COMPARING ORGANIZATIONAL STRUCTURES VIA ALTERNATIVE COOPERATIVE GAME THEORETIC FRAMEWORKS

THESIS

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Abstract

Due to dynamically changing fiscal and operational environments, the Air Force is seeking a deeper understanding of organizational structure and its impact on organizational effectiveness; however, the issue of identifying an effective organizational structure is a concept constantly revisited by organizations in public, private, and governmental sectors alike. Current methodologies for measuring organizational effectiveness, and thereby evaluating organizational structure, tend towards a point in time perspective from an organization's top management. In this research, we propose analyzing organizational structure from a subordinate organization's or representative agent's perspective using coalitional game theory, with particular emphasis on the methodologies of traditional coalitional game theory, Myerson graph theory, and hedonic coalition formation. Upon surveying the literature to assess whether methods exist to classify and analyze contributing elements of organizational effectiveness, we identify three viable alternative methodologies for quantifiably evaluating alternative organizational structures. Considering a representative scenario, we extend the published work by applying and comparing these methodologies. The results of the analysis indicate that, in traditional usage, all three coalitional game theory methodologies perform similarly. However, in cases with situational factors, such as dysfunctional linkages between agents, multi-dimensional levels of preferences, or limitations in the solicitation of effectiveness values or preferences, unique differences emerge between methodologies. We conclude by providing a comparative analysis and discussion with

recommendations to help decision-makers and analysts determine the best strategy for evaluating organizational structure from the agent-based view, followed by an examination of the value of respective methodologies when primary assumptions about agent-to-agent relationships do not hold.

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Niki York

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ANALYZING ORGANIZATIONAL STRUCTURE VIA ALTERNATIVE COOPERATIVE GAME THEORETIC FRAMEWORKS

I. Introduction

1.1 Background and Motivation

During his first month as Air Force Chief of Staff (CSAF) in August 2016, General David Goldfein released a letter to all United States (US) Airmen stressing the essentiality of squadron teams to the success of the Air Force (AF) mission (Goldfein, 2016). He designated the objective of "revitalizing squadrons" as the primary focus for his first year as CSAF, tasking a core project team to interview squadrons and identify areas where improvements can be made to better support the Airmen. Some of the key tasks of the Revitalizing AF Squadrons team are to determine "if squadrons are properly organized and resourced for their missions in the 21st century," "if squadrons are properly sized and have the most effective total force and military/civilian mix to accomplish their missions," and "if decision authorities are at the right level for squadron success" (Vidal, 2017). The nature of these specific tasks and the focus on understanding the layers of bureaucracy impeding the AF mission have motivated an examination of AF organizational structure. In a recent May 2017 keynote speech at the Air Force Operations Research Symposium (AFORS), the Vice Chief of Staff of the Air Force (VCSAF) addressed the need for an expansion of this effort beyond squadrons, encouraging all to take ownership and think about how AF organizations can adapt to better face the capabilities and threats of the future (Wilson, 2017). To this end, we focus on the organizational structure of Air Force Material Command (AFMC) by leveraging agent-based prescriptive models to evaluate the effectiveness of past and present AFMC organizational structures.

1.2 AFMC History

The organizational structure of AFMC has evolved through several different variants, including both realignment at the Headquarters (HQ) AFMC level as well as significant reorganizations at the subordinate AFMC "Center" level. AFMC is the product of a merge in 1992 of the Air Force Logistics Command and Air Force Systems Command. The original AFMC structure consisted of 19 centers performing four core mission areas: technology, testing, acquisition, and sustainment. At the time of AFMC's inception, there was virtually no attempt to consolidate or realign centers; rather, the reassignment focused on bringing all the existing centers, with their internal organizational structures, under the control of the newly-formed AFMC (Haulman, 2011). At the time, the "System Program Office" (SPO), an organizational structure which dated to the 1950's, was the dominant organizational arrangement below-the-center-level for acquisition. Air Logistics Centers were the primary structure for the sustainment mission (Office of the Command Historian HQ Air Force Materiel Command, 2005).

Over the next few years, many centers within AFMC were either inactivated or realigned according to mission function, ultimately reducing the number of direct reporting centers from 19 to 12. However, even with an amalgamated configuration, the AFMC organizational structure vastly differed from other AF Major Commands (MAJCOMs). Most of AFMC was organized primarily in "non-unit" directorate-division-branch structures, while the rest of the AF was organized in a more traditional "unit" wing-group-squadron format. General Gregory Martin, AFMC Commander from 2003-2005, perceived this difference as a detriment to outside MAJCOMs' ability to understand the functions of AFMC and began converting almost all of AFMC to the traditional wing-group-squadron format (Office of the Command Historian HQ Air Force Materiel Command, 2005). Due to the unique, business-like structure of AFMC, the conversion was a complex process, and AFMC leadership considered multiple proposals regarding how to most effectively execute the wing-group-squadron structure for AFMC. The detailed discussions involved the activation/inactivation of various groups and squadrons and the reformation of hierarchical center command chains to support civilian leadership. After much debate, final proposals were captured in Organization Change Request (OCR) packages and approved by Headquarters Air Force (HAF), but many concerns on structural templates and responsibility distribution continued to persist even into the implementation phase (Office of the Command Historian HQ Air Force Materiel Command, 2005).

At the same time as the wing-group-squadron conversion, HQ AFMC (as well as every other AF MAJCOM) was directed to reorganize to better focus on the areas of capability planning, acquisition logistics, and fielding (Mikulcik, 2006). The reorganization involved adopting the common nomenclature of joint forces, wherein a letter describing a functional staff directorate responsibility was preceded by a "J". Most of the responsibilities of HQ AFMC were reformed into new "A"-staff directorates, with the exception of Engineering (EN), Contracting (PK), and various staff offices. The original A-staff structure designations, as approved in 2005, are shown in Table 1 below (Ely, 2005).

Table 1. AFMC A-Staff Structure in 2005

A-Staff	Directorate Responsibility (Prior two-letter designation)
A1	Personnel (DP)
A2	Intelligence (XRI; reports to A9)
A3	Operations (DO)
A4	Logistics & Sustainment (LG)
A5	Plans & Programs (XP)
A6	Communications & Information
A7	Installations & Mission Support
A8	Financial Management
A9	Capabilities Integration & Transformation

In 2010, shortly after completing the implementation of wing-group-squadron structures, AFMC reverted back to a business-like, non-unit structure. This reversion was conducted in response to changes in AF Instruction 38-101, which prescribed minimum manning thresholds for various unit structures (i.e., at least 1000 people within each wing, 400 within each group, and 35 within each squadron-sized unit) (Department of the Air Force, 2017). Upon enforcing these manpower-to-unit requirements, the resulting AFMC organization did not align well with the AFMC functions and, after many unsuccessful attempts to remain in the wing-group-squadron format through force size waivers, AFMC leadership petitioned HQ AF to allow AFMC return to a non-unit structure. Organizations below the center-level predominantly restructured around mission function, but the quick transformation resulted in a mix of unit "wings" or "groups" and non-unit "wing-like" and "group-like" organizations (Office of the Command Historian HQ Air Force Materiel Command, 2010). Similarly, the A-Staff in

HQ AFMC reorganized in 2008 with consolidations to create merged Directorates of A2/5, A6/7, and A8/9, as well as the establishment of a new Directorate for Strategic Deterrence and Nuclear Integration (A10) (Office of the Command Historian HQ Air Force Materiel Command, 2010; AFMC/DS Workflow, 2017).

AFMC did not experience another major organizational restructure until 2012, when the Budget Control Act of 2011 required the US Department of Defense (DoD) to reduce future spending over the next decade by approximately $487 billion dollars. To achieve this reduction in spending, the Office of the Secretary of Defense (OSD) issued a mandate requiring all military services to shrink the size of their workforce to Fiscal Year (FY) 2010 civilian staffing levels. The AF distributed the overall reduction in manpower among its MAJCOMs according to mission risk, and AFMC was tasked to cut approximately 20% of its civilian operations and maintenance (O&M) authorizations. As a means to achieve this target reduction, AFMC proposed the 5-Center construct – a complete reorganization to combine the functions of the twelve centers into only five centers aligned with AFMC's core mission areas (RAND Project Air Force, 2012). Although this reorganization was a comprehensive undertaking that will not be detailed for the purpose of this research, the key takeaway of the 5-Center construct is the decision to align the new centers according to core mission function. Each center was developed with a unique structure below the center-level that encompassed features of both units and non-units.

Since the adoption of the 5-Center construct, two more recent AFMC reorganizations are worth noting. First is the creation of a sixth center, the Air Force

Installation and Mission Support Center (AFIMSC), which reports directly to AFMC but exists to deliver installation support capabilities to all of the AF (Briggs, 2015). The creation of AFIMSC consolidated installation and mission support (I&MS) functions throughout the AF, including most of the functions of the AFMC/A7 Directorate. This leads to the second notable reorganization since the 5-Center construct adoption. HQ AFMC adjusted the A-staff directorates by splitting A2/5 into a separate A2 and A5 sections, joining A5 with A8/9 to form A5/8/9, merging A3 and A6, and consolidating the remaining A7 functions under A4 (AFMC/DS Workflow, 2017).

Figure 1 shows AFMC structure as it exists today, at both the headquarters- and center-levels (Herbert, 2016).

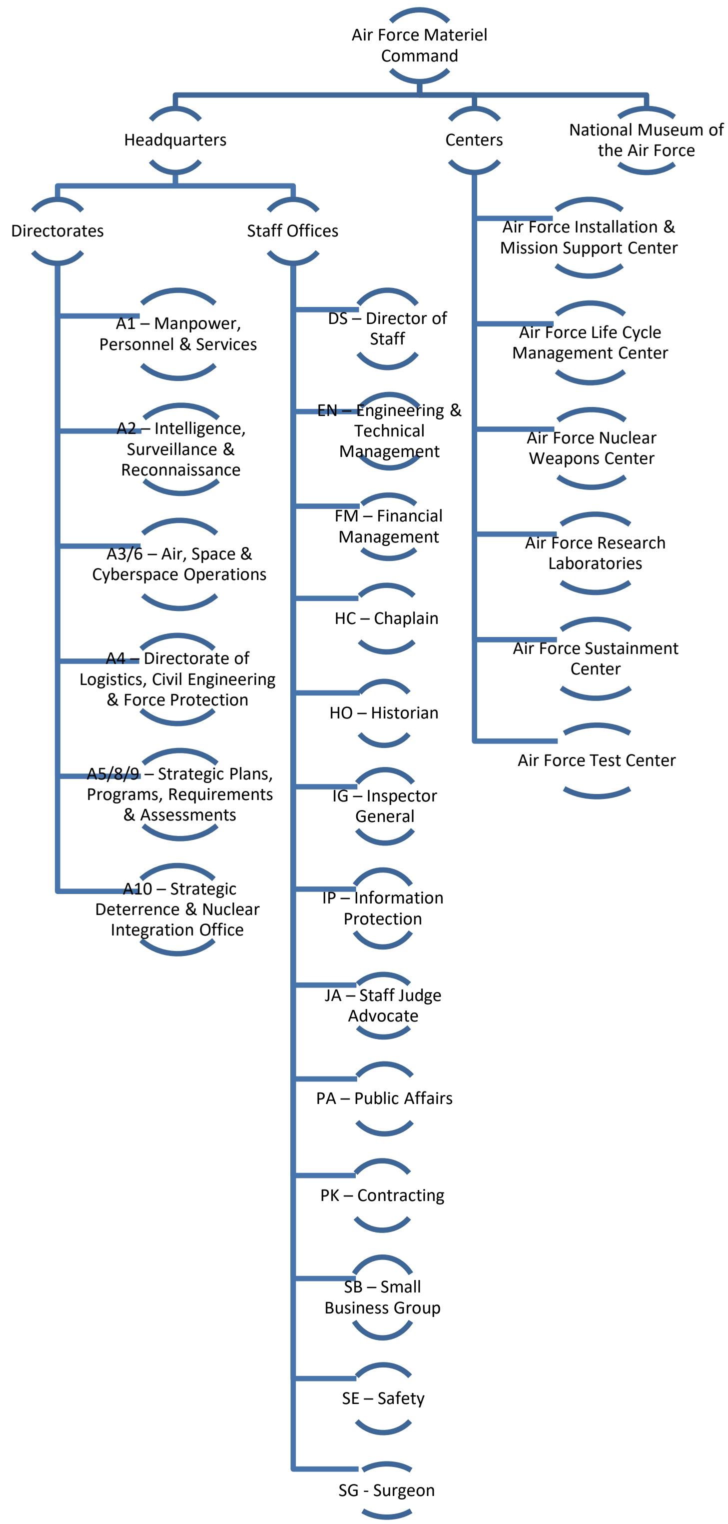

Figure 1. AFMC Structure as of 2017

1.3 Extension to Commercial and Private Enterprises

As a strategic concept, organizational structure requires agile adaptation to redefine evolving interrelationships between the various individuals and activities of an enterprise. Much like AFMC, major corporations, small businesses, and public services alike are impacted by a changing environment, both internally and externally, and typically iterate through multiple organizational structures over the course of their existence. Therefore, we believe that our research can be extended beyond a specific AF context to conceptualize organizational structures from a broader perspective. We will reexamine this idea later in the paper.

