information contained in the primary references listed in *italics,* and the organizations shaded in light grey based on them, are not approved for public release. We will show some results from analysis of these platoons, but will not provide the data based on these.

[21] Platoon Sergeant

[22] For example, the BCT field manual goes so far as to suggest the membership of targeting boards and targeting meetings.

Structural Measurement of Organization Capability

CHAPTER 4

The goal of this chapter is to develop a structural measurement of general organization capability from the meta-network model of military organizations described in chapter 3. This is not a stretch of logic - general organization capability claims themselves are an assertion about an organization and a task. When we separate the task element from the claim-specific context – of terrain, enemy, mission, etc. – then what remains is the *task-organization,* or how the elements that organization of elements conducting a task. The general organization capability claim then asserts that the organization can properly task-organize to conduct that task.

This chapter develops two types of capability measurements – one based on aligning the specific elements of the organization against the elements required by tasks; the other by using given capability data to compute the ability of a set of organizations to meet a set of tasks. Finally, this chapter explores ways to consider non-hierarchical dimensions of organization when assessing capability.

Section 1: The Structural Measurement of Capability

The structural measurement of organization capability is a function that derives the $\underline{\mathbf{OT}}_{capable}$ network within a combined meta-network of unit and task information. By the definitions given previously, an organization is capable of a task if it has (1) sufficient resources to meet the resource requirements and (2) sufficient personnel to meet the role requirements. Expressed formally, this equates to $\underline{\mathbf{OT}}_{capable}$. = $\underline{\mathbf{OT}}_{resource} \cap \underline{\mathbf{OT}}_{personnel}$.

The methods used to derive these networks are inspired by the network algebra described in "A PCANS Model of Structure in Organizations (Krackhardt and Carley 1998)" (see also (McCulloh, Armstrong and Johnson 2013)). This section proceeds by introducing the notation for the matrix operations used to compute the various networks, then describing how to compute the $\underline{\mathbf{OT}}_{resource}$ & $\underline{\mathbf{OT}}_{personnel}$ networks in turn.

1. Matrix Algebra Operations

We define 3 matrix algebra operations (and notations) used in the computation of the various **OT** networks:

Binarized Data

We indicate that a valued matrix *M* has been converted to a binary matrix with the | operator - $|(M)_{ij} = 1$ if $M_{ij} \neq 0$; else $|(M)_{ij} = 0$.

Binary normalized matrix multiplication

We annotate ordinary matrix multiplication by the • symbol for the dot product of a matrix. For determining compound relationships on graphs with unvalued links via matrix multiplication, we annotate the operation with the **X** symbol. For two matrices *L* and *R* of conformal dimensions[1], let $L \bullet R = P$ *and* L **X** $R = N$. N_{ij} = *true (1)* iff $P_{ij} \neq 0$, or N_{ij} = *false (0)* otherwise. *L* ***X*** *R* is equivalent to **|**($L \bullet R$).

Path Transformation

We define a further operation, 'path transformation,' on square matrices between the same entity classes (e.g., the **AA**, **OO**, **TT**, etc. matrices). This operation is symbolized by →(*M*) = *T*, where *M* is a square matrix being transformed. $T_{ij} = 0$ if no path exists between node *i* and node *j.* If a path exists, let W be shortest directed walk between nodes *i* and *j* in the original matrix N, and $W_i = v$ be the value of a connecting edge, and $T_{ij} = \prod_i v$ for all edges W_i.[2]

2. 'Aggregated' Composition and Decomposition networks

As mentioned in chapter 2, organization and task nodes represent individual organizations or tasks, respectively, and the links in the **OO** and **TT** composition and decomposition networks show their hierarchical structure. We can represent the organization and all of its component parts as an aggregated matrix of the composition or decomposition networks, symbolized by $\mathbf{OO}_{aggregated}$ and $\mathbf{TT}_{aggregated}$, respectively.

We will describe this for $\mathbf{OO}_{aggregated}$ – $\mathbf{TT}_{aggregated}$ has the same logical structure. A link $\mathbf{OO}_{ij}$ exists in $\mathbf{OO}_{aggregated}$ if organization *i* is a part of organization *j*. Similarly, a link **TT***ij* exists in $\mathbf{TT}_{\text{aggregated}}$ if task *i* is part of task *j*. Path transformation efficiently captures this structure:

- $\mathbf{OO}_{aggregated}$ = **|**(→**OO**)
- $\mathbf{TT}_{aggregated}$ = →**TT**.[3]

*3. Deriving the **OT** 'resource capable' network*

The $\mathbf{OT}_{\text{resource capable}}$ network indicates whether an organization has sufficient resources of the right kind to complete a task. This holds – *i.e.,* a link between the respective organization and task entities exists - if the organization has as many or more resources, indicated by the $\mathbf{RO}_{\text{assignment}}$ network, as the $\mathbf{RT}_{\text{requirement}}$ network indicates the task requires.[4]

The resources available to the organization are based on the aggregated composition of the organization – *i.e.,* an organization has the resources available to it and all of its component parts. This is determined by simple matrix algebra:

- $\mathbf{RO}_{aggregated\ assignment}$ = **RO X** $\mathbf{OO}_{aggregated}$

The resources required for the task are derived similarly, accounting for the fact that relationships within the **RT** and **TT** networks are integer-valued. The matrix representation is given by:

- $\mathbf{RT}_{aggregated\ requirement} = \mathbf{RT} \bullet \mathbf{TT}_{aggregated}$.[5]

Each column in **RO** $_{aggregated}$ indicates the total resources available to that organization; likewise, each column in **RT** $_{aggregated}$ indicates the resources that task requires. Since tasks don't require specific resources – rather, resources of a certain type – we add a subsequent operation to count the resources by type. Let $\mathcal{R}$ be the set of resource types in the data.[6] For each column in **RO** $_{aggregated}$ we generate a vector $\mathcal{R}_{\mathbf{O}}$, where each value indicates the number of links to resources of that type in that column. For tasks, since each link in **RT** $_{aggregated}$ indicates type information, we simply use the value of one of the links.

This gives a vector $\mathcal{R}_{\mathbf{O}}$ for each organization and a vector $\mathcal{R}_{\mathbf{t}}$ for each task, each of length *k* (where *k* is the number of unique resource types in the data). From these vectors, we can determine the **OT** $_{\text{resource capable}}$ network. For each organization *i* and each task *j*, and for each resource type *k,* if ($\mathcal{R}_{\mathbf{Ok}} \geq \mathcal{R}_{\mathbf{tk}}$) = *true*, then **OT** $_{\text{resource capable}}$ = 1; otherwise, **OT** $_{\text{resource capable}}$ = 0.[7]

*4. Deriving the **OT** 'personnel capable' network*

The **OT** $_{\text{personnel capable}}$ network indicates whether an organization has personnel qualified to fulfill the roles required by the task. Formally articulated, a link **OT***ij* exists in the **OT** $_{\text{personnel capable}}$ network if there exists a suitable mapping between each member of the set of Agents that are members of Organization *i* and the set of Roles required by Task *j.*

The derivation of this network is complicated because (1) the networks that convey the supply of personnel (**AO** $_{\text{membership}}$) and requirements for them (**LT** $_{\text{personnel}}$) networks are not conformal, and (2) there are criteria which govern what agents are suitable for the roles (the **AL** $_{\text{qualified}}$ network, itself derived), and (3) the availability of personnel for roles is exclusive (i.e., even if qualified, an agent can fulfill only one role in a given task). We address each of these issues in turn.

Supply of Agents and Demand for Roles

As in the **OT** $_{\text{resource capable}}$ network, the supply of agents in the organization is based on the **AO** $_{aggregated\ membership}$ network, and the 'demand' from the task is given by the **LT** $_{aggregated\ personnel}$ network. These are defined similarly:

- **AO** $_{aggregated\ membership}$ = **AO** X **OO** $_{aggregated}$
- **LT** $_{aggregated\ personnel}$ = **LT** X **TT** $_{aggregated}$

Suitability criteria

The suitability criteria are given by the **AL** $_{\text{qualified}}$ network, where **AL** $_{\text{qualified}}$, as defined before, is given by:

- **AL** $_{\text{qualified}}$ = **AL** $_{\text{skill qualified}}$ ∩ **AL** $_{\text{access qualified}}$

Deriving the AL $_{skill\ qualified}$ ***network***

The **RL** $_{\text{utilization}}$ network indicates which resources roles require, and the **AR** $_{\text{skill}}$ network indicates which resources agents are skilled to employ. A link **AL***ij* exists in the **AL** $_{\text{skill qualified}}$ network if one of two criteria are met: (1) Agent *i* has a link to each resource required by Role *j*, or (2) Role *j* does not require any resources. This is conveyed by:

- **AR X RL = AL** $_{\text{skill qualified}}$. For each role *j*, if max (**RL**$_j$) = 0 then **AL***j* = 1.[8]

Deriving the AL $_{\textit{access qualified}}$ ***network***

The **AL** $_{\text{access qualified}}$ network is derived the same way as the **AL** $_{\text{skill qualified}}$ network. A link **AL***ij* exists in the **AL** $_{\text{access qualified}}$ network if: (1) Agent *i* has a link to the knowledge Role *j* contributes, or (2) Role *j* does not require any knowledge.

- **AK X KL = AL** $_{\text{access qualified}}$. For each role *j*, if max (**KL**$_j$) = 0 then **AL***j* = 1.

Mapping available agents to required roles

For each Organization *i*, the process of determining if there is a mapping between its members (**AO***i* $_{\text{aggregated membership}}$) and the requirements of each task *j* (**LT***j* $_{\text{aggregated personnel}}$) can be articulated as a variation of a type of integer programming problem known as a 'set covering problem' (Winston and Venkataramanan 2003). That is, each member of **LT***j* must be 'covered' by an acceptable member of **AO***i*, subject to the suitability constraint **AL** $_{\text{qualified}}$.

In order to determine if a solution exists to this problem, we articulate it as a system of equations with binary variables and solve it. For each pair of Organizations and Tasks *i* and *j* in **OT** $_{\text{personnel capable}}$, the solution is an **AL** $_{\text{assignment}}$ matrix, where each cell is an individual decision variable.

For *n* Agents in **AO***i* and *m* Roles in **LT***j*, let there be a binary variable for each combination of Agent and Role indicating that the Agent is assigned to the corresponding Role:

$$\begin{bmatrix} A_1L_1 & \cdots & A_nL_1 \\ \vdots & \ddots & \vdots \\ A_1L_m & \cdots & A_nL_{m,} \end{bmatrix}$$

Let there be an additional variable for each Agent indicating if that Agent is unassigned:

$$[U_1 \quad \cdots \quad U_n]$$

This gives a total number of decision variables equal to the number of (**A+**1)**L.** There are two sets of constraints to this system: Agents must be suitable for their assigned roles and Agents cannot be assigned to more than one role.

Only those agents that are suitable for each role can be assigned. The **AL** $_{\text{qualified}}$ network then gives coefficients for each decision variable:

$$\begin{bmatrix} \boldsymbol{AL_{11}} \times A_1L_1 & \cdots & \boldsymbol{AL_{n1}} \times A_nL_1 \\ \vdots & \ddots & \vdots \\ \boldsymbol{AL_{1m}} \times A_1L_m & \cdots & \boldsymbol{AL_{nm}} \times A_nL_m \end{bmatrix}$$

Constraint set 1 - Suitability: For each Role requirement for Task *j* in **LT***j*, sufficient Agents must be assigned:

$$\begin{bmatrix} \sum_{a=1}^{n} \boldsymbol{AL}_{a\mathbf{1}} \times A_a L_1 & = & \mathbf{LT}j_1 \\ \vdots & \vdots & \vdots \\ \sum_{a=1}^{n} \boldsymbol{AL}_{\boldsymbol{am}} \times A_a L_m & = & \mathbf{LT}j_m \end{bmatrix}$$

Constraint set 2 - Exclusivity: Each Agent in **AO***i* can only be assigned to one role or left unassigned:[9]

$$\begin{bmatrix} \sum_{l=1}^{m} \boldsymbol{AL}_{1l} \times A_1 L_l + U_1 & = & 1 \\ \vdots & \vdots & \vdots \\ \sum_{l=1}^{m} \boldsymbol{AL}_{nl} \times A_n L_l + U_n & = & 1 \end{bmatrix}$$

If a solution exists to the set of linear equations given by constraint set 1 and constraint set 2, then there exists a mapping between the available Agents and required Roles in **AO***i* and **LT***j*, and **OT***ij* $_{\text{personnel capable}}$ = 1. Otherwise, **OT***ij* = 0.[10]

5. Example

The previous pages described the derivation of the **OT** $_{\text{capable}}$ network from the network itself down to each of its component parts. In order to describe how it works in practice, this section shows its construction from the combined meta-network to the **OT** $_{\text{capable}}$ network.

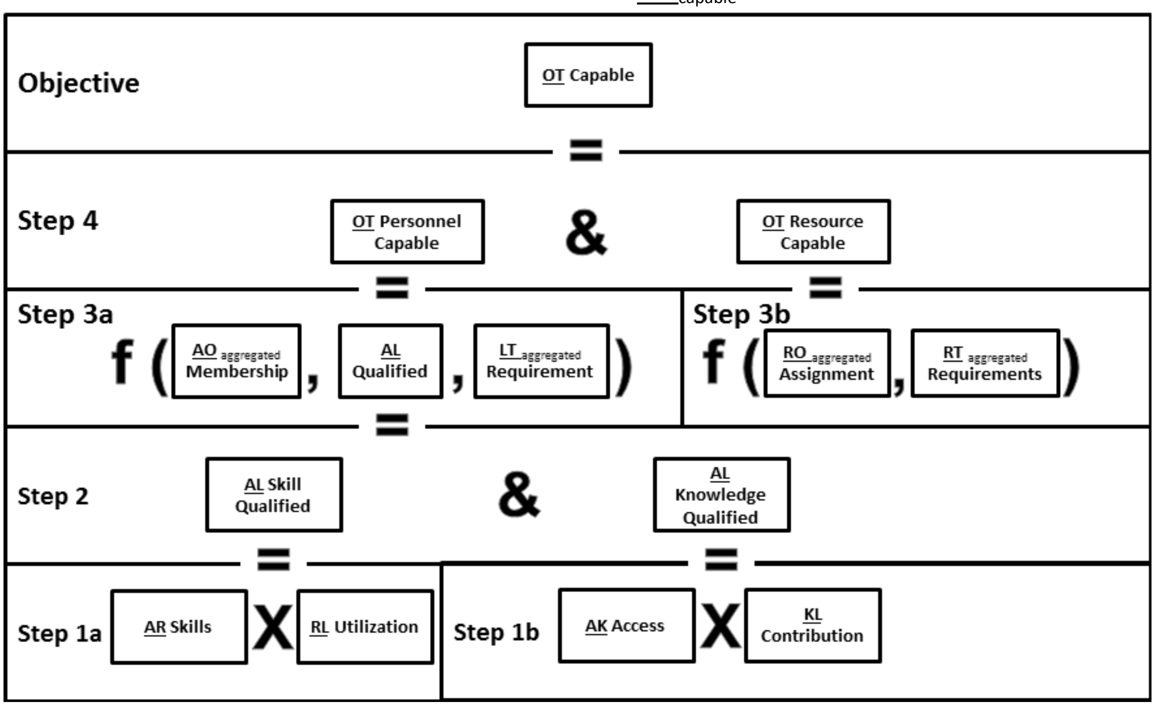


Figure 15 – Derivation of the **OT** $_{\text{capable}}$.network

We use the tank platoon from chapter 2 as an example of this process. Steps 1a and 1b are simple matrix algebra (as described above) and yield the following **AL** $_{\text{skill qualified}}$ and **AL** $_{\text{access qualified}}$ networks.