1.4 Problem Statement

With a view towards examining alternative organizational structures for AFMC from the perspective of subordinate organizations (i.e., centers and staff directorates), this research examines the following problem:

Problem Statement: Develop, illustrate, and compare methods of analyzing alternative organization structures with respect to improving organizational effectiveness and gaining consensus for potential reorganization from the viewpoint of autonomous subordinate organizations.

Related to addressing this problem statement are several key questions to be answered.

1. Can an organization's effectiveness, based on its organizational design, be evaluated and empirically quantified?

2. Given quantitative measures of effectiveness for an organizational structure, are there useful models to compare different structures from the macroscopic view or the organizational leader viewpoint?
3. Given quantitative measures of effectiveness for an organizational structure, are there useful models to compare different structures from the agent-based view of a subordinate organization (or staff directorate) within the larger organization?

1.5 Thesis Overview

The remainder of this research is organized as follows. Chapter 2 reviews the relevant literature regarding characteristics of organizations, organizational theory, and cooperative game theory. Chapter 3 proposes methodologies for evaluating organizational structures using theories from cooperative game theory and introduces a test instance for analysis. Chapter 4 applies the methodologies to the test instances and extrapolates results to AFMC-like organizations as well as organizations in the private sector. Chapter 5 concludes with final remarks and information for future research.

II. Literature Review

This chapter summarizes the relevant literature pertaining to our research. We begin by examining the mission sets of AFMC organizations as well as the key characteristics of general corporate and/or service organizations.

2.1 Characteristics of Organizations

2.1.1 AFMC Organizations

As mentioned in the previous chapter, AFMC is unique to other AF MAJCOMs in that it tends to function more like a business enterprise than a typical AF operational unit. Today, AFMC is primarily comprised of a headquarters and six centers, each with a separate mission set and subordinate structures. We will review each headquarters and center mission set briefly to detail the different functions and core competencies throughout the MAJCOM.

Since its adaption in 2005, the AFMC two-letter A-staff has restructured several times to a meet the needs of a dynamic environment. These restructures included aligning the two-letters to best fit mission function, normalize directorate size, and share similar resources across the headquarters staff. Table 2 shows the current structure and primary function of AFMC headquarters directorates today.

Table 2. Current AFMC A-Staff Structure

A-Staff	Directorate Title
A1	Manpower, Personnel, & Services
A2	Intelligence, Surveillance, & Reconnaissance
A3/6	Air, Space, & Cyberspace Operations
A4	Logistics, Civil Engineering, & Force Protection
A5/8/9	Strategic Plans, Programs, Requirements, & Analysis
A10	Strategic Deterrence & Nuclear Integration Office

Each directorate is comprised of subsequent divisions specializing in different aspects of the overall directorate mission. The workforce mix of subject expertise varies depending on the function of each individual division, and many divisions hire external contractors to fill a gap in subject matter knowledge. Alongside the directorates, the headquarters also consists of specified staff offices. The staff offices are typically standard across every MAJCOM and, to a smaller extent, duplicated at levels below the MAJCOM (e.g., AFMC centers). The standard staff functions include the Director of Staff (DS), Engineering & Technical Management (EN), Financial Management (FM), Contracting (PK), and Safety (SE). Some of the more specific staff offices are mandated by law or AF policy and include the Inspector General (IG), Small Business Group (SB), Chaplain (HC), Public Affairs (PA), Staff Judge Advocate (JA), and others. These staff offices are usually very small and perform very specific indirect mission activities (AFMC/DS Workflow, 2017).

While the six centers are closely integrated, each center executes a different mission set and is comprised of a unique structure and workforce mix (U.S. Air Force, 2015). The Air Force Research Laboratory (AFRL) is dedicated to the discovery, development, and integration of technologies for air, space, and cyberspace domains. It leverages the expertise of a diverse workforce of scientists, engineers, and other technical experts distributed across multiple technical directorates to develop and deliver various warfighting technologies. The Air Force Test Center (AFTC) performs the mission of testing and evaluating air, space, and cyberspace systems to provide timely, objective, and accurate information to the AF. To meet the test and evaluation mission, test wings provide AFMC with necessary expertise in flight simulation, the developmental testing of sub-systems (e.g., airframe, avionics, propulsion, navigation, weapons, etc.), and overall integration of test flying operations, maintenance, and engineering. The Air Force Nuclear Weapons Center (AFNWC) strives to sustain nuclear surety for the AF across all domains. AFNWC seeks to ensure "safe, secure, and effective nuclear capability for the warfighter" and provide "on-time, on-target nuclear solutions" (U.S. Air Force, 2015).

The last three centers have very broad missions encompassing a wide spectrum of activities. The Air Force Life Cycle Management Center (AFLCMC) is responsible for the total life cycle management of a diverse portfolio of aircraft, engines, munitions, technology systems, and networks. It has a wide mission set of delivering affordable and sustainable war-winning capabilities, not only to the US, but also to nations identified as foreign military partners. To effectively implement the acquisition process, AFLCMC is comprised of a diverse workforce of expertise matrixed across a large portfolio of systems. The Air Force Sustainment Center (AFSC) strives to sustain weapon system readiness by providing depot maintenance, supply chain management, and installation support to the warfighter. The AFSC team consists of a variety of maintainers, supply chain management professionals, engineers, contractors, and other subject experts trained to sustain anything from small electronics to large aircraft all around the US. Finally, the Air Force Installation and Mission Support Center (AFIMSC) provides centralized management and standardization of installation and mission support capabilities not just within AFMC, but across the entire AF. The AFIMSC workforce specializes in security forces, civil engineering, communication, logistics readiness, and other mission support areas (U.S. Air Force, 2015).

The geographical separation, both within and across centers, creates a challenge to effectively integrate the mission sets of AFMC. The 12-to-5 center reorganization in 2012 attempted to minimize any negative effects of responsibility transition between centers by merging four acquisition-centric centers into one AFLCMC, two testing-centric centers into one AFTC, and four sustainment-centric centers into one AFSC. In this manner, AFMC has structured according to its multi-faceted mission tasks, leading to a divergence from the wing-group-squadron construct followed by the rest of the AF. The business-like nature of AFMC lends an opportunity to relate its structure and core mission sets to sectors outside of the government.

2.1.2 Private Sector Organizations

There are a countless number of different commercial, private, and not-for-profit organizations, each varying in sector, size, mission, location, culture, and other factors. For the sake of our research, we will briefly address AFMC similarities to two particular organizations and generalize observations and insights, where appropriate.

The first organization we will examine is the Procter & Gamble Company (P&G). P&G is a well-known, globally-established, consumer product company. We believe this company can be abstractly representative of the commercial sector due to P&G's influence and control of the entire life cycle of a product, from manufacturing to retirement. P&G is structured according to its four main brand categories and operates in six geographic regions around the globe (P&G News Stories, 2016). The brands and selling operations are supported by corporate functions or shared services, as shown in Figure 2 (Procter & Gamble Co., 2016).

Figure 2. P&G Organizational Structure

Similar to AFMC, the transition to this structure only occurred in the past few years (Fox, 2013) and was stimulated by a rapidly changing environment. This reinforces the notion that different types of companies are creatively rearranging their subordinate units and sharing functional expertise to best meet their mission within a changing context.

The second company we propose as a notional construct is Cardinal Health, a well-known and globally-established company in the private sector. Cardinal Health services pharmacies, supports hospitals, and manufactures home healthcare and medical equipment. Through its integrated network of logistics, business, product, and patient solutions, Cardinal Health resembles the multi-faceted mission of AFMC (Cardinal Health, 2016). In the past few years, Cardinal Health restructured its organization to reflect the two primary segments of its business: the medical segment and the pharmaceutical segment (Ghose, 2013). These primary segments are supported by an executive team of standard corporate functions. In this manner, the realignment of Cardinal Health's subordinate units to better meet functional operations is consistent with both AFMC and P&G. By establishing this notational foundation of similar structural constructs, we seek to extrapolate our research beyond the governmental sector and relate to organizations in the commercial and private sectors as well.

2.2 Organizational Theory

Whereas our research focuses primarily on organizational structure, we would be remiss not to expand our literature review to the broader context of organizational theory. Organizational theory is defined as "the study of how organizations function and how they affect and are affected by the environment in which they operate" (Jones, 2013). It encompasses concepts involving both the internal workings of an organization as well as the external environment motivating adaptation and change. Organizational theory primarily relates to three key facets of organizations: organizational structure, organizational culture, and organizational design and change (Jones, 2013). For the purposes of this research, we will focus on these three areas and the space in which they interact and influence one another.

Organizational structure is dynamic, constantly evolving to define the interrelationships between the various individuals and activities of a commercial, private, or governmental organization. The primary purpose of organizational structure is to control the way an organization motivates and coordinates actions to best achieve the mission (Jones, 2013). Traditionally, organizations have structured either functionally (according to business areas), divisionally (according to product areas), or combinatorically (using a matrix integration of both products and functions). Recently however, organizations have been applying more creative logic and employing constructs such as the process structure or the network structure. These structures tend to focus more on the inherent work of the organization, emphasizing strong lateral relationships and connectivity between coordinating mechanisms (Cummings & Worli, 2012). The emergence of new structures reflects the need to adapt to evolving internal and external factors. A noteworthy example of an evolving organizational structure is the US Army Brigade. Since the American Revolutionary War, the Army Brigade has constantly redesigned and reconstructed itself to meet the need of changing global threats and operational environments (McGrath, 2004). According to Cummings & Worli (2012), there are four key contingencies that affect structural design: the environment, organizational strategy, technology, and organization size. These factors manifest in many different forms, so organizations constantly consider and evaluate these factors when determining an optimum structure. Organizations should also be cognizant of the effect of changing an organizational structure, especially on employees. Howard & Frink (1996) conducted a survey to determine the effects of reorganization and found significant correlation between reorganization and employee satisfaction with supervision, coworkers, and company growth. Similarly, further research suggested that the degree of individual work-team identification versus overall organization identification were important indicators of positive/negative reactions to organizational restructure and resulting employee satisfaction (Jetten *et al*., 2002; Riketta & Van Dick, 2005). This correlation alludes to the overlap between the concepts of organizational structure and organizational culture.

Organizational culture is the set of values and norms shared by the people inside of an organization. It incorporates the ethics, ethos, and rights of employees and translates them into an environment in which people communicate and interact (Jones, 2013). Like organizational structure, culture is evolutionary and adapts to a changing workforce. It typically has a "feel", and sometimes individual personalities can clash with the cultural values of an organization (Chatman & Barsade, 1995). One commonly studied theme in organizational culture is the idea of attachment to an organization, and many articles in the published literature examine the dynamic between the levels of attachment. Riketta & Van Dick (2004) explored the foci of attachment and discovered that attachment at the working group level is much stronger than overall organizational attachment. This factor led to higher satisfaction ratings, more dedicated behavior, less absenteeism, and a healthier climate for individual workgroup changes rather than sweeping organizational movements. Research also showed that the foundation of trust was better cultivated at this workgroup level, driving organizational cooperation and advantage (Jones & George, 1998). Finally, organizational culture relates to the idea of organizational identification, which is another popular area of study in the organizational literature (Riketta, 2003).

Both organizational structure and culture are constantly changing in response to an unpredictable environment. *Organizational design* is the means by which an organization seeks to manage culture and structure to best achieve its goals. It balances the pressures of the external environment with the needs of the internal processes to influence behavior and motivate change (Jones, 2013). Nadler & Tushman (1990) examined the idea of organizational change as it manifests along two main dimensions: strategic versus incremental changes, and reactive versus anticipatory changes. The authors detail a basic typology by combining these dimensions and describing the factors, environment, and levels of risk associated with each type of organizational change. Regardless of the dimensions or type of change, organizational leaders play a key role in organizational design. Nadler & Tushman (1990) also studied this aspect and address the influence of leadership on organizational change, finding charismatic leaders who embody the components of "envisioning," "energizing," and "enabling" have more success in leading major organizational reforms. These leaders function as change agents by focusing on the vision and creating a positive and motivated environment conducive to organizational change. However, an academic study found that the large majority of respondents feel as though their prior organizational leaders rarely, if ever, implemented change effectively, suggesting that functioning as a change agent does not always lead to a successful organizational change outcome (Gilley *et al*., 2009). This shows that leadership engagement is not enough to foster effective change; a cooperative approach to change must be employed and promoted across the organization. In this way, cooperation is required for both a change within an organization (e.g., a restructure of functional or product areas) or between organizations (e.g., a merger of two previously distinct businesses). There are many theoretical frameworks by which to describe cooperation, including economical exchange theories, attraction theories, power and conflict theories, and social structure theories (Smith *et al*., 1995). These methodologies seek to capture the way that people, divisions, or whole businesses interact with each other. Relevant research in this area found that cooperation between functional areas is largely driven by internal facilitators such as reward structures and management expectations (Song *et al*., 1997). Similarly, Amiot *et al*. (2006) found that employees consulted about a merger prior to implementation associated a more positive perception of the change and exhibited higher levels of job satisfaction and self-efficacy. These findings suggest that the behavior exhibited by organizational leadership and internal staff functions play a crucial role in facilitating effective organizational change.

The themes of organizational structure, organizational culture, and organizational design are closely intertwined, and a change in one component will undoubtedly cause direct or indirect effects on the other components. The literature highlights the importance of understanding values, biases, motivators, and allegiances at the lowest echelon unit or employee group level since these largely dictate the success of an organizational change.

2.3 Organizational Effectiveness

There exists a comprehensive body of literature seeking to define the concept of organizational effectiveness. Many theorists in the areas of organizational theory, social science, and behavioral science have proposed methodologies for measuring organizational effectiveness, but the abstract nature of the field prevents research community consensus for of any one direction of study (Goodman & Pennings, 1977). The crux of the issue is that organizational effectiveness is dependent upon perspective, meaning it is heavily influenced by the individual assessment of a particular manager/leadership team member at a particular point in time, in a particular framework for evaluation. According to Quinn and Rohrbaugh (1981), organizational effectiveness is "a value-based judgement about the performance of an organization"; however, the characteristics associated with organizational effectiveness suggest that no one definition can completely capture the concept (Campbell, 1977). As a result, our literature review seeks to document the dominant themes, criteria, and assessment models for organizational effectiveness.

Two relatively well-known models for assessing organizational effectiveness are the *goal-centered* view and the *natural systems* view (Campbell, 1977). The goal-centered view begins with the assumption that an organization is actively working to achieve a set of publicized and clearly defined goals typically generated by rational, decision-making leadership. In this view, criteria corresponding to respective organizational goals are identified and assessed over time as a proxy for measuring organizational effectiveness. Conversely, the natural systems view assumes that complex and changing environments render specific organizational goals too difficult to meaningfully achieve, so organizational effectiveness is assessed as the consistent continuation of activities over time and the judicious use of resources. This model seeks to classify characteristics of the overall "health" or performance of an organization rather than the progress made toward pre-specified goals (Campbell, 1977). Both models have been well-studied in the literature and offer complementary insights for examining organizational effectiveness.

Alongside the assessment models, there exists a paradigm of research linking organizational effectiveness to empirical measures. Campbell (1977) established the early foundation by surveying the literature to identify variables proposed as potential indices of organizational effectiveness. His work has been widely cited in recent literature on the subject, and the complete list of variables (in no particular order) is provided in Table 3.

Table 3. Campbell's List of Organizational Effectiveness Variables

1. Overall Effectiveness
2. Productivity
3. Efficiency
4. Profit
5. Quality
6. Accidents
7. Growth
8. Absenteeism
9. Turnover
10. Job Satisfaction
11. Motivation
12. Morale
13. Control
14. Conflict/Cohesion
15. Flexibility/Adaptation
16. Planning & Goal Setting
17. Goal Consensus
18. Internalization of Organizational Goals
19. Role & Norm Congruence
20. Managerial Interpersonal Skills
21. Managerial Task Skills
22. Information Management & Communication
23. Readiness
24. Utilization of Environment
25. Evaluations by External Entities
26. Stability
27. Value of Human Resources
28. Participation & Shared Influence
29. Training & Development Emphasis
30. Achievement Emphasis

Since its conception, several researchers have sought to address the multi-dimensional aspect of Campbell's list. Quinn & Rohrbaugh (1981) interviewed a suite of organizational theory experts to establish the degree of generality, singularity, operationalization, and performance indication of each variable on Campbell's list. Ultimately, their research led to a graphical depiction of the variables on competing scales of structure (flexibility versus control), focus (people versus organization), and perspective (organizational means versus ends). This graphical depiction was an important discovery because it yielded insights into the natural clustering of Campbell's effectiveness criteria. Using the criteria in the clustering, Quinn & Rohrbaugh (1983) defined four general models for categorizing organizational effectiveness through empirical data, as shown below in Figure 3, which has since been applied to specific fields such as effectiveness in higher education institutions (Cameron, 1978), as well as in more general constructs such as strategic alliances (Das & Teng, 2000) and corporate social performance (Graves & Waddock, 1994).

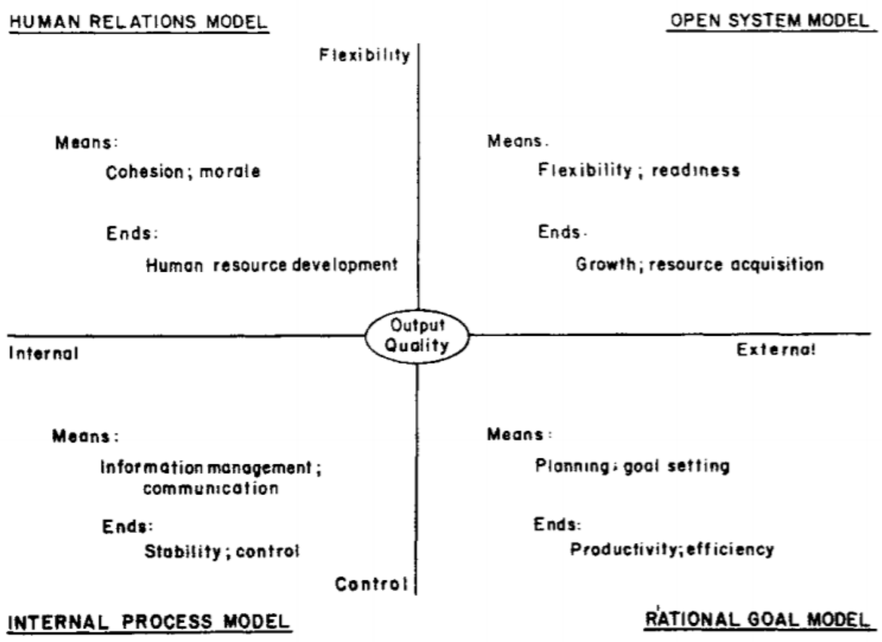

Figure 3. Quinn & Rohrbaugh (1983) spatial model of effectiveness criteria

Even though it originally began as a multivariate analysis of empirical criterion, the spatial model is primarily a perspective-wide look at organizational effectiveness. The conclusions from the published literature suggest that a broader understanding of the multiple dimensions of effectiveness typically provides more insight than multivariate analysis when comparing and evaluating organizations (Campbell, 1977).

Building upon the foundational theories of organizational structure, strategy, and process, Doty *et al.* (1993) demonstrated that configurational types and characteristics of organizations can be used to evaluate and compare effectiveness. Their work contributed the notion of utilizing strategies such as psychometric validation and canonical correlations to assess criteria and empirically derive resemblance to the ideal types of the effective organizations from the research of Mintzberg (1979, 1983) and Miles *et al.* (1978). Whereas effectiveness will most likely be measured differently at various organizations, a broad approach to organizational effectiveness typically includes defining an organization-wide framework and tracking appropriate goals, resources, or criterion according to the designated framework.

2.4 Prescriptive Game Theory Models

According to Chakravarty *et al*. (2015), modern game theory is "the study of mathematical models of conflict and cooperation between intelligent rational decision-makers." Based on the model of interaction between decision-makers, game theory is partitioned into many areas. The most dominant forms include *non-cooperative* game theory, wherein decision-makers are modeled as independent, self-interested agents (i.e., players), and *cooperative* game theory, wherein agents work together as a group (Shoham & Leyton-Brown, 2009). In the scope of this research, we focus primarily on cooperative or *coalitional* game theory. (Henceforth, we use these two terms interchangeably.)

Cooperative game theory is rooted in the perspective of the coalition, with two key questions driving research: (1) which coalition will form and (2) how should the resulting payoff of the coalition be divided among the coalition members (Shoham & Leyton-Brown, 2009). To answer these questions, the literature considers many different methodological approaches of cooperative game theory, applied to various commercial, private, and governmental enterprises. Prior to discussing the related applications, we introduce several conceptual elements of cooperative game theory that underpin the related works.

Typically, cooperative game theory concepts and studies are divided by the assumption of whether the utility (i.e., payoff) achieved by the coalition is a *transferable utility*, wherein the collective utility must be divided among members via a centrally-determined allocation, or is a *non-transferable utility*, wherein each coalition member's individual utility is determined by their participation in the coalition (Chakravarty *et al.*, 2015). Most of the literature on cooperative game theory assumes transferable utility. The assertion of transferable utility for a game imposes inherent properties on the game, including the classification of additivity, essentiality, monotonicity, or symmetry (Gilles, 2010). These properties help address the question of which coalition will form. Due to the dominance of the superadditivity property in game representation within the literature, agents can usually achieve higher payoffs by cooperating than by working independently. This incentivizes agents to cooperate with as many other agents as possible, ultimately leading to the formation of what is called the *grand coalition*, a single coalition comprised of all agents (Shoham & Leyton-Brown, 2009). The grand coalition is the most famous of coalition structures, but we present some alternative structures later in this section.

Regarding the allocation of transferability utility among agents within a coalition, there is a rich body of research pertaining to the identification of allocation schema (i.e., imputations) that are fair and/or stable. The Shapley value solution concept is the first to address the idea of fairness. Shapley values allocate payoffs according to the marginal contribution of each player, considered over all permutations via which the grand coalition could iteratively form, so each agent's individual payoff is dependent upon their expected contribution to the overall coalition payoff (Shapley, 1952). While this metric is generally accepted as a fair allocation distribution between agents, it fails to ensure stability of the coalition because agents will rationally maximize individual outcomes and, should the opportunity arise, they will leave coalitions and possibly form new sub-coalitions to achieve higher individual payoffs, regardless of the impact to the payoffs of the other agents.

As a result of this potential instability, Gillies (1959) introduced the concept of the *core* of a coalition structure. The core is the set of all payoff structures (i.e., imputations) for transferable utility that correspond to a stable coalition; the existence of a core enables the sharing of collective utility in a manner that removes any incentive for one or more agents to deviate, individually or collectively, from the current coalition structure (Shapley, 1967). However, the identification of the core for a cooperative game is non-trivial, as is the computational complexity of determining whether a non-empty core exists and, if it does exist, whether it is unique (Conitzer & Sandholm, 2003).