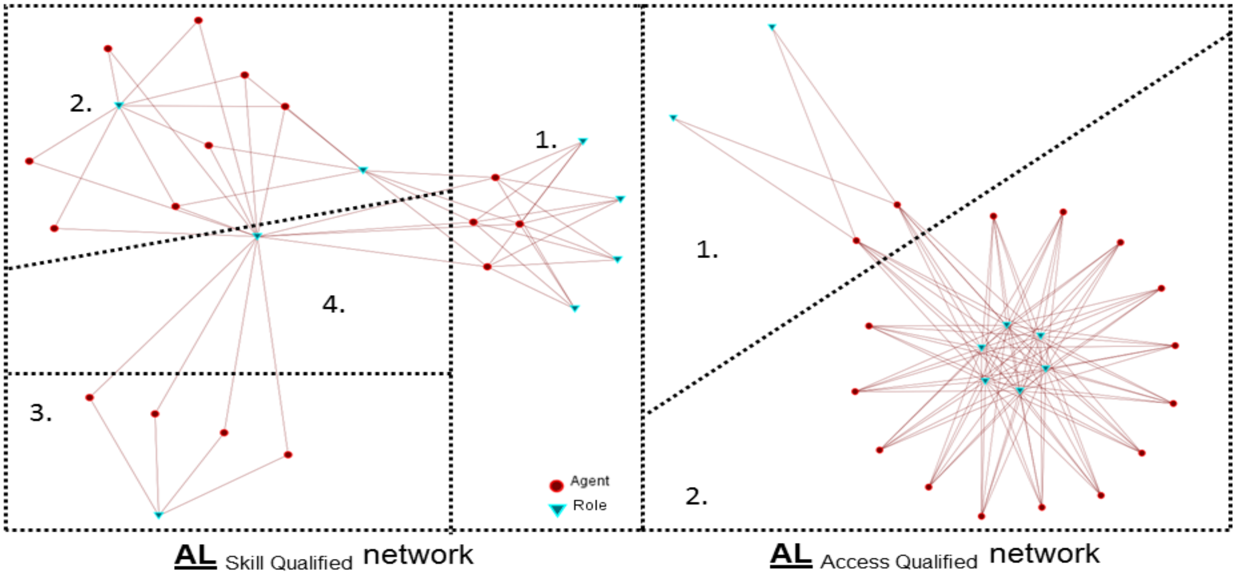


Figure 16 – Step 1a & Step 1b, the **AL** $_{\text{skill-}}$ and **AL** $_{\text{access qualified}}$ networks.

AL Skill Qualified	1. Vehicle commanders for section and platoon-level tasks
	2. Loaders and Gunners
	3. Drivers
	4. Vehicle commander for crew level tasks (does not require skills with radios)
AL Access Qualified	1. Platoon Leader and Platoon Sergeant
	2. Everyone Else

Step 2, the intersection of these networks, resembles the **AL** $_{\text{skill qualified}}$ network, save for the PL and PSG:

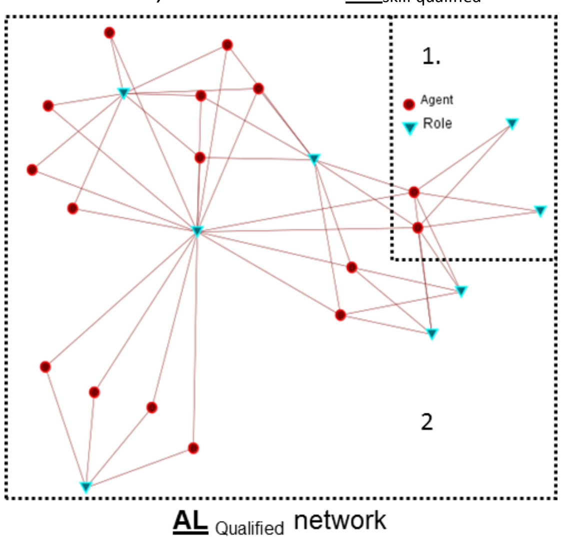
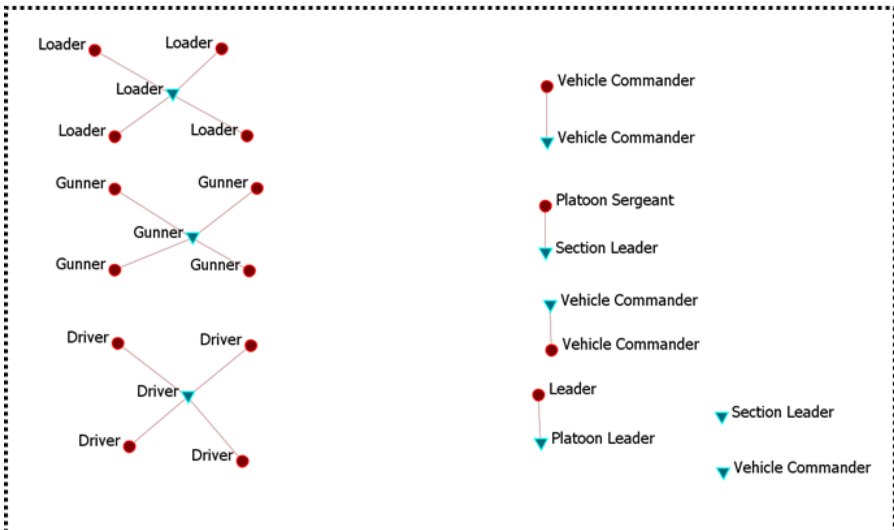


Figure 17 – Step 2, the **AL** $_{\text{qualified}}$ network. 1. Shows the leadership, 2. is by step 1a (above).

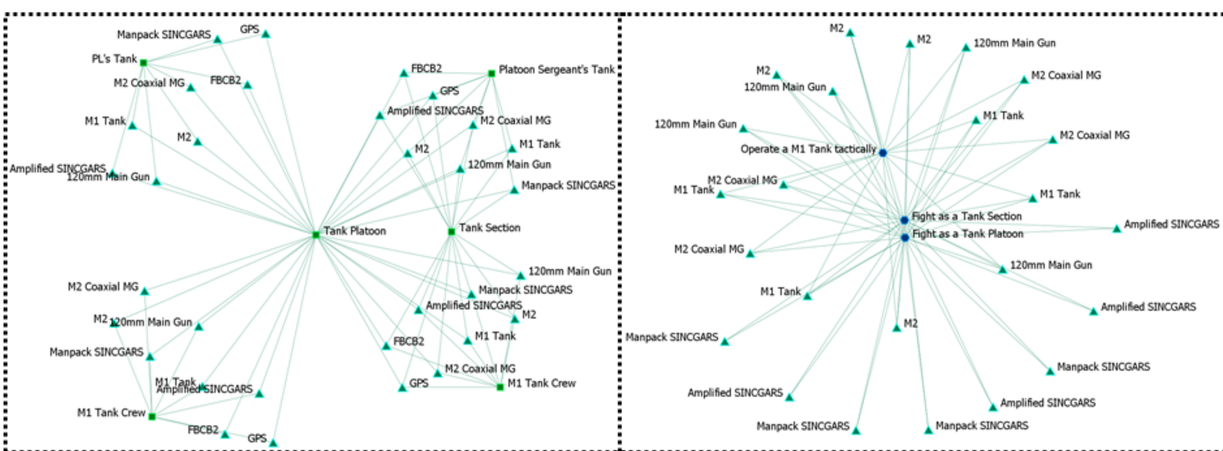
Step 3a compares the available supply of agents (**AO** $_{\text{aggregated membership}}$) against demand (**LT** $_{\text{aggregated requirement}}$) subject to suitability criteria given by **AL** $_{\text{qualified}}$. If an **AL** $_{\text{assignment}}$ matrix exists that is an acceptable solution to the set of matching constraints, then an organization is personnel capable. Figure 13, below, shows an example of the **AL** $_{\text{assignment}}$ matrix for the tank platoon conducting the task "fight as a tank platoon."



AL assignment network

Figure 18 – Step 3a involves checking for the existence an **AL** $_{\text{assignment}}$ network.

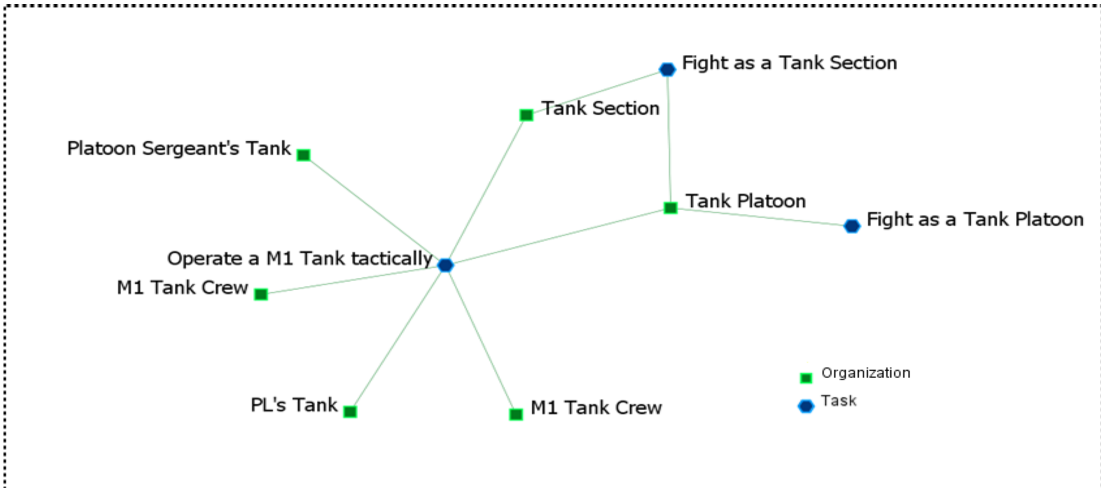
Step 3b compares the available supply of resources (**RO** $_{\text{aggregated assignment}}$) against the demand (**RT** $_{\text{aggregated requirement}}$). Figure 14 shows these **RO** and **RT** networks.



RO aggregated assignment network **RT** aggregated requirement network

Figure 19 – Step 3b compares the quantitiy of supplied resources to requirements.

As previously shown, for each combination of organization and task in the combined meta-network, if this network exists for that combination then the organization is personnel capable. In the case of the tank platoon, the **OT** personnel--- and **OT** resource capable networks are identical, so figure 14 shows step 4 and the conclusion; the **OT** capable network for the Tank Platoon.



OT capable network

Figure 20 – The **OT** capable network for the Tank Platoon.

Section 2: Assessing capacity based on given capability data

The method given above for assessing organization capability has two general flaws – (1) it is computationally expensive, especially for large organizations; and (2) it requires extremely specific data regarding the structure of units and tasks.[11] While this level of specificity may be appropriate for certain force development decisions, it is too detailed for force structure or operational planning decisions writ large.

The 'network programming' method described in the process of determining the **OT** personnel capable network can apply also to the modeling of new tasks using given capability data, or to the study of aggregate organization capacity. In this case we are given an **OO** composition network that represents the structure of an organization and an **OT** capable network contains the sufficiency criteria for mapping subordinate units to tasks. Our objective is to determine whether this organization and task combination can be mapped to a set of requirements articulated by a **TT** decomposition network.

	ORGANIZATION	**TASK**
ORGANIZATION	Composition	Capability
TASK		Requirement

Table 11 – Data Requirements for Organization-Level capability assessment

In a fashion similar to that for the **OT** personnel capable network, for each combination of organization and task this generates a set-covering problem and associated system of equations. That is, for each combination of organization *i* and task *j* in **OT** capability there is a set covering system of linear equations, where the 'supply' is given by the vector of organizations that compose **OO***i* aggregated composition, the requirements that must be covered are the vector of tasks **TT***j* aggregated requirement, and the suitability criteria are given by **OT** capable.

This gives us a set of (**O+**1)**T** decision variables corresponding to the possible assignment of organizations to tasks or unassigned:

$$\begin{bmatrix} O_1T_1 & \cdots & O_nT_1 \\ \vdots & \ddots & \vdots \\ O_1T_m & \cdots & O_nT_{m,} \\ U_1 & \cdots & U_n \end{bmatrix}$$

Suitability and exclusivity constraints are articulated similarly:

Constraint set 1 - Suitability: For each Sub-Task requirement for Task *j* in **TT***j*, sufficient capable Organizations must be assigned:

Organizations are capable according to coefficients given by the **OT** capable network:

$$\begin{bmatrix} \boldsymbol{OT_{11}} \times O_1T_1 & \cdots & \boldsymbol{OT_{n1}} \times O_nT_1 \\ \vdots & \ddots & \vdots \\ \boldsymbol{OT_{1m}} \times O_1T_m & \cdots & \boldsymbol{OT_{nm}} \times O_nT_m \end{bmatrix}$$

Then the constraint becomes:

$$\begin{bmatrix} \sum_{a=1}^{n} \boldsymbol{OT_{a1}} \times O_aT_1 & = & \mathbf{TT}j_1 \\ \vdots & \vdots & \vdots \\ \sum_{a=1}^{n} \boldsymbol{OT_{am}} \times O_aT_m & = & \mathbf{TT}j_m \end{bmatrix}$$

Constraint set 2 - Exclusivity: Each Organization in **OO***i* can only be assigned to one Task or left unassigned:[12]

$$\begin{bmatrix} \sum_{l=1}^{m} \boldsymbol{OT}_{1l} \times O_1T_l + U_1 & = & 1 \\ \vdots & \vdots & \vdots \\ \sum_{l=1}^{m} \boldsymbol{OT}_{nl} \times O_nT_l + U_n & = & 1 \end{bmatrix}$$

The existence of a solution to the set-covering problem for the organization and task combination means that the organization has sufficient sub-organizations to perform each element of the task. Due to the nature of the hierarchical composition of the **OO** composition and **TT** requirement networks, it is meaningless to consider the 'top line tasks' – for example, if we are worried about the ability of a BCT to conduct a certain brigade level task, we can remove the BCT and the task from the respective **OO** and **TT** networks, and consider the question of whether the components of the BCT are capable of performing the components of the BCT-level task.[13]

This method also produces an **OT** *assignment* network that maps units to tasks and a vector of unassigned units, or 'residual capability.' For our purposes, simply establishing that a capability network exists is a sufficient measure of capability. Figure 16, below, shows the **OT** assignment network for the tank platoon conducting the task 'fight as a tank platoon.'