Various refinements of the core, including the *ε-core*, *least core*, and *nucleolus*, attempt to rectify this possible non-existence and non-uniqueness (Shoham & Leyton-Brown, 2009). The ε-core assigns a penalty of ε to a deviating coalitional payoff, expanding the solution region by the size of ε. For large enough ε-value, there will always be a stable imputation but, as ε decreases in size, the ε-core may become empty. Accordingly, the least core is defined as the smallest existing ε-core, or the smallest ε-value that still yields a feasible solution (i.e., an imputation that corresponds to a stable coalition). As such, the least core will always be non-empty but not always unique (Chakravarty *et al.*, 2015). The nucleolus is a strengthened version of the least core to ensure both existence and uniqueness in a solution. By formulating the game as a linear program and recursively tightening each constraint, a unique payoff vector can be found that constitutes the nucleolus solution (Shoham & Leyton-Brown, 2009).

Although the majority of research within the literature assumes the grand coalition to be the ideal coalition structure, herein we note that this assumption does not always hold, as institutional or legal barriers may prevent the grand coalition from forming. Moreover, superadditivity may not always hold; larger coalitions may yield organizational inefficiencies, either due to the larger scale of interactions or the inclusion of agents for which a subadditive relationship exists (i.e., they are less productive when working together). Alternatively, several works within the literature examine the formation of *sub-coalitions* or *multi-coalitions* among a set of agents in a cooperative game theoretic environment. Aumann and Dreze (1974) led the research examining a multi-coalition structure wherein agents are constrained to form specified or arbitrary coalitions that are not the grand coalition. They redefined solution concepts such as the core and the Shapley values according to the payoffs of each partitioned coalition. Myerson (1977) applied graph theory to multi-coalition formation to determine payoff allocation according to cooperating links within the network. Further analysis into this area established the notion of stability in multi-coalition structures (Guajardo & Ronnqvist, 2015). The literature extends this work to examine important factors driving multi-coalition formation, including the size of a coalition (Audy *et al.*, 2012), positive or negative externality effects (Yi, 1997), and agent bargaining ability in various coalition structures (Roth, 1977).

Alternative to transferable utility models of cooperative game theory are models that assume non-transferable utility, wherein coalition payoffs cannot be explicitly divided between members of the coalition. Agents receive their respective utilities via their membership in a given coalition (Banerjee *et al.*, 2001). One notable exploration within the non-transferable utility literature is the *hedonic* formation of coalitions. Hedonic models focus on the concept that a player receives utility solely from the identities of the members in a given coalition. Therefore, each agent can rank their preferences for various coalition structures, and solution concepts are generated from the intersection of their preferences (Bogomolnaia & Jackson, 2002; Dreze & Greenberg, 1980).

Within the literature, there are several predominant areas to which cooperative game theory is applied. Foremost among such literature related to our research is the distribution of power within an institution, particularly within a political environment.

The natural affinity of grand coalition formation is a popular notion, prevalent in works examining the idea of collective democratic rights in a society (Lijphart, 1969) or competition between European Parliament parties (Kreppel & Hix, 2003). Specific solution concepts such as the Shapley value and the core have been applied to model fair distribution of political power (Shapley & Shubik, 1954) and the stability of political party change (Ibenskas and Sikk, 2015).

Another major research thread within applied coalitional game theory research, especially in terms of modeling coalition imputations, consists of analyzing various types of networks, with the arcs (i.e., connections) between nodes (i.e., entities) characterizing either physical or non-physical relationships. Concepts such as the core, the ε-core, and the nucleolus have been successfully applied to wireless and communication networks (Charilas & Panagopoulos, 2010; Saad *et al.*, 2009) in public, private, and governmental sectors. Cognitive radio networks are modeled in hedonic coalitions by assuming non-transferrable utility between primary and secondary users (Saad *et al.* 2010). Distribution networks are another related area of research, with recent studies focusing on core stability and cost allocation in vehicle routing (Dai & Chen., 2012) and collaborative transportation analysis (Sherali & Lunday, 2011; Guajardo *et al.*, 2016). Similarly, supply chain networks have been modeled through a coalitional game theory perspective, using Shapley value solution concepts for fair inventory management (Fiestras-Janeiro *et al.*, 2011) and supply chain cost apportionment (Bartholdi & Kemahlioglu-Ziya, 2011).

Resource allocation connects a wide span of cooperative game theory literature, including relevant methodologies such as the application of Shapley values to determine fair allocations of property rights (Casajus & Labrenz, 2014), and an examination of the core solution for stable distributions of water resources (Parrachino *et al.*, 1992). Carraro *et al.* (2006) view international environmental agreements as a multi-coalition game where stability can be analyzed via transfer schemes between members of the agreements.

To date, there is not a significant body of research that considers either the formation or stability of military organizational structure through a coalitional game theory perspective. Perhaps the most applicable literature is summarized by Rahwan *et al.* (2015), who conducted a survey to identify institutional coalitional structures that lead to optimized performance and social welfare. Of note in the coalitional structures survey (Rahwan *et al.*, 2015) is the dynamic between forming coalition structures, solving an optimization problem to identify the best structure, and allocating the resulting payoffs in a fair and stable fashion, developed and presented by Silaghi (2006). Other relevant research includes a study of competitive and cooperative military teams using a graphical coalitional game (Aurangzeb *et al.*, 2013), but no published research directly related to our application of cooperative game theory has been found in an exhaustive search of the literature.

2.5 Descriptive Theory to Prescriptive Model Gap

Reflecting on the areas of research detailed above, the question arises of how to translate the descriptive areas of organizational theory to the prescriptive models of analysis. The literature tends to favor either organizational theory or prescriptive models, and few researchers have tried to bridge the gap between the two areas. The research that does exist, especially with regard to a change in organizational structure, is typically assessed from the macroscopic view, or from the viewpoint of the organizational leader. When organizational missions and alignments thereof are quantifiable, grouping of subordinate elements into larger subordinate groups can be done by such methods as math programming (Lee *et al.*, 1982; Obel, 2014), multivariate analysis (Quinn & Rohrbaugh, 1983; Meyer *et al.*, 1993), clustering algorithms (Levchuk *et al.*, 2002; Ketchen *et al.*, 1993), and similar approaches. While these models are useful, research in this area tends to rely on survey data from the upper management level, making it very subjective in nature and limited to a point-in-time perspective. Therefore, we focused our review of the literature on agent-based analysis that examines relationships between three key areas: *organizational structure*, *coalitional game theory*, and *value measurement* of a coalition structure. While no one piece of research covered all three areas, we identified concepts that motivate the connection between descriptive and prescriptive models.

One thread of literature focused on drawing parallels between political coalitions and business organizations by relating political situations of power and bargaining to the independence of individual business units, organizational goals and commitments, and the role of the corporate executive (March, 1962). Extrapolating upon the modeling of business firms as political coalitions, the constructs of coalitional game theory applied to politics (Kreppel & Hix, 2003) could be utilized for a business firm. In an analysis of the general staff concept, Stanley (1959) drew relationships between an effective military general staff and the administrative staff organization of a successful business. The author used historical references from major military and business operations to illustrate effective versus ineffective applications of staff roles and responsibilities. In another thread of research, Sims *et al.* (2003) addressed the self-organizing aspect of coalition structure by considering unit preferences in a model of distributed sensor network coalitions. This idea motivates the notion of organizational subunits forming coalitions according to their individual preferences. Conversely, coalition structures can also manifest due to irreconcilable constraints driving particular feasible structures (Ueda *et al.*, 2010). Another interesting thread of research is the determination of an "optimal structure." There are multiple ways to optimize utility across all coalitions; Sen & Dutta (2000) created an algorithm to search all feasible coalition structures to determine the structure that maximizes the sum total of all coalition payoffs. Similarly, there exist algorithms that also implement a learning function to evolve the algorithm as business units interact and gain more experience (Abdallah & Lesser, 2004).

Transitioning to the concept of measuring coalitional value, the literature varies in technique and application. First, the mechanisms to be modeled must be identified. Campbell (1977) established a foundational taxonomy of organizational effectiveness criteria, but individual inter-firm organization mechanisms also exist. These forms of inter-firm coordination mechanisms, to include pooled, intensive, sequential, and reciprocal dimensions, affect the efficiency and effectiveness of an overall firm (Grandori, 1997). Dess & Robinson (1984) took a different approach to measuring organizational effectiveness by examining the correlations between objective and subjective measures and the consequence of using one or the other in terms of overall organizational performance. Once the criteria or methodology for capturing effectiveness is established, researchers such as Ohta *et al*. (2009) developed algorithms to calculate overall superadditive coalition value (or characteristic functions) according to the associated value inputs for each individual agent. Finally, Holler & Widgren (1999) asserted that the value of a coalition is power. Their research suggested that individual preferences or utility values of agents do not combine into the same unit of measure; rather, they present formulations for representing multi-agent coalitions according to a power framework.

All of these threads provide insight into our research, but no one piece of literature seeks to model a general framework for the agent-based view of translating organizational theory to prescriptive coalitional game theory. Our research will contribute to this concept and focus on the relationships between the threads of organizational structure, coalitional game theory, and value measurement of a coalition structure.

III. Methodologies & Test Instances

3.1 Methodologies

Our research will examine three key methodologies for evaluating an organizational structure from the agent-based view.

3.1.1 Traditional Cooperative Game Theory

The first methodology is traditional cooperative game theory analysis, focusing primarily on Shapley value solution sets and the core solution sets. The Shapley Value solution utilizes the value of each coalition structure to determine fairness between coalition members (i.e., payoffs are distributed according to the marginal contribution of each agent). Shapley value payoff vectors *x* can be calculated for a coalitional game (***N***, *v*) according to the following equation, wherein Φ_i represents the Shapley value payoff for agents *i* =1, 2, …, 10, *N* represents the number of agents in the particular coalition under examination, *v* represents the characteristic equation values (i.e., effectiveness values), and ***S*** represents a formation of a sub-coalition of agents in the set ***N*** (not including *i*) (Shoham & Leyton-Brown, 2009).

$$\Phi_i(\boldsymbol{N}, v) = \frac{1}{N!} \sum_{\boldsymbol{S} \subseteq \boldsymbol{N} \setminus \{i\}} |S|!\,(|N| - |S| - 1)!\,[v(\boldsymbol{S} \cup \{i\} - v(\boldsymbol{S})]$$

This formula captures the marginal contributions of each agent by weighting and averaging the payoffs according to the different ways in which the grand coalition could have been formed.

The core solution concept ensures coalition structures are stable by distributing payoffs so each agent receives as least as much as could be earned alone, leaving no incentive to deviate. The requirement for a payoff vector *x* to be in the core of a coalitional game (***N***, *v*) can be formulated as follows, wherein *i* = 1, 2, …, 10 again represents the individual agents, x_i represents the payoff to an individual agent, *N* represents the number of agents in the particular coalition under examination, *v* represents the characteristic equation values (i.e., effectiveness values), and *S* represents a formation of a sub-coalition consisting of agents in the set ***N*** (including *i*) (Shoham & Leyton-Brown, 2009).

$$\forall \boldsymbol{S} \subseteq \boldsymbol{N}, \sum_{i \in \boldsymbol{S}} x_i \geq v(\boldsymbol{S})$$

The existence of the core provides resolution to the question of whether an agent will cooperate in a coalition if the resulting payoffs to the agent are not the highest payoff that can be achieved through any (or no) cooperation. In this manner, traditional cooperative game theory analysis represents the self-organization solution sets of subordinate organizations.

3.1.2 Myerson Graph Theory

The second methodology we will examine is Myerson graph theory for multi-coalition formation. A Myerson graph is a network of cooperating links between agents, each with an associated value of cooperating between specific agents. It is regarded as a new derivation of the Shapely values that focuses on the notion of connectedness within cooperation graphs. Two agents are considered to be connected if and only if there is a "path" or a "link" (i.e., feasible sub-coalition) that goes between the two agents (either directly or indirectly) while remaining within the coalition in examination. Myerson

(1977) translates the idea of traditional cooperative game theory to the notion of either connected or non-connected agents within a graph (i.e., coalition formation). The payoffs are dependent upon the allocation rule utilized for the cooperation structure. The allocation rule must meet the following condition, wherein ***N***, ***S***, and *v* can be interpreted as in previous sections, *g* represents the graph of links between agents, *GR* represents the set of all graphs on ***N***, ***N***/*g* represents the natural partitions into which ***N*** would break up if agents could only cooperate along links in *g*, and $Y_n(g)$ represents the *n*-component of the allocation rule mapping $Y : GR \to \mathbb{R}^N$(Myerson, 1977).

$$\forall g \in GR, \forall \boldsymbol{S} \in \boldsymbol{N}/g, \qquad \sum_{n \in \boldsymbol{S}} Y_n(g) = v(\boldsymbol{S})$$

This condition asserts that the total payoffs available to a coalition of agents will be utilized. To narrow the scope of possible allocation rules, Myerson asserted that an allocation rule should be stable so agents always benefit from cooperating. The following condition is required for stability, wherein *n* and *m* represent agents within *g*, the symbol ":" denotes a link between two agents, and the symbol "\" represents removal of an agent from a particular coalition (Myerson, 1977).

$$\forall g \in GR, \forall\, n : m \in g,$$
$$Y_n\,(g) \geq\ Y_n\,(g \setminus n : m) \text{ and } Y_m\,(g) \geq\ Y_m\,(g \setminus n : m)$$

Finally, Myerson also asserted that the selected allocation rule should be fair and agents should gain equally from an agreement. The allocation rule must meet the following condition to be fair (Myerson, 1977).

$$\forall g \in GR, \forall\, n : m \in g,$$
$$Y_n\,(g) -\ Y_n\,(g \setminus n : m) = Y_m\,(g) -\ Y_m\,(g \setminus n : m))$$

In this manner, the Myerson value calculations determine the average value of an agent to a coalition based on the relative value added at each permutation of coalition formation.

3.1.3 Hedonic Coalition Formation

Finally, we will examine the hedonic formation of coalitions. This model uses coalition structure information to capture the hedonic preferences of each agent cooperating with every other agent. Hedonic coalition formation differs from the previous methodologies because it is rooted in the notion of non-transferrable utility (i.e., each agent's individual payoff is determined by their participation in a particular coalition). In a hedonic setting, agents have preferences over the identity of other agents in a given coalition since his or her payoff is completely determined by the composition of agents in a coalition. Due to the nature of hedonic preferences, hedonic coalition formation is most common in social groupings such as teams, clubs, faculties, and societies (Bogomolnaia & Jackson, 2002).

For the purposes of our research, we analyze our organizational structures as they relate to three stability concepts within a hedonic setting. For context and clarity, we follow the notation of Bogomolnaia & Jackson (2002), wherein N represents the number of agents; i denotes an individual agent; $\boldsymbol{S}_k$ represents a coalition in the set $\boldsymbol{N}$; $\boldsymbol{\Pi}$ denotes a partition of $\boldsymbol{N}$ completely separated into coalitions $\boldsymbol{S}_1, \boldsymbol{S}_2, \dots, \boldsymbol{S}_k$; $\boldsymbol{S}_\Pi\ (i)$ denotes the set $\boldsymbol{S}_k \in \boldsymbol{\Pi}$ such that $i \in \boldsymbol{S}_k$; and the operator $\succ_i$ represents the strict preferences of i between two coalitions. (Likewise, the operator $\succcurlyeq_i$ represents non-strict preferences.)

The first stability concept is the *core stable* coalition partition. Core stability for a partition $\boldsymbol{\Pi}$ requires that there does not exist some coalition T such that $T \succ_i S_\Pi\ (i)$ for all

$i \in T$. That is, if there exists a coalition for which every agent (strictly) prefers relative to the coalition in which they exist within $\mathbf{\Pi}$ (i.e., they each have incentive to deviate), then the partition $\mathbf{\Pi}$ is not core stable. Identification of core stability requires an exhaustive search of all alternatives or, in the instance considered herein, all available alternatives. As such, the computational complexity of analyzing this property can be quite cumbersome. Consider, as a motivating example, a group having $n = 10$ agents that will be partitioned into four sub-coalitions, each of which has at least one agent and at most three agents. The resulting number of combinations is 420,000, as derived from the combination formula below, wherein n_i represents the number of agents assigned to coalition $i = 1, \dots, 4$:

$$\sum_{n_1=3}^{3} \sum_{n_2=2}^{3} \sum_{n_3=2}^{3} \sum_{n_4=1}^{(n-n_1-n_2-n_3)} \frac{10!}{n_1!\,n_2!\,n_3!\,n_4!} = 420{,}000$$

In order to determine core stability, one would have to search every combination to determine if there exists a coalition for which every agent strictly prefers relative to every other combination. We will revisit this issue of computational complexity in a later section to create a reasonable sample set of combinations for analysis.

The next stability concept is the *Nash stable* coalition partition. Nash stability exists if $\forall i \;\; \boldsymbol{S}_{\Pi}\,(i) \succ_i \boldsymbol{S}_k \cup \{i\}$ for all $\boldsymbol{S}_k \in \mathbf{\Pi} \cup \{\emptyset\}$. In other words, every agent is better off in their coalition corresponding to the current partition $\mathbf{\Pi}$ compared to unilaterally leaving their coalition to either join another coalition or operate alone. The analysis of Nash stability is much simpler than core stability in terms of computational complexity. The non-existence of Nash stability requires that only coalitions preferred to the current partition be examined and that only one agent worse off in their current partition as compared to joining another coalition or operating alone be identified.

Finally, an *individually stable* coalition partition requires that there does not exist $i \in \boldsymbol{N}$ and a coalition $\boldsymbol{S}_k \in \boldsymbol{\Pi} \cup \{\emptyset\}$ such that $\boldsymbol{S}_k \cup \{i\} \succ_i \boldsymbol{S}_{\Pi}(i)$ and $\boldsymbol{S}_k \cup \{i\} \succ_j \boldsymbol{S}_k$ for all $j \in \boldsymbol{S}_k$ (Bogomolnaia & Jackson, 2002). That is, no agent can unilaterally depart their coalition in the partition $\boldsymbol{\Pi}$ to either join another coalition or operate alone with the result of that agent being better off and every other agent being no worse off. In fact, Nash stability implies individual stability, so if a coalition partition satisfies Nash stability it also satisfies individual stability. However, core stability and Nash stability are not related in the fact that satisfying one stability concept in no way implies satisfaction of the other (Bogomolnaia & Jackson, 2002).

3.2 Test Instances

Due to the dynamic nature of existing organizations, we utilize test instances of an organization randomly generated using similar characteristics to our notional examples of AFMC, P&G, and Cardinal Health. As detailed in Chapter 2, we assert that an organization's effectiveness, based on its organizational design, can be evaluated from a macroscopic perspective and empirically quantified through the identification of relevant criteria and the use of models such as math programming, multivariate analysis, clustering algorithms, or similar approaches. The literature has also proven that there are useful models to compare different structures from the macroscopic view (i.e., the organizational leader viewpoint); therefore, we assume methodologies to determine the effectiveness value of organizational structures exist and hereby focus our attention on comparing different structures from the agent-based view of a subordinate organization (or staff section) within the larger organization.

As an aside, we consider our methodologies with respect to comparing alternative organization structures herein, rather than generating and evaluation all possible combinations of alternative organizational structures. Using the motivating example from the previous section, a group having $n = 10$ agents would have 420,000 combinations of organizational structure, which is an unreasonably large sample set from which to draw meaningful comparisons using our proposed methodologies.

For the sake of computational complexity and rational comparison for the motivating problem of AFMC organizational structure, we consider test instances comprised of an organization having 10 agents to mirror the staff structure within AFMC, which consists of A1, A2, …, A10. Moreover, we consider three alternative organizational structures as depicted in Table 4, wherein, an entry such as "2/5" represents that the A2 and A5 staff sections are assigned to a common directorate or, within a game theoretic context, assigned to a coalition consisting of the agents $\{A2, A5\}$.

Table 4. Alternative Organizational Structures

Org Structure #1	**Org Structure #2**	**Org Structure #3**
1	1	1
2/5	2	2/5/8/9
3	3/6	3/4/6/7
4	4/7	10
6/7	5/8/9	
8/9	10	
10		

These structures are notional but representative, and the coalition values and agent preferences for cooperation are synthetically generated to account for synergies in functional expertise, workforce mix, mission set, location, and other factors. We propose the following test instances based off of the assumptions and constraints detailed above. The effectiveness values (i.e., characteristic values) for individual staff organizations were randomly generated using a uniform distribution, and the effectiveness values of coalitions consisting of multiple staff organizations were determined by summing the values of the subordinate organizations and adding a small random number from a uniform distribution as a cooperation incentive (i.e., superadditivity factor). We assume that if an agent selects not to participate in a coalition, the payoff to the agent will be the effectiveness value for the individual agent.

Table 5. Characteristic Values of the Test Instance

Agent/Coalition	Effectiveness Value	Agent/Coalition	Effectiveness Value
1	9	4/6	9
2	5	4/7	10
3	10	5/8	13
4	3	5/9	15
5	2	6/7	8
6	1	8/9	19
7	4	2/5/8	20
8	7	2/5/9	22
9	9	2/8/9	29
10	6	3/4/6	20
2/5	10	3/4/7	25
2/8	16	3/6/7	23
2/9	19	4/6/7	13
3/4	18	5/8/9	28
3/6	12	2/5/8/9	38
3/7	18	3/4/6/7	30

This test instance with corresponding values will be utilized in subsequent chapters.

IV. Testing, Results, & Analysis

This chapter presents the results of testing and analyses on the three key methodologies discussed previously: traditional cooperative game theory, Myerson graph theory, and hedonic coalition formation. Each methodology is examined and discussed separately, yielding an overarching comparison of the advantages/disadvantages associated with each methodology. The chapter concludes with an analysis of the effects of alternative test instances on preferred organizational structures.

4.1 Traditional Cooperative Game Theory

4.1.1 Shapley Value Solution Concept

The calculations below demonstrate the computation of the Shapley value solution for the coalition consisting of agents $\{2, 5, 9\}$.

$$\Phi_2(\{2,5,9\},22) = \frac{1}{3!}\left[(|2|!\,(|3|-|2|-1)!\,[22-15]) + (|1|!\,(|3|-|1|-1)!\,[10-2]) + (|1|!\,(|3|-|1|-1)!\,[19-9]) + (|0|!\,(|3|-|0|-1)!\,[5-0])\right] = 7.0$$

$$\Phi_5(\{2,5,9\},22) = \frac{1}{3!}\left[(|2|!\,(|3|-|2|-1)!\,[22-19]) + (|1|!\,(|3|-|1|-1)!\,[10-5]) + (|1|!\,(|3|-|1|-1)!\,[15-9]) + (|0|!\,(|3|-|0|-1)!\,[2-0])\right] = 3.5$$

$$\Phi_9(\{2,5,9\},22) = \frac{1}{3!}\left[(|2|!\,(|3|-|2|-1)!\,[22-10]) + (|1|!\,(|3|-|1|-1)!\,[19-5]) + (|1|!\,(|3|-|1|-1)!\,[15-2]) + (|0|!\,(|3|-|0|-1)!\,[9-0])\right] = 11.5$$

Therefore, the fair distribution of payoffs to agents in the coalition $\{2, 5, 9\}$ is 7 units to $\{2\}$, 3.5 units to $\{5\}$, and 11.5 units to $\{9\}$. This distribution reflects the marginal contribution of each individual agent to the coalition $2/5/9$ (i.e., $\{9\}$ has the highest individual effectiveness value and therefore receives the highest Shapley value payoff, followed by $\{2\}$ and then $\{5\}$).

Similarly, the Shapley value payoffs can be calculated for each coalition of 2 agents or more, and the results are shown in Table 7. The blue font identifies the maximum payoff that can fairly be achieved by each agent individually or in in any size coalition.