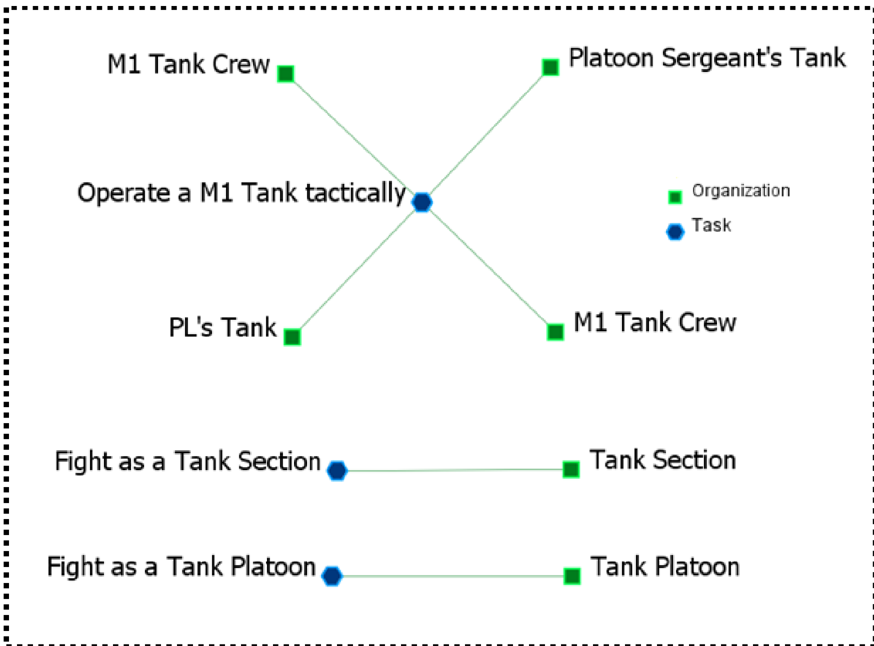


Figure 21 – The **OT** assignment network for the Tank Platoon.

This method of measuring general organization capability is also a method of measuring aggregate organization capacity, consistent with the definitions of both given in section 3 of chapter 2. That is, it measures the capability of an organization (defined by the **OO** composition network) to perform a set of tasks (defined by the **TT** requirement network). Whether or not it is a computationally convenient way of measuring general organization capability or a way of measuring aggregate organization capacity based on known general capabilities depends on how the **OO** network is structured and where the data in the **OT** network comes from.

Section 3: Non-hierarchical dimensions for aggregating organizations

Both of the above methods of assessing capability aggregate the organization and the task according to their hierarchical composition given in the **OO** composition and **TT** decomposition networks. For many purposes, especially force development purposes, this is sufficient as it represents the intended configuration of the organization.

However, for many operational planning problems, and certain force structure and force development problems, we are concerned with the organizational capability available according to some other criteria than those of formal organization. This section outlines some ways to mathematically aggregate elements across other dimensions.

The output of a non-hierarchical organization aggregation method is an **OO** $_{\text{aggregated}}$ network. For *m* organizations, a link **OO***ij* in this network indicates that organization *i* is linked to organization *j* by some criteria.

1. Alternate composition data

The simplest way to generate a non-hierarchical organization scheme is to provide an alternate set of composition data. Alternate composition data can reflect alternate schemes of organization, or command relationships – for example, the Army lists six different types of command relationships and four separate types of support relationships, each of which can be represented as a different **OO** networks (HQDA 2008).

The mathematics of alternate composition data are different depending on whether or not the individual entities are modeled as instances or types. In the case of the data used within this research, the **OO** $_{\text{composition}}$ network is based on individual instances of organizations, while the **TT** $_{\text{decomposition}}$ network is based on types of tasks.

2. Relational composition data

The PCANS model of structure in organizations (Krackhardt and Carley 1998) specifies several ways to generate square matrices of relationships between entities according to 'network words' of the relational data. The PCANS paper applies this to network models of mutual interdependence using an **AT** network and a **TT** network[14] - and shows, among other things, how **AT** ● **AT'** gives an **AA** network where a link **AA***ij* = *v* indicates that Agents *i* and *j* work with each other on *v* tasks.

The method of measuring organization capability given in sections 1 and 2 used this version of network multiplication to derive many of the subordinate matrices involved in its computation steps. We can also use this method to derive alternate composition schemes based on the relationships between other aspects of the organization.

An interesting example is the **OO** 'can communicate' network – The **RO** $_{\text{assignment}}$ network gives the list of resources within the organization, and the **RR** $_{\text{communication}}$ network gives the list of resources that can mutually communicate. **RO'** **X** **RR** gives an **OR** 'has mutually communicating resources' network, and this network **OR** **X** **RO** $_{\text{assignment}}$ gives an **OO** network where a link **OO***ij* indicates that organizations *i* and *j* share links with resources that can mutually communicate.

As well as allowing for a number of different capability assessments using the given data, this method of generating relational composition data allows us to include other dimensions for considering capability. Two examples, locational and temporal data, are explored in the future work section.

3. Aggregating non-hierarchical organization data

The **OO** composition and **TT** decomposition networks are aggregated by binarized path transformation and simple path transformation respectively, due to the nature of the data. For other data, the method of aggregation in each case depends on the nature of the data. There are too many possible aggregation schemes to discuss here, but we will give examples of the applicability of some:

Non-Aggregated Composition

In some cases, we may not need to aggregate the composition data at all – using the example of the **OO** can communicate network given above, if we are concerned with the capability that can be self-organized along a communication network then we don't need to aggregate the network at all.

Aggregation across a relational network

We can also aggregate composition networks across the relational network. Using the example of the **OO** can communicate network, we may be concerned with the ability to self-organize across multiple communication steps, rather than only the ability to communicate between specific sets of resources.

This 'extended' communication network is given by **|(→ RR)** = **RR** extended where a link **RR***ij* indicates that resource *i* can communicate, either directly or through a walk of other communication systems, with resource *j.* Similarly with the above example, then, **RO**' **X RR** extended **X RO** gives an **OO** extended communication network, where links indicate the ability to communicate as above, but the communication may be mediated through multiple systems.

Binarized, Additive, or Multiplicative Aggregation

The various ways of aggregating the **OO** composition and **TT** decomposition networks reveal some of the intricacies of aggregating composition networks. For any network between entities of the same type – i.e., networks that are guaranteed to be described by a square matrix[15] - the path transformation operation described above will show whether or not there is a path to aggregate across. There are two primary methods of path transformation – Multiplicative or additive path transformation.

Section 2 describes multiplicative path transformation, and mentions additive transformation in a note. In each case the basic logic remains the same – for each pair of nodes *i and j* in the original matrix, let W be the set of *k* edges in the shortest directed walk between the two nodes, and for each edge $W_k = v$ is the value of that edge. Let us denote multiplicative path transformation as $\rightarrow_{\Pi} (M) = T$, where *M* is the matrix being transformed, *T* is the output matrix and $T_{ij} = \prod_{W_k} v$. For additive path transformation, $\rightarrow_{\Sigma} (M) = T$ and $T_{ij} = \sum_{W_k} v$. Both of these forms of path transformation are directed – T_{ij} does not necessarily equal T_{ji}.

Practically, though, there are three methods – the multiplicative and additive described above, and binarized path transformation. The binarized case is used when the existence of a link is more important than its value, which is the case for many of the networks in the given data. We use binarized path transformation to aggregate the $\underline{\mathbf{OO}}_{composition}$ network, because the simple existence of a link conveys the affiliation between the parts of the organization. The $\underline{\mathbf{RR}}_{extended}$ network given as an example above is also a binary aggregated network.

We use multiplicative path transformation to aggregate the $\underline{\mathbf{TT}}_{decomposition}$ network because its edges represent the number of instances of a type of task – for example, if 'fighting as a brigade' requires three 'maneuver a battalion' tasks, which each require three 'fight as a company' tasks, then the aggregated requirement for fighting as a brigade is nine company level tasks.

For an example of an additive network, consider an 'extended' $\underline{\mathbf{RR}}_{communication}$ network given by $\rightarrow_{\Sigma}(\underline{\mathbf{RR}})$ instead of $\mathbf{|(\rightarrow \underline{RR})}$. In the case of this extended network, each valued link $\underline{\mathbf{RR}}ij = v$ indicates the number of intermediate steps each communication device must go through to communicate with another communication device.

The valued composition networks given by the additive and multiplicative path transformation operations may have theoretical value, either for determining the number of requirements (as is the case in the $\underline{\mathbf{TT}}_{aggregated\ decomposition}$ network) or as part of a more complicated aggregation scheme.

Threshold limited aggregation

If we have a composition or relational network that has valued links, we can aggregate that network according to links that are greater than or less than a certain threshold. Using the example of the valued $\underline{\mathbf{RR}}_{extended}$ network given by $\rightarrow_{\Sigma}(\underline{\mathbf{RR}})$, we may declare that we are only aggregating by those organizations that are less than or equal to 2 steps apart.

Compound Aggregation

Finally, we can aggregate networks by any combination of the above operations and general matrix operations that has theoretical value. For example, if we are concerned with the determining the capability of a set organizations that is either collocated with each other or can communicate with each other within 2 steps by some resource, and we have the data in the meta-network described in section 1 and an additional $\underline{\mathbf{OO}}_{collocated}$ matrix, we can determine the objective aggregation by the following steps:

Let $\underline{\mathbf{RR}}_{extended} = \rightarrow_{\Sigma}(\underline{\mathbf{RR}}_{communication})$

For each combination of Resources i and j let $\underline{\mathbf{RR}}ij_{extended \leq 2} = 1$ if $0 \leq \underline{\mathbf{RR}}_{extended} \leq 2$, 0 otherwise.

$\underline{\mathbf{OO}}_{can\ communicate} = \underline{\mathbf{RO}}' \mathbf{X}\ \underline{\mathbf{RR}}_{extended \leq 2}\ \mathbf{X}\ \underline{\mathbf{RO}}$

$\underline{\mathbf{OO}}_{compound\ aggregated\ example} = \mathbf{U}(\underline{\mathbf{OO}}_{can\ communicate}, \underline{\mathbf{OO}}_{collocated})$

4. Utility of non-hierarchical aggregation schemes

The various means of composing organizations described above extend the applicability of the structural measurement of capability given in sections 2 and 3 to other planning or policy problems. Any composition network – either the given ones, or non-hierarchical composition networks given according to the criteria in this section – can be used in lieu of the $\underline{\mathbf{OO}}_{\text{aggregated composition}}$ networks in in step 3a and step 3b of the structural measurement in section 2, and for the $\underline{\mathbf{OO}}$ network of the capacity measurement in section 3.

While each of these operations works on any square matrix, we do not have any reason to examine alternate aggregation criteria for the $\underline{\mathbf{TT}}_{\text{decomposition}}$ network – the definition of the task is given. For the purpose of measuring capability, we are more concerned with how we can organize, through varying schemes, then how the tasks are structured.

Section 4: Conclusion and Findings

This chapter presents the cornerstone of this research – how, given meta-network descriptions of organization and tasks, and common resource and knowledge information we can quantitatively model the capability of the organization to meet the requirements of the task. This chapter presents the following key findings:

- *General organization capability can be quantitatively assessed based on meta-network representations of organizations and tasks.*
- *Aggregate organization capacity can be quantitatively assessed based on a set of organizations, requirements, and capability data.*
- *Network models can be used to articulate certain types of set-covering integer programming problems*
- *Both models of capability assessment can be applied to multiple concepts of organization.*

1. Findings

Finding 1: A network-science based method of measuring general organization capability.

Given meta-network models of organizations and tasks represented according to the description in chapter 3, sections 1 and 2 of this chapter show how we can measure organization capability based on the ability to align the elements of the organization against the elements of the task. The general method described focuses on aligning the organizations' agents against the tasks' role requirements and assessing that the organization has a sufficient inventory of resources to meet the task's resource requirements.

This method is consistent with the definition of general organization capability argued by analogy with doctrine given in chapter 2 because of the way the network data of organizations and tasks are constructed. The essential insight is that the military policy elements involved in the structure of the organization can be aligned with the practical elements of warfighting described in the task descriptions *in their own terms.* To the extent that the task requirements can be modeled to this level of specificity, this method of measuring capability provides a robust and consistent method of determining the general capability of various organization structures by comparison with the doctrinal description of tasks.

This version of the model is extremely sensitive to interpretation decisions, because it requires an exact match between the elements of the organization and the elements of the task. If the organizations and tasks are not coded similarly, the model may not be able to find corresponding entities to match against requirements. Using the authorization documents for unit data – which list equipment items specifically and consistently – and conducting a comprehensive survey of Army organizations to provide authoritative task data[16] can mitigate this sensitivity.

Finding 2: A method for measuring capacity based on given capability data

In addition to being able to align the specific elements of organization against task requirements, we can align a set of organizations against a set of tasks. This method of measuring capability, articulated in section 3, is consistent with the definition of aggregated organization capacity given in chapter 2. This has several important implications – first, it can serve as a method for assessing general organization capability for task requirements that cannot be modeled to the level of specificity required by the general method described above; second, it can be used to describe the capacity of a force to provide specific organization capabilities, depending on the source of the $\underline{\mathbf{OT}}_{capable}$ network.

Finding 3: A network method of articulating set-covering integer programming problems.

Both the general organization capability and aggregate capacity models developed in this chapter determine capability by determining if there exists a set of alignment decisions that aligns (1) a set of supplied elements against (2) a set of required elements, subject to (3) certain eligibility and exclusivity criteria. These three elements are derived directly from the meta-network models of organizations – where the supply and requirements are vectors within supply and requirement matrices, and the exclusivity criteria are given by a separate matrix conformal with the quantity supplied by the quantity required. This becomes a set-covering binary integer programming problem, where the decision space is given by a matrix of dimension (magnitude (supply+1))*magnitude (demand).

The exclusivity matrix used in this chapter is simply a matrix of ones of the same dimension as the eligibility matrix. In cases where there is some theoretical reason why there should be different exclusivity criteria, the exclusivity constraints can also be articulated by a different matrix.