Table 6. Shapley Value Solutions

Agent	Eff Value	2/5	2/8	2/9	3/4	3/6	3/7	4/6	4/7	5/8	5/9	6/7	8/9
1	**9.0**												
2	5.0	6.5	7.0	7.5									
3	10.0				12.5	10.5	12.0						
4	3.0				5.5			5.5	4.5				
5	2.0	3.5								4.0	4.0		
6	1.0					1.5		**3.5**				2.5	
7	4.0						6.0		5.5			5.5	
8	7.0		9.0							9.0			8.5
9	9.0			11.5							11.0		10.5
10	**6.0**												

Agent	Eff Value	2/5/8	2/5/9	2/8/9	3/4/6	3/4/7	3/6/7	4/6/7	5/8/9	2/5/8/9	3/4/6/7
1	**9.0**										
2	5.0	6.8	7.0	**8.2**						8.0	
3	10.0				11.3	13.2	12.5				**13.5**
4	3.0				**6.3**	5.6		5.0			6.0
5	2.0	3.8	3.5						**5.6**	5.5	
6	1.0				2.4		3.0	3.0			3.3
7	4.0					6.2	**7.5**	5.0			7.2
8	7.0	9.4		9.2					10.2	**11.2**	
9	9.0		11.5	11.6					12.2	**13.3**	
10	**6.0**										

The results from Table 7 suggest that the maximum payoff that can be achieved by an agent is not always through participation in largest coalition that can be formed (i.e., the grand coalition). In fact, these results suggest that the grand coalitions of 2/5/8/9 and 3/4/6/7 are not stable since agents {2}, {4}, {5}, {6}, and {7} have the incentive to deviate and form smaller sub-coalitions of 2 or 3 agents. This perceived lack of stability in the fair distribution of Shapley value payoffs necessitates an examination of core solutions for each coalition.

In terms of the 3 motivating alternative organizational structures in Table 4, no single organizational structure yields the highest Shapley value payoff for all agents; however, the preferred structure for each agent as shown in Table 8 suggests that most agents would prefer organizational structure #3.

Table 7. Shapley Value Solutions for Organizational Structures

Agent	Org Structure #1	Org Structure #2	Org Structure #3
1	**9.0**	**9.0**	**9.0**
2	6.5	5.0	**8.0**
3	10.0	10.5	**13.5**
4	3.0	4.5	**6.0**
5	3.5	**5.6**	5.5
6	2.5	1.5	**3.3**
7	5.5	5.5	**7.2**
8	8.5	10.2	**11.2**
9	10.5	12.2	**13.3**
10	**6.0**	**6.0**	**6.0**

The preference of agent {5} towards organizational structure #2 implies that agent {5} would prefer the smaller sub-coalition of 5/8/9 but would have to receive support from agents {8} and {9}, both of which prefer coalition 2/5/8/9. Therefore, since agent {5} receives a higher payoff from organizational structure #3 than as an individual agent, it can be assumed that agent {5} will tend to join the dominating organizational structure #3 and receive a slightly less payoff than preferred.

4.1.2 Core Solution Concept

To demonstrate the computation of core existence, the formulations below indicate the core requirement for the coalition consisting of agents $\{5, 8, 9\}$. Traditionally, characteristic value equations are normalized to a 0-1 scale prior to analysis of the core for ease of computation and visualization, so the normalized values for the coalition $5/8/9$ are represented by v_r below.

$$v_r(5) = v_r(8) = v_r(9) = 0$$
$$v_r(5/8) = 0.4 \; ; \; v_r(5/9) = 0.4 \; ; \; v_r(8/9) = 0.3$$
$$v_r(5/8/9) = 1$$
$$x_5 + x_8 \geq 0.4$$
$$x_5 + x_9 \geq 0.4$$
$$x_8 + x_9 \geq 0.3$$
$$x_5 + x_8 + x_9 = 1$$
$$x_5 \geq 0 \; ; \; x_8 \geq 0 \; ; \; x_9 \geq 0$$

The set of solutions to this system of equations is depicted graphically in Figure 4.

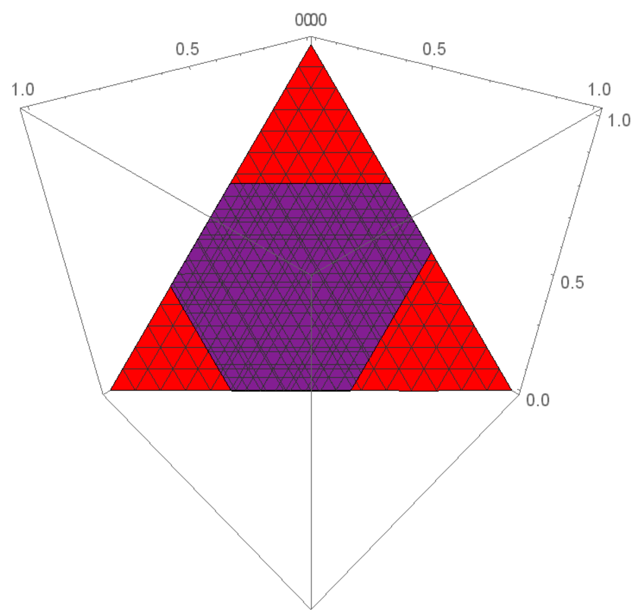

Figure 4. Graphical depiction of the $5/8/9$ core

The entire triangular region of Figure 4 represents the space in which $\{5, 8, 9\}$ could feasibly cooperate. The purple region depicts the set of payoff combinations in which stable cooperation could occur, while the red region depicts the set of payoff combinations in which cooperation would not be stable. In the $5/8/9$ coalition, the existence of a stable set of payoffs (purple region) indicates that agents $\{5,8, 9\}$ would cooperate as a coalition, even if higher individual payoffs could conceivably be achieved through sub-coalitions.

As another example, the formulations below indicate the core requirement for the coalition consisting of agents $\{2, 5, 9\}$.

$$x_2 + x_5 \geq 0.50$$
$$x_2 + x_9 \geq 0.83$$
$$x_5 + x_9 \geq 0.67$$
$$x_2 + x_5 + x_9 = 1$$
$$x_2 \geq 0\ ;\ x_5 \geq 0\ ;\ x_9 \geq 0$$

The resulting feasible solutions are graphically depicted in Figure 5.

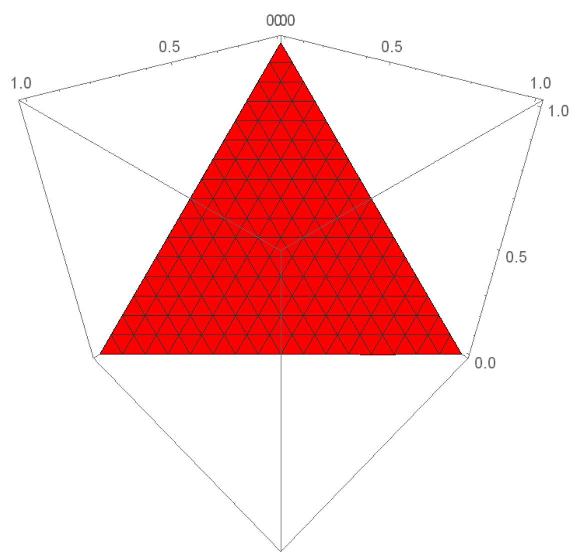

Figure 5. Graphical depiction of the $2/5/9$ core

As indicated by the lack of a purple region in Figure 5, there exists no core solution for the coalition 2/5/9. In this situation, the agents are incentivized to deviate and form smaller sub-coalitions to achieve higher individual payoffs.

The existence (or non-existence) of a core for every coalition of 3 agents among the three alternative organizational structures is illustrated in Figure 6.

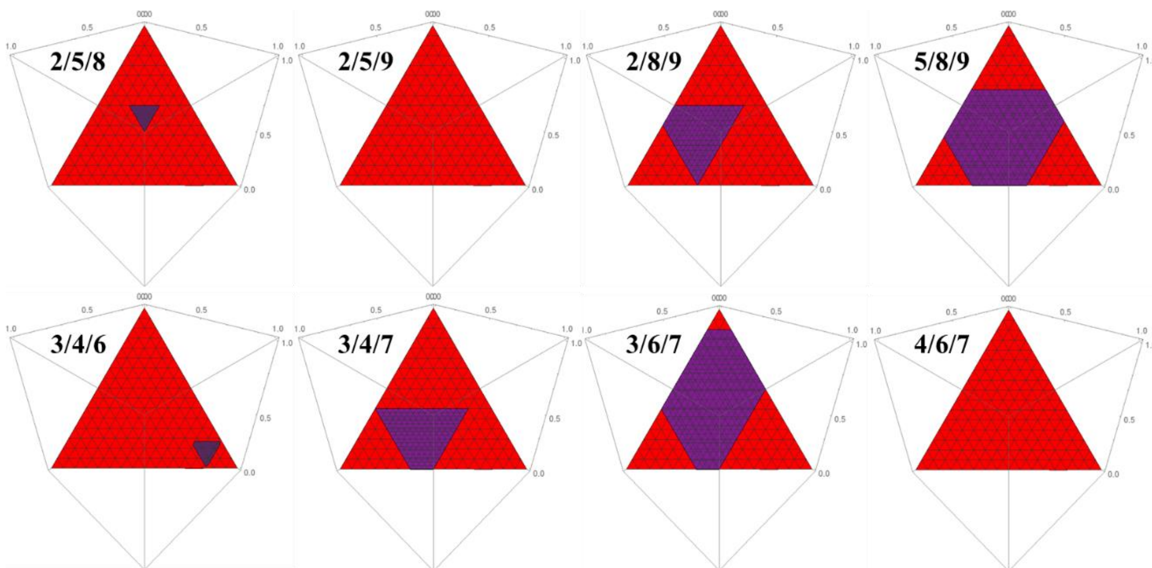

Figure 6. Graphical depictions of 3-agent coalition cores

The coalitions 2/5/9 and 4/6/7 are the only 3-agent coalitions in which a core solution does not exist. This suggests that agents in these coalitions will be incentivized to deviate and form 2-agent coalitions. Coalitions consisting of less than 3 agents do not require core computation since we assumed superadditivity (i.e., agents will receive a higher overall payoff by cooperating than by operating alone), resulting in strictly dominant coalition payoffs for cooperation. Coalitions consisting of more than 3 agents are too difficult to depict graphically; however, core existence can be proven through linear programming methods. By determining that at least one imputation of payoffs does indeed exist for the 4-agent coalitions, we can assert that there is a core solution for the coalition. To prove a core solution exists for the coalition $2/5/8/9$, prove there exists a set of payoffs that satisfies all of the following normalized constraints:

$$v_r(2) = v_r(5) = v_r(8) = v_r(9) = 0$$
$$x_2 + x_5 \geq 0.20$$
$$x_2 + x_8 \geq 0.00$$
$$x_2 + x_9 \geq 0.33$$
$$x_5 + x_8 \geq 0.27$$
$$x_5 + x_9 \geq 0.00$$
$$x_8 + x_9 \geq 0.20$$
$$x_2 + x_5 + x_8 \geq 0.40$$
$$x_2 + x_5 + x_9 \geq 0.40$$
$$x_2 + x_8 + x_9 \geq 0.53$$
$$x_5 + x_8 + x_9 \geq 0.67$$
$$x_2 + x_5 + x_8 + x_9 = 1$$
$$x_2 \geq 0\,;\; x_5 \geq 0\,;\; x_8 \geq 0\,;\; x_9 \geq 0$$

Using the simplex method of linear programming, the existence of imputation $x_2 = 0.73$, $x_5 = 0.27$, and $x_8 = x_9 = 0$ asserts that a core solution for $2/5/8/9$ does indeed exist and is stable. In this coalition, no agent would be incentivized to deviate and form smaller sub-coalitions. Similarly, linear programming can be used to prove that the core of coalition $3/4/6/7$ exists and is stable by the existence of a solution point $x_3 = 0.67$, $x_4 = 0.33$, and $x_6 = x_7 = 0$. Through this analysis, we can assert that all 3 of our motivating alternative organizational structures in Table 4 consist entirely of stable coalitions.