The basic formula – supply vector, requirement vector, criteria matrix/matrices- is expansible to other meta-network models that require some decision of how to align elements of the meta-network to each other.

Finding 4: The capability of non-hierarchically structured organizations can be modeled.

Section 4 of this chapter shows how various meta-network methods can be used to generate alternate structures for organizations articulated by the $\underline{\mathbf{OO}}_{composition}$ network, aggregated across other dimensions. Each of these alternately derived $\underline{\mathbf{OO}}_{composition}$ networks can be used in the measurement of capability. The ability to construct organizations from alternate or network-derived composition data allows us to model the effect of different types of military organization decisions on available capabilities by either the general or aggregate models.

2. Conclusion

This chapter brings together the work presented in chapters 2 and 3 by showing how meta-network models of doctrinal organizations and tasks can be compared to present a robust, quantitative method of assessing general organization capability claims by consistency with doctrine. This method of assessing capability has several advantages over other methods: first, it directly addresses the policy elements of force development and force structure by assessing capability in terms of the elements of organization that involve decisions about expenditure and authority. Second, it is hierarchical from inception – the effects of changes at any level of the hierarchy over the entire organization can be discretely represented and analyzed. Third, the general framework of the models is expandable to account for other criteria or aggregation schemes.

Practically, while the general organization capability model described in section 2 can consider far more elements of the organization and more aspects of tactical doctrine in its representation of tasks, it is only practically useful for the force development of small organizations because of the specificity of the task data required. At higher levels, the much simpler aggregate capacity model becomes more useful. Given the flexibility in the representation of both the **<u>OO</u>** and **<u>TT</u>** composition networks, this capacity model becomes extremely flexible to consider various force development and operational planning problems.

Notes for Chapter 4

[1] i.e., the number of columns in matrix *L* is equal to the number of rows in matrix *R*.
[2] Note that path transformation can be either additive or multiplicative. Multiplicative path transformation is given here; in the case of additive path transformation, $T_{ij} = \sum_i v$ for all edges W_i.
[3] **TT** $_{aggregated}$ is not binarized because tasks have integer links with each other - each link **TT** $_{aggregated}$ = *v* means that *v* instances of task *i* make up task *j.*
[4] Note that resources are modeled individually (see chapter 2, section 3, paragraph 2), not by class.
[5] Note that the **RT** $_{aggregated}$ network is not binarized, since links indicate the number of resources required of a certain type, while the **OT** $_{aggregated}$ network has links to specific resources.
[6] We determine the number of resource types in the data based on the unique values of the "Title" attribute of resource data in the DynetML file for units, as each resource has a unique ID attribute and a Title attribute based on its type in the OrgChart data.
[7] Note that this formulation automatically holds true if the task requires no resources.
[8] Note that this network does not need to be considered against the 'amount of available skill' compared to the number of resource requirements, or a vector of resource types during derivation like the **OT** $_{\text{resource capable}}$ network. This is because the relationship between agents and resources – *skill* – is not exclusive. That is, using a skill to employ one resource doesn't prevent using it to employ another resource of the same type.
[9] The Exclusivity constraint can be softened, to indicate whether or not certain roles are exclusive or not. This will be covered further in findings.
[10] Note that this method also produces an **AL** $_{\text{assignment}}$ matrix and a vector of unassigned agents. These outputs are not necessary for the structural measurement of capability, but may be used to address the modeling of a unit conducting a task and/or the augmented and degraded functionality problems articulated in the future work section.
[11] We will discuss ways to change the data requirements by introducing substitutability and exchange in resources in the future work section.
[12] Similarly to the exclusivity constraint in the **OT** $_{\text{personnel capable}}$ problem, this constraint can be softened to model the ability of one organization to handle multiple requirements. An excellent example of this is a headquarters or coordinating organization, like a fire direction center. The task 'provide fire support' requires a fire direction center to take the call for fire, but the same fire direction center can (indeed, must) respond to multiple calls for fire.
[13] It also works to declare the top-line organization as arbitrarily capable of the top-line task, if there is only one top-line task.
[14] The PCANS paper uses a substantially different notation; we have translated into the notation used here for consistency's sake.
[15] Note, that if you have the same number of entities in two different node-classes, the network is a square matrix, but only in that instance.
[16] See finding 2 from Chapter 3, preceding.

Future Work

CHAPTER 5

From the start, this research was intended to develop a method to answer organizational questions about units described according to doctrine, for the purpose of policy analysis for force structure and force development. This method opens the door for extensive future work, including work on refining the data set, refining the model, extending the types of data used and problems that can be addressed, refining the 'network programming' method developed in Chapter 4, and expanding the theory of capability.

Refining the Data Set

1. Authoritative Data

Two documents provide the authoritative data for the structure of a unit – the Table of Organization and Equipment (TO&E), and the Modification Table of Organization and Equipment (M-TOE). The former, the TO&E – describes the intended structure of a unit if fully resourced; the latter describes the resources (both equipment and personnel) that the Army intends to purchase or provide to the organization.

Adapting the organization data set as given to use authoritative data from these sources would require both extensive programming and subject-matter expert interpretation. These data sources describe the Agent and Resource entity classes down to the individual Agent and Resource elements; and give two or three levels of organization.[1] M-TOEs are usually published for battalion-level organizations or below;[2] higher level units require additional data about unit configuration reported in the Defense Readiness Reporting System – Army.

Subject matter expertise is necessary to determine the knowledge entity class relevant to this organization and the agent, resource, knowledge, and organization networks. Some information is contained in the structure of the document, other information is contained in the titles of lines, and other information is contained in the attributes and remarks. Of note, one specific network, the Agent by Resource $\underline{\mathbf{AR}}_{skill}$ network is relevant to policy regarding individual training. M-TOEs list agent positions (personnel authorizations) by Military Occupational Specialty and/or Additional Skill Identifiers, each of which convey some information about the trained agent's skills for resources and access to knowledge. Development of an additional *MOS* by *Resource* network would allow analysis of the effect of decisions in MOS training against organization capability.

2. Survey of US Army Doctrine

Chapter 3 finds that the task data derived from unit FMs does not consistently convey task organization information that is portable to different units. In addition, the task-organization data in some Field Manuals (especially the Stryker MGS field manuals) is inconsistent with the structure of the established organization. Some organizations, such as the heavy reconnaissance troop and squadron, integrate multiple types of systems in the same platoon-level organization (e.g., the Heavy reconnaissance platoon, which integrates Bradley Fighting Vehicles and HMMWVs in the same platoon-level formation). Finally, some unit-based field manuals (especially the Field Artillery manuals) do not convey sufficient task organization data to determine the specifics of organization at any level.

The task of generating sufficient, consistent, task-organization data to generalize across Army organizations at the level of fidelity required for the individual Agents/Resources requires a comprehensive survey of Army organizations and doctrine. The purpose of this survey would be to generate common task-organization data for various tactical tasks that span across organizations – for example, tasks such as 'Operate a HMMWV'[3], 'Operate as a 3-man (4-man, 5-man) fire team,' etc. Such a data set is necessary to provide the common doctrinal foundation for assessing non-standard higher-order capabilities, such as the ability of a Combined Arms Battalion to fight as an Infantry Battalion.

*3. Refining the **RR** $_{Communication}$ Model*

The **RR** $_{communication}$ network as depicted in Figure 9 represents a fairly narrow view of the intricacy of military communication, based on the technical capability of specific systems to send a signal that another system can receive and interpret. This is sufficient for the levels of organization modeled in the given data set; but for the analysis of larger organizations or different policy problems, it may not provide sufficient data.

Depending on the policy question being considered, we may consider multiple communication networks, including the **RR** 'technical capability' network given above, an **RR** 'within range' network, an intermediate 'Frequency Band' or 'Network' entity class (**F**)with a corresponding **RF** $_{monitoring}$ network (where **RF X RF'** = **RR** $_{\text{monitoring the same network}}$), or others.

These intermediate networks can then be used to derive the **RR** $_{communication}$ network relevant to the specific problem under study. For the policy problems under consideration in this research – force structure and force planning – we may be more concerned with, for example, the technical capability and organizational allocation of frequency/communication networks than with positional matters. For operational planning purposes we are likely to be more concerned with network allocation and range.

Refining the Model

1. Resources by type, rather than instance

Some of the entity-classes in the meta-network developed in Chapter 3 and expanded in Chapter 4 indicate instance based data – where each node is an instance of a thing – and others indicate type-based data. The contrast between the **OO** $_{composition}$ and **TT** $_{decomposition}$ networks is an example of this – a link **OO***ij* indicates a relationship between two separate instances of organizations; a link **TT***ij* = *v* indicates a weighted link between a type of task and another type, where the weight value indicates the number of subtasks required.

In the case of resources and knowledge, many of the relationships that a given entity has with other entities in the meta-network are derived from its type. The **AR** skill, RR communication, **RK** storage, **RT** requirement, and **RL** utilization networks all reflect relationships based on the type of resource involved – we consider an agent who has the skills to operate an instance of a resource has the skills to operate all resources of a type, all resources of a type can communicate with other resources of a type, etc.

In these data, especially the meta-network model of organizations, we model resources as instances to be able to compute the effect of the resource on the organization through network statistics of organization that are not robust against weighted data. We work around the semantic distinction between instances and types by recording a 'title' attribute for each node that indicates its type.[4] When we compute the **RR** communication networks (and other type-based network), we generate links between each instance of a resource and each resource of its type. This method has the side-effect of greatly increasing the density of the **AR**, **RR,** and **RK** networks compared to networks defined if resources and knowledge were modeled as types rather than instances.

There are other legitimate cases for modeling both resources by instance rather than type. Throughout this research we have assumed that all resources of the same type have identical relationships as other resources of the same type. If we relax this assumption, we must model individual resources and their network effects separately. As a simple, concrete example of this, consider the **RF** monitoring network listed above in *'refining the communication model'* – if different radios are set to monitor different networks[5], then the different radios must be modeled as separate instances in an instance-based resource entity class.

2. The augmented- or degraded-functionality problem

While an Infantry Platoon armed with Javelin close-combat missiles can organize to attack enemy Armor, an Infantry platoon with Javelins, close air support, and field artillery with precision munitions can do so more effectively and safely. Similarly, while a 40 man infantry platoon can organize and operate as a platoon, so can 32- or 28-man organizations, only less effectively. These questions involve both the definition of task and capability.

The definition of tasks used in both chapters 3 and 4 is highly specific. Tasks are defined to the individual role and resource, and organizations are capable of them if the organizations can correspond to those requirements *exactly.* Real life applications are not so demanding – units often perform military tasks without all of the equipment or people required. Addressing augmented- or degraded functionality has some value for force development decisions. The ability to show a variable level of capability within the organization allows one to articulate the risk of cuts to a part of an organization or the robustness of an organization against casualties.

The integer programming model of organization capacity developed for mapping organizations to tasks subject to the **OT** capable constraint offers a potential solution to this problem; especially if combined with the additional data gathered by a more thorough survey of Army doctrine (see above) and combined with the addition of effects (see below). Given these networks, we can then model an alternate set of constraints given by a $\underline{\mathbf{TT}}_{\text{augmentation}}$ network, which rank-orders which equivalent tasks are more or less capable for a given higher-order task.

3. Adding Effects Data

The current method of modeling task data designates requirements for specific resources (the $\underline{\mathbf{TR}}$ network) and subtasks, rather than the effects that those resources produce and the subtasks that employ them. A good example of this is given by the 'fight as a machine gun squad' task – with separate versions for the M240, M2, and MK19 machine guns.

The underlying rationale behind mission-system analysis (Davis 2002) and effects-based planning (Smith 2002) is that systems - be they organizations employing a technical capability or technical capabilities themselves – can be tied to the 'effects' required within an operations plan. These 'effects' are logically the mission elements in claims of military capability.

There are two ways to consider 'effects' within the given model of organization structure – as criteria for resource substitutability or as requirements to be matched against suitable organizations subject to appropriate suitability and exclusivity constraints. Both are consistent with the general sense of effect in the above references.

We can model the former problem – resource substitutability – as a set of 'resource roles' within a task. Rather than stating that the task requires a particular type of resource, we state that the task requires a resource capable of performing a specific function. Then, given the $\underline{\mathbf{RO}}_{\text{assignment}}$ network, a Resource by Resource Role suitability network, and the $\underline{\mathbf{RT}}_{\text{requirement}}$ network, we can assign resources to the elements of the task as necessary. This model has the advantage of permitting the substitution of resources, but adds significant additional data, as the Resource Role entity class will be much larger than the Resource entity class.

Modeling effects as requirements is more consistent with the idea of 'effects based planning.' To do so, we would add a vector of required effects to the Aggregate Capacity model given in Chapter 4. Then, given the $\underline{\mathbf{OT}}_{\text{capable}}$ network, an additional Task by Effect $_{\text{relative capability}}$ network, and some set of criteria for determining how to propagate C2 requirements for the tasks aligned against effects, we could theoretically determine an $\underline{\mathbf{OT}}$ mapping subject to both capability constraints and satisfaction of the effect requirements. Future work is necessary to determine the feasibility of such a model.

Expanding the data used in the organization and task model

This dissertation has been directed towards a model of capability based only on doctrinal structure, and primarily relevant to modeling military policy concerns in force structure and force development. Adding additional data allows for further relevance to operation planning considerations.

1. Framework for including geographic information

Most of the descriptions for tactical tasks given in doctrine list elements and functions by positions that are geographically linked to each other in some way – either by the nature of the task itself or by external considerations, such as the range of supporting fires.

Incorporating positional data allows for several interesting avenues of analysis – aggregating organizations by position for capability measurement, selection of positions for supporting elements, refining the communication model, and other considerations.

Incorporation of positional information within the given meta-network simply entails adding an entity class consisting of position nodes (**P**) and a corresponding **PP** $_{distance}$ network.[6] Simply by adding these data, we can aggregate organizations by an **OP** $_{located}$ network and consider capability as geographically dispersed. Other aggregation methods (as described in chapter 4), especially threshold limited aggregation with the **PP** $_{distance}$ network as an intermediate relational network, allow for substantially more flexible interpretation. Finally, we can add an additional threshold limiting factor by adding either speed or range properties to elements in the data set – where the range or speed property can be used to compute a relational **PP** $_{within\ range}$ or **PP** $_{within\ appropriate\ travel\ time}$ network.

Inclusion of positional data as an element within Task data – for example, to generate a relational network between battle positions and engagement areas in order to model the amount of firepower that could be brought to bear on a certain position – would require instance-based task data. While such analysis is possible, it would require a thorough redesign of the capability models developed in this work.

2. Framework for including temporal or sequential information

The original PCANS model of structure in organizations defined the **TT** relationship as 'Precedence' (Krackhardt and Carley 1998). This precedence information is represented as sequential data –a link **TT***ij* indicates that Task *i* occurs before task *j*. Temporal information can also be represented by simply time-stamping entity sets, and generating a square matrix of temporal information based on the time-stamp property, where a link (using tasks as an example) **TT***ij* = *v* indicates that entity *i* occurred *v* units of time before entity *j*.

Temporal information has several applications. Previous work by this author explored the feasibility of using sequential information to represent cycles of planning tasks and dependencies in parallel planning (Behrman and Carley 2009), in order to model the characteristics of network participants over time. Requirements can be aggregated across sequential networks in order to determine the total requirement – for example if a mission involves several steps, and does not permit refit or organization between steps, the set of organizations must be capable of the sequential requirements subject to suitability criteria as described in chapter 4 and exclusivity criteria based on which tasks are simultaneous..

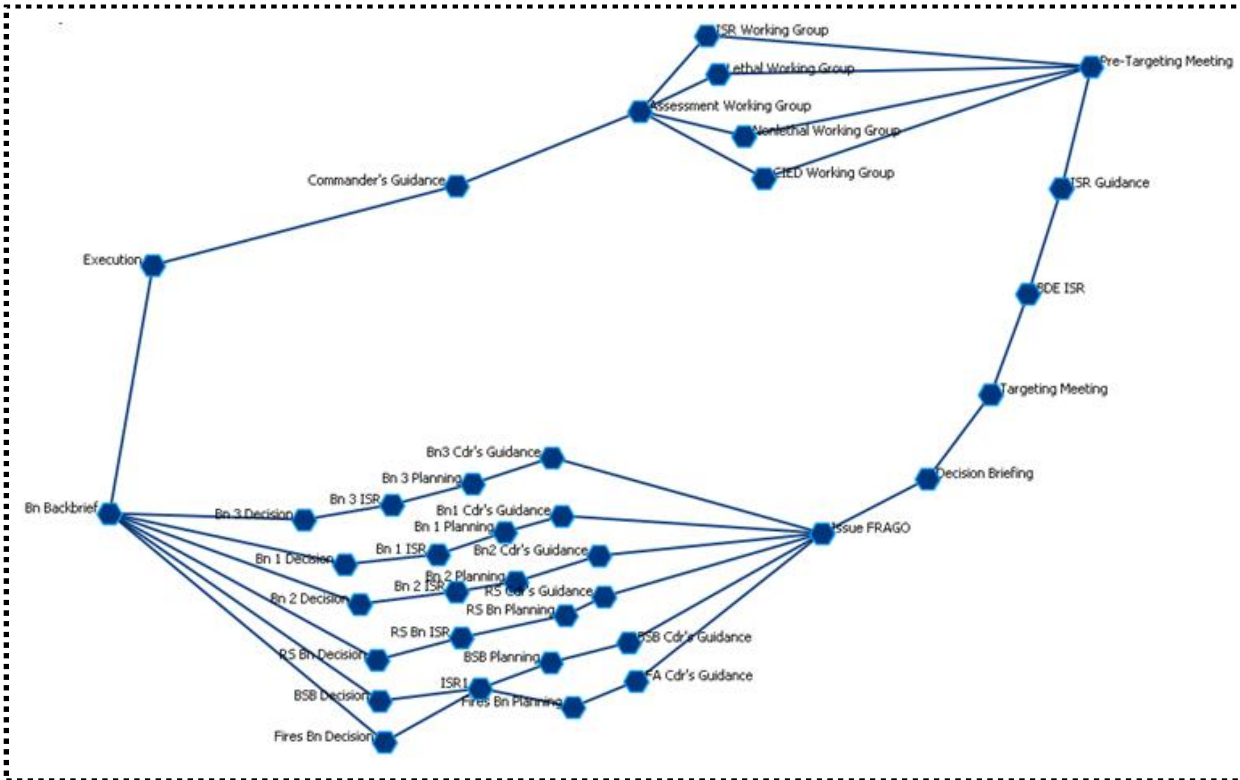


Figure 22 – Example $\underline{\mathbf{TT}}_{precedence}$ network for the BCT Staff.

Precedence information enables extension of the theoretical framework to cover two important policy problems – military risk in terms of capability, and readiness. For the former, sequential or temporal information represents when forces are committed to tasks; for the latter, temporal information allows us to aggregate capabillity across the stages of a Time-Phased Force Deployment Data[7] timeline, or assess the inventory of available organizations at a given point of time within the ARFORGEN process.

Refining the 'Network Programming' Model

1. Adding exclusivity criteria to the assignment problem

Tank platoon leaders have a distinctly different network position than Infantry platoon leaders – in addition to their 'hat' as the leader of the platoon they are also the vehicle commander of their own tank and the leader of their section. In this case, the role of 'platoon leader' is distinct from the role of 'vehicle commander', but the same agent can perform both roles simultaneously.

The current model accounts for the two-hat problem by explicitly coding the platoon leader's role as a combination of the requirements of platoon leader, section leader, and vehicle commander. In addition to being cumbersome, this method does not account for other non-command situations in which certain roles can be performed simultaneously.

A more general solution to the 'two-hat' problem is applicable to both the $\underline{\mathbf{OT}}_{\text{personnel capable}}$ step of the structural capability model (chapter 4, section 2) and the $\underline{\mathbf{OT}}_{\text{capacity}}$ problem (chapter 4, section 3). In each case we constrain the allocation program to find a solution based on suitability criteria and exclusivity criteria; where the exclusivity criteria are set to a matrix of ones for each decision variable.

We can incorporate additional information into these exclusivity criteria based on known information about the 'demand' entities. The simplest way to do so is by simply marking certain demand entities as 'non-exclusive', such that all column coefficients in the supply by demand exclusivity matrix for it are set equal to zero. A more powerful, but computationally expensive, way to compute this is to create a demand by demand 'exclusivity' matrix. This changes the set of exclusivity constraints to a vector of length (supply x demand), where for each supplied entity and each potential demanded entity it can be assigned with it cannot be assigned to any entity the demanded quantity is exclusive with.

Refining the exclusivity model allows us to develop a more nuanced model of task requirements by considering overhead tasks – such as the supporting battle staff – that must be present but can support multiple tasks simultaneously.

Refining the theoretical framework

1. Towards a theory of Readiness

The model described throughout this research is oriented towards the measurement of general organization capability based on doctrinal unit structure, and primarily applied to the military policy aspects of force structure and force development. In general, we have hand-waved away considerations of actual units and training decisions – the elements that justify the 'training and readiness' military policy problem mentioned on figure 3 and in the description of operations planning.

The force development and force structure problems are primarily relevant to military policy decisions throughout the 'Future Years Defense Program', or two to five years from the current fiscal year. Concern about the readiness of units, the allocation of resources against their M-TOEs, the missions they will be performing, and the residual risk involved in committing them to steady-state missions is relevant to the training and readiness problem within the 'budget years' – now to two fiscal years from now.

Adopting this model to data about the present rates of fill of general units, their assigned mission manning and equipment levels, their levels of training, etc. provides a sense of the capability of real units. These data are authoritatively reported in Unit Status Reports (USR), governed by Army Regulation 220-1 (HQDA 2010). However, USR reporting has several difficulties, including limited accountability for task-organized equipment (i.e., equipment not on the M-TOE) and no ability to consider hierarchical capability. Future work can, and should, develop this into a detailed model of real unit capability, to model the effects of personnel assignment and allocation practices, equipment distribution, steady-state missions, etc. upon the capability of the force.

2. Towards a consideration of risk in terms of capability

There is a significant body of work on the effects of isolating or removing agents upon the command structure or performance of a network (Carley, Lee and Krackhardt 2002, K. M. Carley 2004, Carley, Reminga and Kamneva 2003, Tsvetovat and Carley 2006, Moon, Carley and Levis 2008, Moon 2008). This research focuses on identifying critical nodes to either protect or isolate in order to minimize or maximize, respectively, the effect on the organization's performance *as it operated prior to the change.*

Several of the methods proposed within this research also speak to the notion of residual capability, or that capability which is not committed to a specific task. This capability is an essential part of military doctrine – it is the tactical, operational, or strategic reserve (depending on the level of the task under consideration) – and it represents the overall force's ability to respond to unanticipated situations or emergent contingencies.

These speak to two senses of risk – the force development risk, in the ability to design forces that are robust against loss; and the force structure risk, or a reserve of sufficient capability to respond to contingencies.

With regards to the former, the model presented here suggests an alternate criterion for selecting nodes to protect or target, based on their ability to maintain the capability of the organization and the amount of effort it would take to restore that capability. Implementing this method would require a conceptual solution to the augmented- or degraded-functionality probability problem, and simulation to determine both appropriate interventions and recovery strategies. Such a method could be used to evaluate organizational risk and robustness in terms of capability.

With regards to the latter, both the theoretical answer to the augmented- and degraded-functionality problem and the 'unassigned' vector from the models of capability speak to aspects of this risk – the former, the ability to conduct the mission given a degraded force capability; the latter, the ability to respond to an unexpected mission. Development of these two aspects of capability into a more formalized theory can add to the assessment of risk by allowing us to represent it in terms of available capability.

Notes for Chapter 5

[1] Separate M-TOEs are given for units with Unit Identification Codes that end in 'AA', which indicates the smallest level of organization that is intended to be employed independently. For Battalion-level M-TOEs, they are then organized by paragraph numbers, with the first digit of the three-digit paragraph numbers giving the company and the last two digits giving the elements of the company. For lower-level organizations, such as companies with AA level UICs, the paragraph numbers give subordinate echelons.

[2] As mentioned above, the M-TOE is published for the smallest level of organization intended to be employed independently.

[3] High Mobility Multipurpose Wheeled Vehicle

[4] Note, that this method is logically equivalent to creating a Resource Type node class and a Resource by Resource Type network, constrained that each resource can only have one link to a resource type.

[5] This is standard operating procedure for every independent combat organization the author is familiar with – one radio is set to listen/transmit on the platoon network, another to listen to the higher (company or battalion) network.

[6] Note, that this position network can be computed from a set of position entities with geographic coordinates and a geodetic distance calculator. In addition, the position network may be derived from properties of other elements in the network, such as the location of an FBCB2 system. In this case, for modeling purposes we would separate the position entity class from the entity with associated positional properties, in order to avoid conflating the relationships between the entities that positional in nature versus the relationships associated with the original entity class.

[7] The TPFDD is the list of when forces are required, and when they will arrive, in the event of a major contingency. It shows the force flow from home station to the theater of conflict.

Summary and Conclusions

Chapter 6

This research was inspired by some fairly esoteric questions about the organization of Army tactical formations. How could we determine the benefit – or cost – of some seemingly inconsistent decisions made by the Army in the structure of its Brigade Combat Teams? Why were Stryker MGS systems organized so differently than Abrams Tanks? Why do some BCTs have BSTBs, and others do not?

This research has not answered these questions – instead, it has focused on the meta-question "how do structural decisions about a unit affect or determine its capability?" This meta-question is broad, expansive, and central to one of the key activities of the Army – organizing men and materiel into combat units. The sprawling line of inquiry that this research has undertaken in pursuit of this meta-question, documented in the past four chapters, has taken us from the basics of capabilities-based planning at the highest levels of Department of Defense policy to developing data on how many vehicles are in a single platoon.

Section 1: Summary

The final outcome of this sprawling line of inquiry, and the original product of this work, is a structural measurement of general organization capability, based on the network structure of organizations and tasks. We presented two versions of this – one that measures capability according to the individual elements of an organization, and one that measures capability based on the capability of component parts. Each model asserts that if we can align the components of an organization against a required quantity of organizational elements the organization is capable of the task. Both versions of this model use meta-network data of organizations and tasks to represent the 'supplied' elements provided by the organization and the 'required' elements needed by the task.

These meta-networks from a data set this research developed based on Army doctrine as described in doctrine. This data set represents policy decisions involved in the construction and organization of Army forces and the doctrinal description of the tasks they perform. The construction of these data sets differs from many data sets in the Network Science literature as these data do not reflect observed interactions between elements of an organization, but are derived from formal organization descriptions and policy documents. Because this data is substantially different in both structure and context from standard meta-network models of organization, we devote the majority of chapter 3 to documenting how it is constructed. We also present some findings and descriptions of organization in chapter 3 to establish how doctrinal data performs differently from observed data.

These doctrinal descriptions of organizations and tasks are important because they comport with the organization and task elements of generic organization capability claims. General organization capability claims assert the ability of an organization to task-organize to perform some task. The data set in chapter 3 describes a method to rigorously represent the premises and predicate of these capability claims in terms of authoritative data that represents policy decisions. For force development and force structure decisions, this allows us to consider organization capability claims according to their consistency with published doctrine and policy. These types of capability claims are involved in each of the three elements of military policy.

Overall, from its final product to the esoteric questions about Army organization structures that originally inspired the approach, this research has attempted to relate decisions about military organization to outcomes in terms of military capability. It shows how minute arguments about the number of trucks in a platoon relate, through various types of capabilities and requirements, to arguments about the size, posture, and strategy of the United States' Armed Forces writ large. In doing so, it has showed that one specific type of capability claim – general organization capability – is of central importance to policy decisions on force structure and force development, and how that kind of capability claim can be tested and measured through structural network science methods.

Section 2: Key Findings

1. General organization capability claims tie together force structure and force development decisions.

There are five basic kinds of capability claims used to justify positions on military policy issues – (1) claims of specific organization capability, (2) claims of technical capability, (3) claims of general organization capability, (4) claims of aggregate organization capacity, and (5) claims of relative military capability.

All forms of capability can be validated by observation of systems in combat, subject to the context of the particular engagement and enemy. More important, however, is how we predict capability prior to combat. For policy purposes, we validate specific organization capability by observing generally capable organizations in the performance of a task or an exercise of a task. Likewise, we predict relative capability based on combination of the general capability of an organization to perform a task, and the technical capability of its systems to achieve effect given the context of the task. Finally, aggregate capacity claims are merely a specific (useful) case of general organization capability claims. In each case, there is a general organization capability claim underlying the other claim.

Decisions about force structure and force development attempt to answer policy requirements articulated in terms of current plans and future concepts. Both current plans and future concepts articulate requirements for general organization capabilities and technical capabilities. The general capability elements represent how the force will conduct the plan or future warfighting concept; the technical capability elements articulate the kinds of effects that force can achieve relative to designated or anticipated context and enemy.

This description of the types of military capability claims and their logical relations in chapter 2 is innovative, as it provides a means to clearly articulate the application of various concepts of capability to the capabilities based planning paradigm and military force structure and force development decisions. Excessive focus on technical capabilities neglects the organizational requirements of *employing* those capabilities. By clearly differentiating the logic of the different types of capability claims, we can identify when a focus on specific capabilities is inappropriate.