The Shapley value solution concept and the core solution concept provide insight into organizational structures that are stable and fair from the perspective of the agent. The results from this traditional game theory analysis imply that our motivating organizational structures are stable and there is tendency to form organizational structure #3.

4.2 Myerson Graph Theory

To illustrate Myerson graph theory analysis, again consider the coalition consisting of agents $\{2, 5, 9\}$. Using Myerson's fair and stable allocation rules, visually depict the links between agents, compute the relative value added of each agent at each permutation, and determine the resulting payoff distributions represented in the order of agents $\{2, 5, 9\}$.

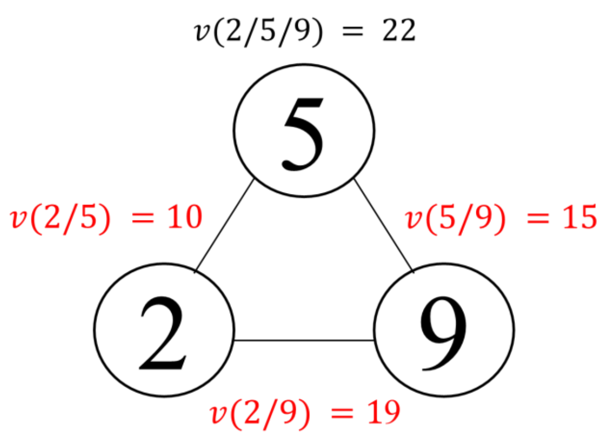

Figure 7. Myerson graph of coalition $2/5/9$

$$\begin{array}{ll} Y(\emptyset) = (0.0, 0.0, 0.0), & Y(\{2:5,\ 2:9\}) = (8.4, 2.8, 10.8), \\ Y(\{2:5\}) = (5.0, 5.0, 0.0), & Y(\{2:5,\ 5:9\}) = (6.2, 5.2, 10.6), \\ Y(\{2:9\}) = (9.5, 0.0, 9.5), & Y(\{2:9,\ 5:9\}) = (6.5, 3.0, 12.5), \\ Y(\{5:9\}) = (0.0, 7.5, 7.5), & Y(\{2:5,\ 2:9,\ 5:9\}) = (7.0, 3.5, 11.5) \end{array}$$

The results above indicate that the payoffs of the coalition $2/5/9$ with all agents connected are the same payoffs yielded in the Shapley value analysis. In this manner, the Myerson graph theory values are a derivation of the Shapley values with a focus on the benefits from cooperation between individual players (i.e., link values). However, the Myerson graph theory can yield insight into special circumstances where a coalition is not operating with full connectivity between agents. For illustration, suppose agents $\{5, 9\}$ have a dysfunctional linkage where there is an incentive to avoid cooperation even with fair and stable payoff distributions. A dysfunctional linkage can stem from organizational differences that result in some sort of negative impact to players (e.g., size of organizations, functional specialties, past history, etc.). With this assumption of a dysfunctional linkage, the Myerson graph can be represented without a link between agents $\{5\}$ and $\{9\}$, as shown in Figure 8 below.

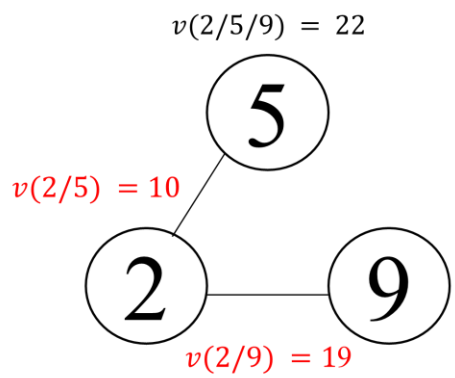

Figure 8. Myerson graph of dysfunctional coalition $2/5/9$

The payoff distributions corresponding to the dysfunctional coalition are calculated below, with the assumption that the link between agents $\{5\}$ and $\{9\}$ is nonexistent.

$$Y(\emptyset) = (0.0, 0.0, 0.0), \qquad Y(\{2:9\}) = (7.5, 0.0, 11.5),$$
$$Y(\{2:5\}) = (6.5, 3.5, 0.0), \qquad Y(\{2:5, 2:9\}) = (8.4, 2.8, 10.8)$$

To illustrate Myerson graph theory's capacity to analyze dysfunctional linkages, the graph of all agents in the test instance can be visually represented as follows (assuming a dysfunctional linkage between agents $\{5\}$ and $\{9\}$.

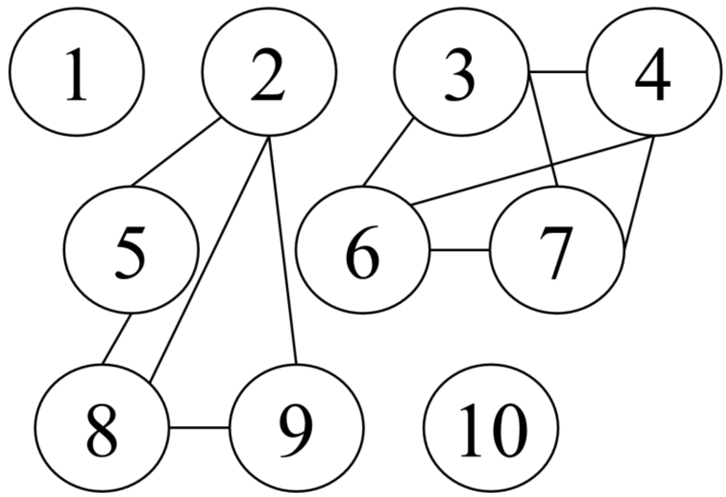

Figure 9. GR representation of test instance

4.2.1 Organizational Structure #1

The first organizational structure is depicted below in graph form with all associated link values. Agent payoffs are represented in the order $\{1, 2, 3, 4, 5, 6, 7, 8, 9, 10\}$.

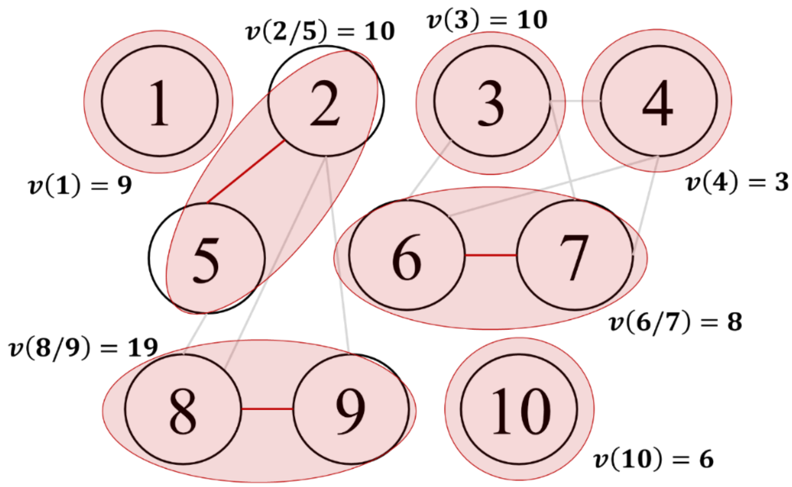

Figure 10. Organizational structure #1 in graph form

Using the same formulation of a fair and stable allocation rule, the payoffs to each agent in this organizational structure are calculated as:

$$Y(\emptyset) = (0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0),$$
$$Y(\{1\}) = (9.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0),$$
$$Y(\{2:5\}) = (0.0, 6.5, 0.0, 0.0, 3.5, 0.0, 0.0, 0.0, 0.0, 0.0),$$
$$Y(\{3\}) = (0.0, 0.0, 10.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0),$$
$$Y(\{4\}) = (0.0, 0.0, 0.0, 3.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0),$$
$$Y(\{6:7\}) = (0.0, 0.0, 0.0, 0.0, 0.0, 2.5, 5.5, 0.0, 0.0, 0.0),$$
$$Y(\{8:9\}) = (0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 8.5, 10.5, 0.0),$$
$$Y(\{10\}) = (0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 6.0),$$
$$Y(\{1, 2:5,\ 3,\ 4,\ 6:7,\ 8:9,\ 10\}) =$$
$$(9.0, 6.5, 10.0, 3.0, 3.5, 2.5, 5.5, 8.5, 10.5, 6.0).$$

In this structure, each agent is receiving at least as much as could be achieved individually, implying the structure is stable according to Myerson's allocation rule. The additional gains from cooperation are also divided up evenly between coalitions (i.e. the Shapley value solutions for corresponding 2-agent coalitions), suggesting that this structure is also a fair distribution of payoffs.

4.2.2 Organizational Structure #2

The second organizational structure is depicted in Figure 11 in graph form with all associated link values.

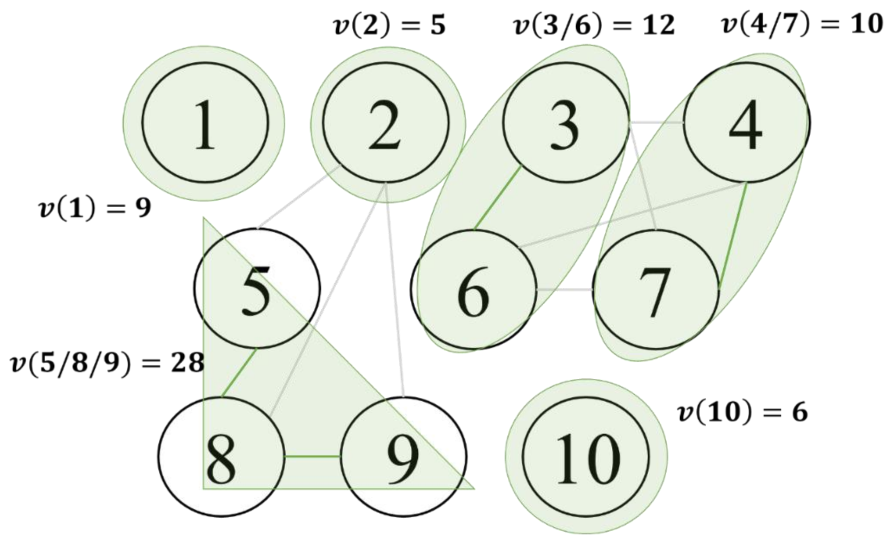

Figure 11. Organizational structure #2 in graph form

Again using the same formulation of a fair and stable allocation rule, the payoffs to each agent in this organizational structure are calculated as:

$$Y(\emptyset) = (0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0),$$
$$Y(\{1\}) = (9.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0),$$
$$Y(\{2\}) = (0.0, 5.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0),$$
$$Y(\{3:6\}) = (0.0, 0.0, 10.5, 0.0, 0.0, 1.5, 0.0, 0.0, 0.0, 0.0),$$
$$Y(\{4:7\}) = (0.0, 0.0, 0.0, 4.5, 0.0, 0.0, 5.5, 0.0, 0.0, 0.0),$$
$$Y(\{5:8,\ 8:9\}) = (0.0, 0.0, 0.0, 0.0, 5.0, 0.0, 0.0, 11.5, 11.5, 0.0),$$
$$Y(\{10\}) = (0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 6.0),$$
$$Y(\{1,\ 2,\ 3:6,\ 4:7,\ 5:8,\ 8:9,\ 10\}) =$$
$$(9.0, 5.0, 10.5, 4.5, 5.0, 1.5, 5.5, 11.5, 11.5, 6.0).$$

According to Myerson's allocation rules, this organizational structure is both stable and fair because each agent is receiving at least as much as could be achieved individually and the additional gains from cooperation are divided up evenly between coalitions. However, the dysfunctional link between agents {5} and {9} causes the payoff allocation schema of this organizational structure to differ from the Shapley value solution.

4.2.3 Organizational Structure #3

The third organizational structure depicted in Figure 12 in graph form with all associated link values.