2. General organization capability can be measured based on doctrinal organization and task structure.

The only way to assess the validity of general organization capability claims prior to originally fielding the system is by consistency with doctrine. We originally articulated this axiom in terms of force development decisions – we can assess the capability of a new system or organization by determining in what ways it exceeds or falls short of current doctrine – but it has much wider applicability. We have shown that we can also assess the residual capacity of an organization with committed forces, the capability of a non-hierarchically structured organization, or (subject to data availability) the performance of an organization against non-designed tasks. Each of these organizations are emergent from operational or planning contexts, and often cannot be validated by repeat observation, simply because of the circumstances in which they emerge.

The structural model of organization capability addresses this by aligning the elements of the organization against the requirements of the task, subject to varying types of suitability criteria. We present two versions of the structural model – an individual-element model and an aggregate capacity model. The individual-element version uses multiple criteria based on the particulars of each type of requirement. The aggregate capacity version simply aligns a supplied quantity against a required quantity subject to given suitability and exclusivity criteria.

The two versions of the structural model are robust, quantitative methods of assessing general organization capability claims by consistency with doctrine. These methods of assessing capability have several advantages over other methods: first, they directly address the policy elements of force development and force structure by assessing capability in terms of the elements of organization that involve decisions about expenditure and authority. Second, they are hierarchical from inception – the effects of changes at any level of the hierarchy over the entire organization can be discretely represented and analyzed. Third, the general framework of the models is expandable to account for other criteria or aggregation schemes.

Section 3: Applications

1. Military Policy

The two structural models of organization capability are applicable to widely different policy problems.

The first, the individual-element level model of organization capability, is applicable for the kind of detailed doctrinal or analytic work done by the Centers of Excellence and branch-proponency offices, the, U.S. Army Training and Doctrine Command Analysis Center, the United States Army Force Management Support Activity, and possibly the Center for Army Analysis. It is relevant to the design of lower-echelon organizations and the articulation of tactical tasks. While it can be used to model larger organizations, it rapidly becomes extremely computationally expensive. Additionally, at higher echelons, the details of how the lower-echelon organizations conduct their operations become less relevant to the overall capability of the organization.

The second model, of aggregated capacity/capability, is much more flexible because of its more limited data requirements. Though it is theoretically applicable to a wide range of policy problems, adapting it for many of them still requires definitive data of organizations, tasks, and their composition. Provided either accurate or authoritative requirement data, the capacity model is both simple enough to be applied to numerous elements of policy and easy enough to implement that it can be done without significant development.

2. Organization Theory & Network Science

The technical insights of this research for organization theory and network science are not particularly groundbreaking. The basic PCANS and meta-network models have been around for over a decade, and the network algebra used to compute them has been available for much longer. The structural measurement of capability is merely a way of articulating a well-known integer programming problem using inputs from a network.

The basic contribution to network science and organization theory is the application of network science to authoritative information, and the articulation of the constraints of the capability measurement in the terms of the decisions made in the design of organizations. These contributions, while technically simple, are groundbreaking in that they extend the class of problems that network science can address.

3. Other fields

The model of organization capability developed here is applicable to the study of other organizations, provided there is sufficiently robust data to act as doctrine and provided there is some need to examine the capability of subordinate parts of the organizations or ad-hoc combinations of organizations.

This is particularly appropriate for organizations that must task-organize capabilities from available assets at short notice. A potential application is the analysis of regional or national disaster response capability, which must be task-organized, often across jurisdictions and organizational stovepipes, in order to provide a set of capabilities in a particular location. Depending on the aggregation scheme used and the data availability, this can be used to identify the supply of organizations available, assess their capability to meet requirements, and identify capability gaps.

Bibliography

Ahuja, Manju K., and Kathleen M. Carley. "Network Structure in Virtual Organizations." *Organization Science* (INFORMS) 10, no. 6 (1999): 741-757.

Albert, Réka, and Albert-László Barabási. "Statistical Mechanics of Complex Networks." *Reviews of Modern Physics* 74 (January 2002): 47-97.

Alberts, David, John Garstka, and Frederick Stein. *Network Centric Warfare: Developing and Leveraging Information Superiority.* Washington, District of Columbia: National Defense University Press, 1999.

Allison, Graham, and Philip Zelikow. *Essence of Decision: Explaining the Cuban Missile Crisis.* 2nd Edition. New York, New York: Longman, 1999.

Behrman, Robert. *Data Representation of Army Brigade Combat Teams for Network Science Analysis.* Pittsburgh, PA: Carnegie Mellon University, 2010.

Behrman, Robert, and Kathleen Carley. "Network Analysis of Organizational Planning and Decision Making Processes." *Proceedings of the 2009 NAACSOS Conference.* Tempe, AZ: NAACSOS, 2009. 10.

—. "Network Theory Analysis of SBCT Task Organization." *Network Science Symposium.* West Point, NY: United States Military Academy, 2008. 14.

Beyerchen, Alan. "Clausewitz, Nonilinearity, and the Unpredictability of War." *International Security*, Winter 1992: 59-90.

Biddle, Stephen. *Military Power: Explaining Victory and Defeat in Modern Battle.* Princeton, New Jersey: Princeton University Press, 2004.

Blau, Peter M., and W. Richard Scott. "The Concept of Formal Organization." In *Classics of Organization Theory*, by Jay M. Shafritz, & J. Steven Ott, 206-210. Stanford, Orlando: Harcourt, Inc., 1962/2001.

Bonin, John A., and Telford E. Crisco. "The Modular Army." *Military Review*, March-April 2004: 21-27.

Brown, Kevin. "Re-Architecting the DoD Acquisition Process: Transitioning to the Information Age." *Proceedings of the 2006 International Command and Control Research and Technology Symposium.* Vienna, VA: Evidence-Based Research, Inc., 2006.

Burton, James G. *The Pentagon Wars: Reformers Challenge the Old Guard.* Annapolis: Naval Institute Press, 1993.

Cares, Jeff. *Distributed Networked Operations: The Foundations of Network Centric Warfare.* Newport: Alidade Press, 2005.

Carley, Kathleen M. "Dynamic Network Analysis." *Summary of the National Research Council Workshop on Social Network Modeling and Analysis.* Washington, D.C.: National Research Council, 2003. 133-145.

Carley, Kathleen M. "Efficiency in a Garbage Can." In *Ambiguity and Command: Organizational Perspecitves on Military Decision Making*, by James G. March, & Roger Weissinger-Baylon, 195-231. New York: Pitman Publishing, Inc., 1987.

—. "Estimating Vulnerabilities in Large Covert Networks." *Proceedings of the 2004 International Symposium on Command and Control Research and Technology.* San Diego: Evidence-Based Research, Inc., 2004.

Carley, Kathleen M. "ORA: A Toolkit for Dynamic Network Analysis and Visualization." In *Encyclopedia of Social Network Analysis and Mining*, edited by Reda Alhajj, & Jon Ronke. Springer, 2014.

Carley, Kathleen M. "Organizational Learning and Personnel Turnover." *Organization Science* 3, no. 1 (1992): 20-46.

Carley, Kathleen M. "Smart Agents and Organizations of the Future." In *The Handbook of New Media*, by Leah Lievrouw, & Sonia Livingstone, 206-220. Thousand Oaks, California: Sage, 2002.

Carley, Kathleen M., and Craig Schreiber. "Information Technology and Knowledge Distribution in C3I Teams." *Proceedings of the 2002 Command and Control Research and Technology Symposium.* Monterey: Evidence Based Research, Inc., 2002.

Carley, Kathleen M., and David Krackhardt. "A Typology for C2 Measures." *Proceedings of the 1999 International Symposium on Command and Control Research and Technology.* Newport, RI: CCRP, 1999. 11.

Carley, Kathleen M., and Jürgen Pfeffer. "Dynamic Network Analysis (DNA) and ORA." In *Advances in Design for Cross-Cultural Activities Part I*, edited by D. D. Schmorrow, & D. M. Nicholson, 265-274. CRC Press, 2012.

Carley, Kathleen M., and Yuqing Ren. "Tradeoffs Between Performance and Adaptability for C3I Architectures." *Proceedings of the 2001 Command and Control Research and Technology Symposium.* Annapolis: Evidence Based Research, 2001. 10.

Carley, Kathleen M., Jeff Reminga, Jon Storrick, and Dave Columbus. *ORA User's Guide 2010.* School of Computer Science, Carnegie Mellon University, Pittsburgh, Pennsylvania: Institute for Software Research, 2010.

Carley, Kathleen M., Jeff Reminga, Jon Storrick, Jürgen Pfeffer, and Dave Columbus. *ORA User's Guide 2013.* Technical Report, Institute for Software Research, School of Computer Science, Pittsburgh: Carnegie Mellon University, 2013.

Carley, Kathleen M., Jeffrey Reminga, and Natasha Kamneva. "Destabilizing Terrorist Networks." *Proceedings of the 8th International Command and Control Research and Technology Symposium.* Washington, D.C.: Evidence Based Research, 2003.

Carley, Kathleen M., Johan Kjaer-Hansen, Allen Newell, and Michael Prietula. "Plural-SOAR: A Prolegomenon to Artificial Agents and Organizational Behavior." In *Artificial Intelligence in Organization and Managment Theory*, by Michael Masuch, & Massimo Warglien, 87-118. Amsterdam: North-Holland, 1992.

Carley, Kathleen M., Ju-Sung Lee, and David Krackhardt. "Destabilizing Networks." *Connections* 24, no. 3 (2002): 79-92.

Carley, Kathleen M., Michael J. Prietula, and Zhiang Lin. "Design Versus Cognition: The interaction of agent cognition and organizational design on organizational performance." *Journal of Artificial Societies and Social Simulation*, 1998.

Carley, Kathleen M., Yuqing Ren, and David Krackhardt. "Measuring and Modeling Change in C3I Archictectures." *Proceedings of the 2000 Command and Control Research and Technology Symposium.* Monterey: Evidence-Based Research, 2000. 11.

Carley, Kathleen, and David Krackhardt. "A Typology for C2 Measures." *Proceedings of the 1999 International Symposium on Command and Control Research and Technology.* Newport, RI: CCRP, 1999. 11.

Carley, Kathleen, Yuqing Ren, and David Krackhardt. "Measuring and Modeling Change in C3I Archictectures." *Proceedings of the 2000 Command and Control Research and Technology Symposium.* Monterey: Evidence-Based Research, 2000. 11.

Cebrowski, Arthur K., and John Garstka. "Network-Centric Warfare: Its Orgins and Future." *Proceedings of the 1998 International Command and Control Research and Technology Symposium.* Vienna: Evidence Based Research, Inc., 1998.

Chamberlain, K. Todd. *Applying Natural System Metaphors to the Force Modernization Process.* Paper, Institute of Land Warfare, Arlington: Association of the United States Army, 2012.

CJCS. *CJCSI 3100.01B - The Joint Strategic Planning System.* Chairman, Joint Chiefs of Staff Instruction, Washington, DC: Office of the Charman, Joint Chiefs of Staff, 2008, 68.

CJCS. *Joint Capabilities Integration and Development System Manual.* CJCS Instruction, Washington, DC: Office of the Chairman, Joint Chiefs of Staff, 2012.

CJCS. *Joint Capability Areas.* Record, Washington, DC: J7/Concepts to Capabilities Division, 2011.

CJCS. *Joint Operational Access Concept.* Joint Publication, Washington, DC: Chairman, Joint Chiefs of Staff, 2012.

CJCS. *JP 1-02: Department of Defense Dictionary of Military and Assoicated Terms.* Joint Publication, Directorate of Joint Force Development, Joint Doctrine and Education Divisions, Washington, D.C.: Joint Staff, 2013, 495.

—. *JP 1-02: Department of Defense Dictionary of Miltiary and Associated Terms.* Washington, District of Columbia: U.S. Department of Defense, 2010.

—. *JP 5-0: Joint Operation Planning.* Washington, District of Columbia: Chairman, Joint Chiefs of Staff, 2011.

CJCS. *Manual for the Operation of the Joint Capabilities Integration and Development System.* CJCS Instruction, Washington: Office of the Chairman, Joint Chiefs of Staff, 2011.

CJCS. *The National Military Strategy of the United States of America.* Strategy, Washington: Office of the Chairman, Joint Chiefs of Staff, 2010.

Clausewitz, Carl Von. *On War.* Edited by Michael Howard, & Peter Paret. Translated by Michael Howard, & Peter Paret. Princeton, New Jersey: Princeton University Press, 1832/1976.

Cohen, Michael D., James G. March, and Johan P. Olsen. "A Garbage Can Model of Organizational Choice." *Administrative Science Quarterly* 17, no. 1 (March 1972): 1-25.

Coram, Robert. *Boyd: The Fighter Pilot Who Changed the Art of War.* Boston: Little, Brown and Company, 2002.

Corbett, Julian S. "The Green Pamphlet." In *Some Principles of Maritime Strategy*, by Julian S. Corbett, 305-325. Annapolis: U.S. Naval Institute, 1909/1988.

CSI. *Sixty Years of Reorganizing for Combat: A Historical Trend Analysis.* CSI Report, Fort Leavenworth, KS: Combat Studies Institute, 1999.

Currie, James T., and Richard Crossland. *Twice the Citizen: A History of the United Sates Army Reserve, 1908-1995.* 2nd. Washington, District of Columbia: Office of the Chief, Army Reserve, 1997.

Cyert, Richard Michael, and James G. March. *A Behavioral Theory of the Firm.* 2nd. Hoboken, New Jersey: Wiley-Blackwell, 1963 (1992).

Davis, Paul K. *Analytic Architecture for Capabilties-Based Planning, Mission-System Analysis, and Transformation.* National Defense Research Institute, Santa Monica: RAND, 2002.

DeGroot, Morris H., and Mark J. Schervish. *Probability and Statistics.* 3rd Edition. Boston, Massachusetts: Addison Wesley, 2002.

Dekker, Anthony. "Applying Social Network Analysis Concepts to Military C4ISR Architectures." *Connection* 24, no. 3 (2002): 93-103.

DNI. *United States Intelligence Community Information Sharing Strategy.* Strategy, Washington: Office of the Director of National Intelligence, 2008.

Duncan, Michael. "The Third Macedonian War." *The History of Rome.* no. 26. Austin, Texas: Self Published, November 28, 2008.

Ellis, John. *The Social History of the Machine Gun.* Baltimore, Maryland: The Johns Hopkins University Press, 1986.

Feickert, Andrew. *U.S. Army's Modular Redesign: Issues for Congress.* Washington: Congressional Research Service, 2005.

Ferrill, Arthur. "The Grand Strategy of the Roman Empire." In *Grand Strategies in War and Peace*, edited by Paul Kennedy, 71-86. New Haven, Conneticuit: Yale University Press, 1991.

Fitzsimmons, Michael. "Whither Capabilities-Based Planning?" *Joint Forces Quarterly*, 1st Quarter 2007: 101-105.

GAO. *Defense Acquisitions: DoD's Requirements Determination Process Has Not Been Effective in Prioritizing Joint Capabilities.* Report to Committee on Armed Services, U.S. Senate, Washington, D.C.: Government Accountability Office, 2008, 39.

GAO. *Force Structure: Actions Needed to Improve Estimates and Oversight of Costs for Transforming Army to a Modular Force.* Washington: Government Accountability Office, 2005.

Gerdes, Luke M. *Codebook for Network Data on Individuals Involved with Terrorism and Counterterrorism.* Technical Report, Center for the Computational Analysis of Social and Organizational Systems, Institute for Software Research, Pittsburgh, PA: Carnegie Mellon University, 2008, 48.

Graham, John. "Dynamic Network Analysis of the Network-Centric Organization: Towards an understanding of cognition and performance." Pittsburgh, Pennsylvania: Carnegie Mellon University, 2005. 90.

Gray, Colin S. *Fighting Talk: Forty Maxims on War, Peace, and Strategy.* Washington, District of Columbia: Potomac Books, Inc., 2009.

—. *Modern Strategy.* Oxford: Oxford University Press, 1999.

Grossman, Dave. *On Killing: The Psychological Costs of Learning to Kill in War and Society.* Boston, Massachusetts: Back Bay Books, 2009.

Hammes, Thomas X. "Let Strategy Drive Procurement." *War on the Rocks.* July 29, 2013. http://warontherocks.com/2013/07/let-strategy-drive-procurement/ (accessed September 18, 2013).

—. "The Evolution of War: The Fourth Generation." *Marine Corps Gazette*, September 1994.

—. "Fourth Generation Warfare Evolves, Fifth Emerges." *Military Review*, May-June 2007: 14-23.

—. *The Sling and the Stone: On War in the 21st Century.* Minneapolis: Zenith Press, 2004.

Harrison, Todd. *Analysis of the FY 2013 Defense Budget and Sequestration.* Backgrounder, Washington, D.C.: Center for Strategic and Budgetary Assessments, 2012, 18.

Higginbottom, Michael S., and Richard Adkison. "Mission Command on the Move in a Networked Force." *Army*, July 2012: 32-35.

Hiromoto, Scott. *Fundamental Capability Portfolio Management.* PhD Thesis, Pardee RAND Graduate School, Santa Monica: RAND Corporation, 2013, 95.

Hoffman, F. G. *Decisive Force: The New American Way of War.* Santa Barbara, California: Praeger Publishers, 1996.

Hosmer, Stephen. *The Conflict over Kosovo: Why Milosevic Decided to Settle When He Did.* Santa Monica: RAND Corporation, 2001.

HQDA. *ADP 2-0: Intelligence.* Washington, District of Columbia: Headquarters, Department of the Army, 2012.

—. *ADP 5-0: The Operations Process.* Washington, District of Columbia: Headquarters, Department of the Army, 2012.

—. *ADP 6-0: Mission Command.* Washington, District of Columbia: Headquarters, Department of the Army, 2012.

—. *ADRP 2-0: Intelligence.* Washington, District of Columbia: Headquarters, Department of the Army, 2012.

—. *ADRP 3-0: Unified Land Operations.* Washington, District of Columbia: Headquarters, Department of the Army, 2012.

—. *ADRP 3-90: Offense and Defense.* Washington, District of Columbia: Headquarters, Department of the Army, 2012.

—. *ADRP 5-0: The Operations Process.* Washington, District of Columbia: Headquarters, Department of the Army, 2012.

—. *AR 220-1: Unit Status Reporting.* Washington, District of Columbia: Headquarters, Department of the Army, 2010.

—. *AR 525-29: Army Force Generation.* Washington, District of Columbia: Headquarters, Department of the Army, 2011.

—. *AR 71-11: Total Army Analysis.* Washington, District of Columbia: Headquarters, Department of the Army, 1995.

—. *AR 71-32: Force Development and Documentation - Consolidated Policies.* Washington, District of Columbia: Headquarters, Department of the Army, 1997.

—. *FM 1-0: The Army.* Washington, District of Columbia: Headquarters, Department of the Army, 2005.

—. *FM 100-5: Operations.* Washington, District of Columbia: Headquarters, Department of the Army, 1982.

HQDA. *FM 1-01: Generating Force Support to Operations.* Washington, District of Columbia: Headquarters, Department of the Army, 2008, 104.

—. *FM 1-02: Operational Terms and Graphics.* Washington, District of Columbia: Headquarters, Department of the Army, 2010.

—. *FM 2-01.3: Intelligence Preparation of the Battlefield.* Washington, District of Columbia: Headquarters, Department of the Army, 2009.

—. *FM 2-91.6: Soldier Surveillance and Reconnaissance: Fundamentals of Tactical Information Collection.* Washington, District of Columbia: Headquarters, Department of the Army, 2007.

—. *FM 3-0: Operations.* Washington, District of Columbia: Headquarters, Department of the Army, 2008.

—. *FM 3-09.12 - Tactics, Techniques, and Procedures for Field Artillery Target Acquisition.* Washington, District of Columbia: Headquarters, Department of the Army, 2002.

—. *FM 3-20.15: Tank Platoon.* Washington, District of Columbia: Headquarters, Department of the Army, 2007.

—. *FM 3-20.151: The Mobile Gun System Platoon.* Washingtion, District of Columbia: Headquarters, Department of the Army, 2005.

—. *FM 3-20.971: Reconnaissance and Cavalry Troop.* Washington, District of Columbia: Headquarters, Department of the Army, 2009.

—. *FM 3-20.98: Reconnaissance and Scout Platoon.* Washington, District of Columbia: Headquarters, Department of the Army, 2009.

—. *FM 3-21.10: The Infantry Rifle Company.* Washington, District of Columbia: Headquarters, Department of the Army, 2006.

—. *FM 3-21.11: The SBCT Infantry Rifle Company.* Washington, District of Columbia: Headquarters, Department of the Army, 2003.

—. *FM 3-21.12: The Infantry Weapons Company.* Washington, District of Columbia: Headquarters, Department of the Army, 2008.

—. *FM 3-21.20: The Infantry Battalion.* Washington, District of Columbia: Headquarters, Department of the Army, 2006.

—. *FM 3-21.21: The Stryker Brigade Combat Team Infantry Battalion.* Washington, District of Columbia: Headquarters, Department of the Army, 2003.

—. *FM 3-21.71: The Mechanized Infantry Platoon and Squad.* Washington, District of Columbia: Headquarters, Department of the Army, 2002.

—. *FM 3-21.8: The Infantry Rifle Platoon and Squad.* Washington, District of Columbia: Headquarters, Department of the Army, 2007.

—. *FM 3-21.8: The Infantry Rifle Platoon and Squad.* Washington, District of Columbia: Headquarters, Department of the Army, 2007.

—. *FM 3-21.9: The SBCT Infantry Rifle Platoon and Squad.* Washington, DC, District of Columbia: Headquarters, Department of the Army, 2002.

—. *FM 3-21.91: The Anti-Armor Platoon.* Washington, District of Columbia: Headquarters, Department of the Army, 2002.

—. *FM 3-21.94: The Stryker Brigade Combat Team Infantry Battalion Reconnaissance Platoon.* Washington, District of Columbia: Headquarters, Department of the Army, 2003.

—. *FM 3-24: Counterinsurgency.* Washington, District of Columbia: Headquarters, Department of the Army, 2006.

—. *FM 3-39: Military Police Operations.* Washington, District of Columbia: Headquarters, Department of the Army, 2013.

—. *FM 3-60.1: Multi-Service Tactics, Techniques, and Procedures for Targeting Time-Sensitive Targets.* Washington, Washington: Air, Land, Sea Application Center, 2004.

—. *FM 3-90.5: The Combined Arms Battalion.* Washington, District of Columbia: Headquarters, Department of the Army, 2008.

—. *FM 3-90.6: The Brigade Combat Team.* Washington, District of Columbia: Headquarters, Department of the Army, 2010.

—. *FM 3-90: Tactics.* Washington, District of Columbia: Headquarters, Department of the Army, 2001.

—. *FM 5-0: The Operations Process.* Washington, District of Columbia: Headquarters, Department of the Army, 2010.

—. *FM 6-0: Mission Command: Command and Control of Army Forces.* Washington, District of Columbia: Headquarters, Department of the Army, 2003.

—. *FM 6-01.1: Knowledge Management Operations.* Washington, District of Columbia: Headquarters, Department of the Army, 2012.

—. *FM 6-20-10: Tactics, Techniques, and Procedures for the Targeting Process.* Washington, District of Columbia: Headquarters, Department of the Army, 1996.

—. *FM 6-50: Tactics, Techniques and Procedures for the Field Artillery Cannon Battery.* Washington, District of Columbia: Headquarters, Department of the Army, 1996.

—. *FM 7-15: The Army Universal Task List.* Washington, DC, District of Columbia: Headquarters, Department of the Army, 2009.

Hume, David. *Essays, Moral, Political, and Literary.* Edited by Eugene F. Miller. Indianapolis, Indiana: Liberty Fund, Inc., 1742/1987.

Hunker, Jeffrey. *Cyber War and Cyber Power: Issues for NATO Doctrine.* Research Paper, Rome: NATO Defense College, 2010.

Jaques, Elliot. "In Praise of Hierarchy." *Harvard Business Review*, 1990.

JFCOM. *The 2010 Joint Operating Environment.* Strategic Environmental Assessment, Suffolk: United States Joint Forces Command, 2010.

Johnson, Douglas V. *Doctrine that Works.* Opinion, Strategic Studies Institute, Carlisle: United States Army War College, 2006.

Joint Staff. *Future Joint Warfare.* 2007. http://www.dtic.mil/futurejointwarfare/ (accessed May 20, 2013).

Jones, Raymond. "Capabilities-centric Acquisition: A System of Systems View of Acquisition Management." *Proceedings of the Fourth Annual Acquistions Research Symposium.* Monterey: Naval Postgraduate School, 2007. 464-472.

Kagan, Donald. "Athenian Strategy in the Peloponnesian War." Chap. 2 in *The Making of Strategy: Rulers, States, and War*, edited by Williamson Murray, Macgregor Knox, & Alvin Bernstein, 24-55. Cambridge: Cambridge University Press, 1994.

Kalloniatis, A.C., I.D.G. Macleod, and P. La. "Process versus Battle-Rhythm: Modelling Operational Command and Control." *18th IMACS World Conference MODSIM09 Proceedings.* Cairns, Australia: IMACS, 2009. 1622-1628.

Keaney, Thomas A., and Eliot A. Cohen. *Revolution in Warfare? Air Power in the Persian Gulf.* Annapolis, Maryland: Naval Institute Press, 1995.

Keeney, Ralph L. "Decision Analysis: An Overview." *Operations Research* (INFORMS) 30, no. 5 (September-October 1982): 803-838.

Kilcullen, David. *The Accidental Guerilla: Fighting Small Wars in the Midst of a Big One.* Oxford: Oxford University Press, 2009i.

Kilduff, Patricia W., Jennifer C. Swoboda, and B. Diane Barnette. *Command, Control, and Communications: Techniques for the Reliable Assessment of Concept Execution (C3TRACE) Modeling Environment: The Tool.* Aberdeen Proving Ground, MD: Army Research Laboratory, 2005.

Klein, Gary. *Sources of Power: How People Make Decisions.* Cambridge, Massachusetts: MIT Press, 1999.

Krackhardt, David. "Graph Theoretical Dimensions of Informal Organizations." In *Computational Organizational Theory*, by Kathleen Carley, & Michael Prietula, 89-111. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1994.

Krackhardt, David. "Predicting With Networks: Nonparametric Multiple Regression Analysis of Dyadic Data." *Social Networks* (Elsevier Science Publishers) 10 (1988): 359-381.

Krackhardt, David, and Kathleen Carley. "A PCANS Model of Structure in Organizations." *Proceedings of the 1998 International Symposium on Command and Control Research and Technology.* Monterrey, CA: Evidence Based Research, Vienna, VA, 1998. 113-119.

Krackhardt, David, and Kathleen M. Carley. "A PCANS Model of Structure in Organizations." *Proceedings of the 1998 International Symposium on Command and Control Research and Technology.* Monterrey, CA: Evidence Based Research, Vienna, VA, 1998. 113-119.

Krulak, Charles C. "The Strategic Corporal: Leadership in the Three Block War." *Marines Magazine*, January 1999.

Lamb, Christopher J., Matthew J. Schmidt, and Berit G. Fitzsimmons. *MRAPs, Irregular Warfare, and Pentagon Reform.* Washington, District of Columbia: National Defense University, 2009.

LaPorte, Todd, and Paula Consolini. "Working in Practice But Not in Theory: Theoretical Challenges of "High-Reliability Organizations"." *Journal of Public Administration Research and Theory*, 1991: 19-47.

Law, Averill M., and W. David Kelton. *Simulation Modeling and Analysis.* 3rd Edition. Boston, Massachusetts: McGraw-Hill, 2000.

Lawrence, Thomas B. "Institutional Strategy." *Journal of Management* 25, no. 2 (1999): 161-188.

Levchuk, Georgiy M., Yuri Levchuk, Shawn A. Weil, and Krishna R. Pattipati. "PERSUADE: Modeling Framework for the Design of Modular Army Organizaitons." *Proceedings of the 2006 Command and Control Research and Technology Symposium.* San Diego, CA: Evidence Based Research, 2006. 24.

Levchuk, Georgiy M., Yuri N. Levchuk, Jie Luo, Krishna R. Pattipati, and David L. Kleinman. "Normative Design of Organizations - Part I: Mission Planning." *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans* 32, no. 3 (May 2002): 346-359.

Levchuk, Georgiy M., Yuri N. Levchuk, Jie Luo, Krishna R. Pattipati, and David L. Kleinman. "Normative Design of Organizations - Part II: Organizational Structure." *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans* 32, no. 3 (May 2002): 360-375.

Levinthal, Daniel, and James G. March. "A Model of Adaptive Organizational Search." *Journal of Economic Behavior and Organization* (North-Holland Publishing Company), no. 2 (1981): 307-333.

Lieven, Anatol. *Chechnya: Tombstone of Russian Power.* New Haven: Yale University Press, 1998.

Lin, Zhiang, and Kathleen M. Carley. *Designing Stress Resistant Organizations: Computational Theorizing and Crisis Applications.* Boston: Kluwer Academic Publishers, 2003.

Lind, William S, Keith Nightengale, John F Schmitt, Joseph W Sutton, and Gary I Wilson. "The Changing Face of War: Into the Fourth Generation." *Marine Corps Gazette*, October 1989: 22-26.

Luttwak, Edward N. *The Grand Strategy of the Roman Empire.* Baltimore, Maryland: The Johns Hopkins University Press, 1979.

The Fog of War. DVD. Directed by Errol Morris. Produced by Errol Morris, Michael Williams, & Julie Ahlberg. Performed by Robert S. MacNamara. Sony Pictures Classics, 2004.

Maltby, William S. "The Origins of a Global Strategy: England from 1558 to 1713." In *The Making of Strategy: Rulers, States, and War*, edited by Williamson Murray, Macgregor Knox, & Alvin Bernstein, 151-177. Cambridge: Cambridge University Press, 1994.

Matheny, Michael R. *Carrying War to the Enemy: American Operational Art to 1945.* Norman, Oklahoma: University of Oklahoma Press, 2011.

McChrystal, Stanley. "It Takes a Network." *Foreign Policy*, March/April 2011.

McCulloh, Ian. *Detecting Changes in a Dynamic Social Network.* Pittsburgh: Carnegie Mellon University, 2009.

McCulloh, Ian, and Kathleen Carley. *Detecting Change in Human Social Behavior Simulation.* Technical Report, School of Computer Science, Carnegie Mellon University, Pittsburgh: Institute for Software Research, 2008.

McCulloh, Ian, et al. *IkeNet: Social Network Analysis of E-Mail Traffic in the Eisenhower Leadership Development Program.* Arlington: U.S. Army Research Institute, 2007.

McCulloh, Ian, Helen Armstrong, and Anthony Johnson. *Social Network Analysis with Applications.* Hoboken, New Jersey: Wiley, 2013.

McCulloh, Ian, Joshua Lospinoso, and Kathleen M. Carley. *The Link Probability Model: A Network Simulation Alternative to the Exponential Random Graph Model.* Technical Report, Institute for Software Research, School of Computer Science, Pittsburgh: Carnegie Mellon University, 2010.

McCulloh, Ian, M. Webb, John Graham, Kathleen Carley, and D.B. Horn. *Change Detection in Social Networks.* Technical Report, Arlington, VA: U.S. Army Research Institute for the Behavioral and Social Sciences, 2008.

Meilinger, Phillip S. "Giulio Douhet and the Orgins of Airpower Theory." In *The Paths of Heaven: The Evolution of Airpower Theory*, by Philip S. Meilinger, 1-40. Maxwell Air Force Base: Air University Press, 1997.

Mishan, Edward J. *Elements of Cost-Benefit Analysis.* London: George Allen & Unwin LTD, 1978.

Mitchell, Diane Kuhl. *Mental Workload and ARL Workload Modeling Tools.* Aberdeen Proving Ground, MD: Army Research Laboratories, 2000.

Moon, Il-Chul. *Destabilization of Adversarial Organizations with Strategic Interventions.* PhD Thesis, Institute for Software Research, School of Computer Science, Pittsburgh: Carnegie Mellon University, 2008.

Moon, Il-Chul, Kathleen M. Carley, and Alexander H. Levis. "Vulnerability Assessment on Adversarial Organization: Unifying Command and Control Structure Analysis and Social Network Analysis." *SIAM International Conference on Data Mining.* Atlanta, 2008.

Morgan, M. Granger, Max Henrion, and Mitchell Small. *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis.* Cambridge: Cambridge University Press, 1992.

Musashi, Miyamoto. *A Book of Five Rings.* Translated by Stephen F. Kaufman. Boston, Massachusetts: Tuttle Publishing, 1645/1994.

National Research Council. *Behavioral Modeling and Simulation: From Individuals to Societies.* Edited by Greg L. Zacharias, Jean MacMillan, & Susan B. Van Hemel. Washington, District of Columbia: National Academies Press, 2008.

National Research Council. *Defense Modeling, Simulation, and Analysis.* Washington: National Academies Press, 2006.

National Research Council. *Naval Analytical Capabilities: Improving Capabilities Based Planning.* Washington: National Academies Press, 2005.

Naval Postgraduate School. *Aggregated Combat Models.* Monterey, California: Naval Postgraduate School, 2000.

O'Reilly, Victor. *Stryker Brigades Versus the Reality of War.* White Paper, Washington: Congressman Jim Saxton, 2003, 108.

OSD. *Defense Budget Priorities and Choices.* Strategic Guidance, Washington, DC: Office of the Secretary of Defense, 2012, 16.

OSD. *Quadrennial Defense Review Report.* Washington: Office of the Secretary of Defense, 2010.

OSD. *Quadrennial Defense Review Report.* Washington: Office of the Secretary of Defense, 2006.

OSD. *Quadrennial Defense Review Report.* Strategic Guidance, Washington, District of Columbia: Office of the Secretary of Defense, 2001, 79.

OSD, The White House. *Sustaining U.S. Global Leadership: Priorities for 21st Century Defense.* Strategic Guidance, Washington, DC: Office of the Secretary of Defense, 2012, 16.

Padgett, John F. "Managing Garbage Can Hierarchies." *Administrative Science Quarterly* 25, no. 4 (1980): 583-604.

Padgett, John F. "Organizational Genesis, Identity, and Control: The Transformation of Banking in Renaissance Florence." In *Networks and Markets*, edited by James E. Rauch, & Alessandra Casella, 211-257. New York, New York: Russel Sage Foundation, 2001.

Papageorgiou, Constantine, and Kathleen Carley. *A Cognitive Model of Decision Making: Chunking and the Radar Detection Task.* Pittsburgh: Carnegie Mellon University, 1993.

Pape, Robert A. *Bombing to Win: Air Power and Coercion in War.* Ithaca: Cornell University Press, 1996.

Posen, Barry R. *The Sources of Military Doctrine: France, Britain, and Germany Between the World Wars.* Ithaca, New York: Cornell University Press, 1984.

Priest, Dana. *The Mission: Waging War and Keeping Peace with America's Military.* New York, New York: W.W. Norton and Company, 2003.

Reminga, Jeffrey, and Kathleen Carley. *Measures in ORA.* Technical Report, School of Comupter Science, Carnegie Mellon University, Pittsburgh: Institute for Software Research International, 2003.

Schelling, Thomas. *Arms and Influence.* Santa Barbara, California: Praeger, 1966.

—. *Micromotives and Macrobehavior.* Revised. New York, New York: W.W. Norton and Company, 2006.

—. *The Strategy of Conflict.* Cambridge, Massachusetts: Harvard Univesity Press, 1960.

Schreiber, Craig. *Human and Organizational Risk Modeling: Critical Personnel and Leadership in Network Organizations.* PhD Thesis, Institute for Software Research, School of Computer Science, Pittsburgh: Carnegie Mellon University, 2006.

Singer, P.W. *Wired For War: The Robotics Revolution and Confilct in the Twenty-first Century.* New York: Penguin Books, 2009.

Smith, Edward A. *Effects-Based Operations: Applying Network Centric Warfare in Peace, Crisis, and War.* Washington, District of Columbia: Department of Defense Command and Control Research Program, 2002.

Sullivan, Patricia L. *Who Wins? Predicting Strategic Success and Failure in Armed Conflict.* New York, New York: Oxford University Press, 2012.

Taylor, Michael, and Stephen Krivitsky. "Death Before Dismount: Transforming an Armor Company." *Armor Magazine*, March-April 2005: 26-34.

Tellis, Ashley J., Janice Bially, Christopher Layne, and Melissa McPherson. *Measuring National Power in the Postindustrial Age.* Monograph, Santa Monica, California: RAND, 2000.

The White House. *The National Security Strategy of the United States.* Strategic Guidance, Washington: Barack Obama, 2010.

Thornton, Rod. *Asymmetric Warfare: Threat and Response in the 21st Century.* Cambridge: Polity Press, 2007.

Tsvetovat, Maksim, and Kathleen Carley. "Structural Knowledge and Success of Anti-Terrorist Activity: The Downside of Structural Equivalence." *Journal of Social Structure*, 2006: 28.

Tzu, Sun. *The Art of War.* Translated by Samuel B. Griffith. Oxford: Oxford University Press, ca. 512 BC/1971.

U.S. Army. "Unified Quest 2013: Deep Future Wargame." *Stand-To!: The Official Focus of the U.S. Army.* September 10, 2013. http://www.army.mil/standto/archive_2013-09-10/ (accessed January 18, 2014).

U.S. DoD. *Chariman of the Joint Chiefs of Staff Manual 3170.01B, Operation of the Joint Capabilities Integration and Development System.* Washington, DC: U.S. Department of Defense, 2011.

U.S. DoD. *Department of Defense Strategy for Operating in Cyberspace.* Government Publication, Washington, D.C.: U.S. Department of Defense, 2011.

USAWC. *How the Army Runs: A Senior Leader Reference Handbook.* 28th. Edited by Harold Lord. Carlisle, Pennsylvania: United States Army War College, 2013.

—. *How the Army Runs: A Senior Leader Reference Handbook.* 27th. Edited by Harold Lord. Carlisle, Pennsylvania: United States Army War College, 2010.

van Hoeve, Willem-Jan. *Operations Research Techniques in Constraint Programming.* PhD Thesis, Institute for Logic, Language and Computation, Amsterdam: Universiteit van Amsterdam, 2005.

Vego, Milan. *Introduciton to Naval Warfare.* Primer, Newport: United States Naval War College, 2011.

Warden, John A. III. *The Air Campaign.* Washington, D.C.: Pergamon-Brassey's, 1989.

Warden, John A. III. "The Enemy as a System." *Airpower Journal* 9, no. 1 (1995): 40-55.

Wasserman, Stanley, and Katherine Faust. *Social Network Analysis: Methods and Applications.* Cambridge: Cambridge University Press, 1994.

Webb, James H. "Flexibility and the Fire Team." *Marine Corps Gazette*, April 1972: 25-28.

Weber, Max. "Bureaucracy." In *Max Weber: Essays in Sociology*, by H.H. Gerth, & C. Wright Mills. Oxford: Oxford University Press, 1922.

Wei, Wei, Jürgen Pfeffer, Jeffrey Reminga, and Kathleen M. Carley. *Handling Weighted, Asymmetric, Self-Looped, and Disconnected Networks in ORA.* Technical Report, Institute for Software Research, School of Computer Science, Pittsburgh: Carnegie Mellon University, 2011.

Winston, Wayne L., and Munirpallam Venkataramanan. *Introduction to Mathematical Programming.* 4th. Pacific Grove, California: Brooks/Cole, 2003.

Woodward, Bob. *Obama's Wars.* New York, New York: Simon & Schuster, 2010.

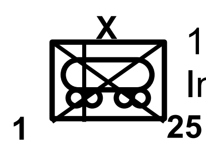
Appendix A – Quick Reference for Military Symbols

ECHELONS
(Largest to smallest)

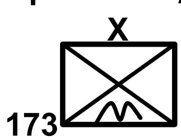
X	Brigade. Three to five battalions. ≈4000 Soldiers
ǀǀ	Battalion. Three to five companies. ≈650 Soldiers
ǀ	Company. Three to five platoons. ≈150 Soldiers
●●●	Platoon. Three to five squads. ≈15-50 Soldiers
●●	Section. Two squads. ≈10-20 Soldiers
●	Squad. Two teams. ≈10 Soldiers
Ø	Team. 3-5 Soldiers.

Note that the number of soldiers is an approximation, and changes with the type of unit. The technical definition is based on the number of smaller units.

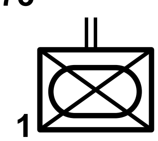
EXAMPLES



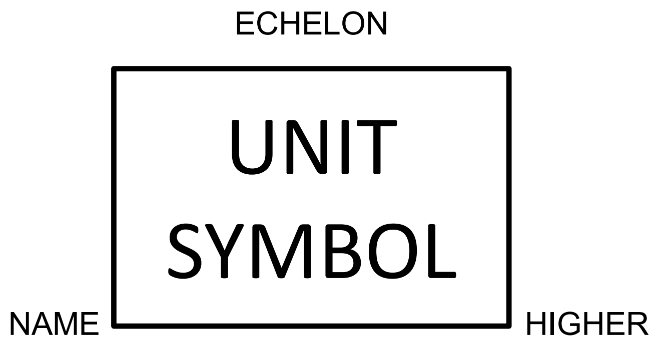
1st BCT, 25th Infantry Division



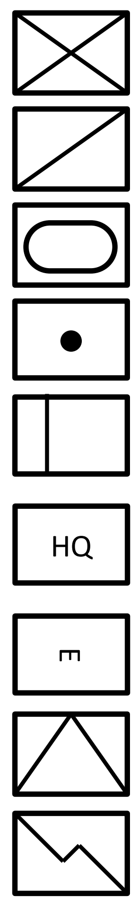
173rd IBCT



1-64 Combined Arms Battalion



ELEMENTS



INFANTRY
SCOUT
TANK
ARTILLERY
LIGHT GUN
HEADQUARTERS (AKA HHC)
ENGINEER
ANTITANK
SIGNAL

Appendix B – Represented Organizations and Data Sources

All data used in this dissertation is derived from official U.S. government publications. As such, these data are the property of the United States Government.

We represented the following organizations in data:

Organization	Primary Reference	BCT Type	WFF/Branch
Stryker Infantry Rifle Platoon	FM 3-21.8 (HQDA 2007)	SBCT	Maneuver/Infantry
Stryker MGS Platoon	*FM 3-20.151* (HQDA 2005)	SBCT	Maneuver/Armor
Tank Platoon	*FM 3-20.15* (HQDA 2007)	HBCT	Maneuver/Armor
Mechanized Infantry Platoon	FM 3-21.7 (HQDA 2002)	HBCT	Maneuver/Infantry
Heavy Recon Platoon	*FM 3-20.971* (HQDA 2009)	HBCT	ISR/Armor
Light Infantry Platoon	FM 3-21.8 (HQDA 2007)	IBCT	Maneuver/Infantry
Infantry Assault Platoon	FM 3-21.12 (HQDA 2008)	IBCT	Maneuver/Infantry

Of these we include DynetML files for the data for 4 of these units that come from Field Manuals that are approved for public release with unlimited distribution.

HBCT Mech Inf PLT.xml contains DynetML data for the Mechanized Infantry Platoon.
IBCT Rifle PLT.xml contains DynetML data for the Light Infantry Platoon.
IBCT Wpns PLT.xml contains DynetML data for the Infantry Assault Platoon.
SBCT Rifle PLT.xml contains DynetML data for the Stryker Infantry Rifle Platoon.