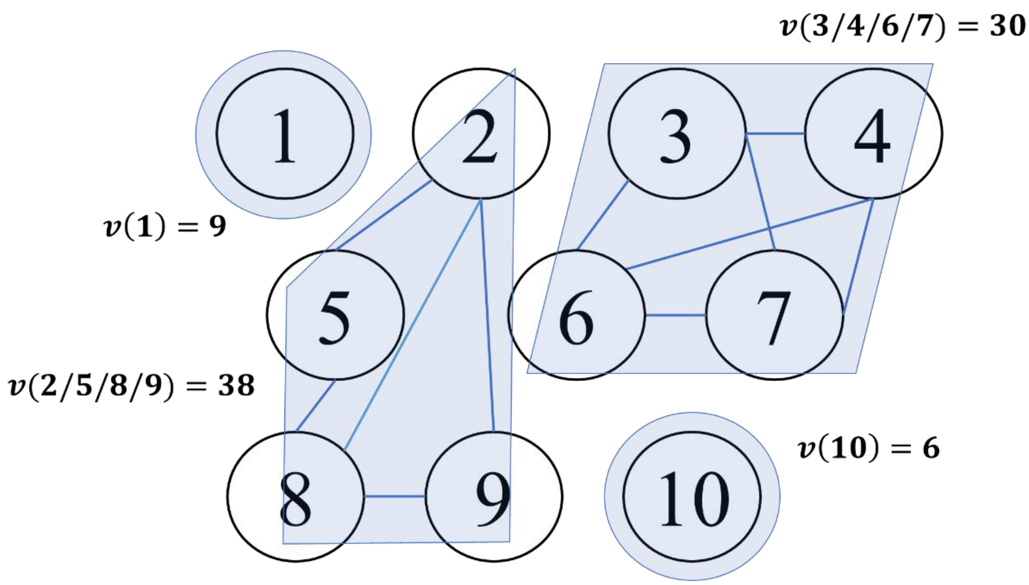

Figure 12. Organizational structure #3 in graph form

The fair and stable payoffs to each agent in this organizational structure are calculated as:

$Y(\emptyset) = (0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0)$,
$Y(\{1\}) = (9.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0)$,
$Y(\{2:5,\ 2:9,\ 5:8,\ 8:9\}) = (0.0, 8.3, 0.0, 0.0, 5.2, 0.0, 0.0, 11.5, 13.0, 0.0)$,
$Y(\{3:4,\ 3:6,\ 3:7,\ 4:6,\ 4:7,\ 6:7\}) =$
$(0.0, 0.0, 13.5, 6.0, 0.0, 3.3, 7.2, 0.0, 0.0, 0.0)$,
$Y(\{10\}) = (0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 0.0, 6.0)$,
$Y(\{1,\ 2:5,\ 2:8,\ 2:9,\ 3:4,\ 3:6,\ 3:7,\ 4:6,\ 4:7,\ 5:8,\ 5:9,\ 6:7,\ 8:9,$
$10\}) = (9.0, 8.3, 13.5, 6.0, 5.2, 3.3, 7.2, 11.5, 13.0, 6.0)$.

According to Myerson's allocation rules, this organizational structure is both stable and fair. The dysfunctional link between agents {5} and {9} also causes the payoff allocation schema of this organizational structure to differ from the Shapley value solution.

4.2.4 Organizational Structure Comparison

For ease of comparison, the resulting Myerson value payoffs for each agent in each organizational structure are shown in Table 8.

Table 8. Myerson Value Solutions for Organizational Structures

Agent	Org Structure #1	Org Structure #2	Org Structure #3
1	**9.0**	**9.0**	**9.0**
2	6.5	5.0	**8.3**
3	10.0	10.5	**13.5**
4	3.0	4.5	**6.0**
5	3.5	5.0	**5.2**
6	2.5	1.5	**3.3**
7	5.5	5.5	**7.2**
8	8.5	**11.5**	**11.5**
9	10.5	11.5	**13.0**
10	**6.0**	**6.0**	**6.0**

Unlike the results of the Shapley value analysis, organizational structure #3 is explicitly preferred through the Myerson value solution. The dysfunctional linkage between agents {5} and {9} yielded lower payoffs to the 5/8/9 coalition in organizational structure #2, causing agent {5} to now prefer organizational structure #3. Therefore, we can assert that organizational structure #3 is the dominating configuration from the Myerson value analysis.

4.3 Hedonic Coalition Formation

To examine the hedonic preferences of the agents in our test instance, we assume all agents are connected in a coalition and can thereby expect to receive the Shapley value payoff of any given organizational structure. Based off Table 6 and the aforementioned assumptions and constraints, the effectiveness values can be mapped to a preference structure over available coalitions for each agent, as reported in Table 9.

Table 9. Agent Coalition Preferences for the Test Instance

Agent	Coalition Preferences
1	1
2	2/8/9 > 2/5/8/9 > 2/9 > (2/8 = 2/5/9) > 2/5/8 > 2/5 > 2
3	3/4/6/7 > 3/4/7 > (3/4 = 3/6/7) > 3/7 > 3/4/6 > 3/6 > 3
4	3/4/6 > 3/4/6/7 > 3/4/7 > (3/4 = 4/6) > 4/6/7 > 4/7 > 4
5	5/8/9 > 2/5/8/9 > (5/8 = 5/9) > 2/5/8 > (2/5 = 2/5/9) > 5
6	4/6 > 3/4/6/7 > (3/6/7 = 4/6/7) > 6/7 > 3/4/6 > 3/6 > 6
7	3/6/7 > 3/4/6/7 > 3/4/7 > 3/7 > (4/7 = 6/7) > 4/6/7 > 7
8	2/5/8/9 > 5/8/9 > 2/5/9 > 2/8/9 > (2/8 = 5/8) > 8/9 > 8
9	2/5/8/9 > 5/8/9 > 2/8/9 > (2/9 = 2/5/9) > 5/9 > 8/9 > 9
10	10

According to these hedonic preferences, the core stable structure is derived to be the partitioning of $\{1\}\{2/5/8/9\}\{3/4/6/7\}\{10\}$, since no agent would have the incentive to deviate from this structure and form another coalition T. Similarly, the Nash stable outcome is also $\{1\}\{2/5/8/9\}\{3/4/6/7\}\{10\}$ since all agents are better off in cooperating in this structure than by joining one of the other coalitions in the partition Π. The relation between Nash stability and individual stability as described in Chapter 3 indicates that the coalition partition satisfies individual stability for every agent as well. Therefore, as in the traditional game theory and Myerson graph theory analysis, the results of the hedonic coalition analysis is the formation of Organizational Structure #3.

The true value of the hedonic coalition formation methodology is in its ability to create preferences of agents derived from more than just the expected payoffs from cooperation. To illustrate this concept, we assume that agents in our test instance also have preferences on the size of the coalition (i.e., the number of agents cooperating in a coalition). Coalition preferences of each agent are first ranked by the number of agents in a coalition and then by the expected Shapley value payoff for the given agent. Let Table 10 represent agent preferences for the size of a coalition. We assume that a deviation of one agent more or less in the size of a coalition is preferred to deviations of two or more.

Table 10. Agent Coalition Size Preference

Agent	Preference #1	Preference #2	Preference #3	Preference #4
1	1			
2	2	3	1	4
3	3	2	1	4
4	1	2	3	4
5	4	3	2	1
6	3	4	2	1
7	4	3	2	1
8	3	2	4	1
9	2	3	1	4
10	1			

Ordering according to the coalition size preferences of Table 10 first and then by the Shapley value payoffs of Table 6, the following coalition preferences are induced for each agent.

Table 11. Agent Coalition Preferences by Coalition Size and Payoff

Agent	Coalition Preferences
1	1
2	2/9 > 2/8 > 2/5 > 2/8/9 > 2/5/9 > 2/5/8 > 2 > 2/5/8/9
3	3/4/7 > 3/6/7 > 3/4/6 > 3/4 > 3/7 > 3/6 > 3 > 3/4/6/7
4	4 > (3/4 = 4/6) > 4/7 > 3/4/6 > 3/4/7 > 4/6/7 > 3/4/6/7
5	2/5/8/9 > 5/8/9 > 2/5/8 > 2/5/9) > (5/8 = 5/9) > 2/5 > 5
6	(3/6/7 = 4/6/7) > 3/4/6 > 3/4/6/7 > 4/6 > 6/7 > 3/6 > 6
7	3/4/6/7 > 3/6/7 > 3/4/7 > 4/6/7 > 3/7 > (4/7 = 6/7) > 7
8	5/8/9 > 2/5/9 > 2/8/9 > (2/8 = 5/8) > 8/9 > 2/5/8/9 > 8
9	2/9 > 5/9 > 8/9 > 5/8/9 > 2/8/9 > 2/5/9 > 9 > 2/5/8/9
10	10

For this varied set of hedonic preferences, the core stable and Nash stable partitions differ from previous solutions. First, there exists a core stable partition of $\{1\}\{2/9\}\{3/6/7\}\{4\}\{5/8\}\{10\}$. Agents $\{2, 9\}$ would willingly cooperate as their first preference, thereby forcing agents $\{5, 8\}$ to cooperate to achieve a higher payoff. Since operating alone is the first preference of agent $\{4\}$, agents $\{3, 6, 7\}$ will recognize that their best option is to cooperate as a 3-agent coalition. For this preference structure, there does not exist a Nash stable solution where every agent is better off cooperating in this structure than by joining one of the other coalitions in the partition Π. As an example, agent $\{5\}$ prefers the coalition $\{2/5/9\}$ over $\{5/8\}$, but the preferences of agents $\{2,9\}$ block the formation of $\{2/5/9\}$. Therefore, the preferences of agent $\{5\}$ (among other agents) prevent the existence of a Nash stable solution. However, the partition of $\{1\}\{2/9\}\{3/6/7\}\{4\}\{5/8\}\{10\}$ is individually stable since no agent can leave to join another coalition in a stable partition and still be better off.

As another aside, if we assume that only coalitions that exist in at least one of our three organizational structures (Table 4) are possible, yet another solution exists. The core stable solution for this scenario is $\{1\}\{2\}\{3\}\{4\}\{5/8/9\}\{6/7\}\{10\}$, which is a blend of organizational structures #1 and #2. Still no Nash stable solution exists, but the core stable partition is also individually stable. Therefore, the hedonic coalition formation methodology provides more insight into preference of agents to cooperate based on individual coalition composition rather than the overall partitioning of agents into a given coalition structure.

4.4 Comparison of Methodology Results

In order to fully understand and appreciate their inherent advantages and disadvantages, we must first consider the attributes of each method and the organizational information required therein. Table 12 concisely summarizes the properties of traditional game theory, Myerson graph theory, and hedonic coalition formation methods. The intent of this table is to provide leadership with a concise summary of the inherent properties, benefits, and limitations of each method.

Table 12. Method Properties

Method	Perspective	Required Information	Value	Limitations
Traditional Cooperative Game Theory	Transferrable Utility	• Characteristic Values – quantitative evaluation over all feasible coalitions	• Commonly accepted standard for identifying fair and stable coalition structures • Demonstrates the difference between what is fair and what is stable	• Requires both Shapley value and core analyses to understand dynamic between fair and stable • No easy visual depiction of core for more than 3-agent coalitions • Computationally complex combinatorics for analysis • Core analysis does not distinguish between preferred structures
Myerson Graph Theory	Transferrable Utility	• Characteristic Values – quantitative evaluation over all feasible coalitions • Other relationships – preference solicitation (quantitative- or qualitative-based value)	• Provides insight for coalitions with dysfunctional linkages • Validates both fair and stable solutions	• If no dysfunctional linkages exist, does not provide any more insight than Shapley value solutions • Computationally complex combinatorics for analysis
Hedonic Coalition Formation	Non-Transferrable Utility	• Individual Preferences – preference solicitation (quantitative- or qualitative-based value)	• Allows for multi-dimension preference usage • Requires relative preferences instead of exact characteristic values for computation	• No information provided on distribution of payoffs • May provide contradicting stable structures according to stability concept considered • Computationally complex combinatorics for analysis

The first factor considered in the comparison is the "perspective" of each method, which helps to identify either a macroscopic or microscopic level of depth for analysis. Traditional cooperative game theory and Myerson graph theory present organizational structure from a macroscopic perspective because utility is represented as an aggregate combination of organizational factors, which can be translated into divisible units (i.e., transferrable utility). In other words, effectiveness criteria is aggregated into utility values (i.e., characteristic values) that represent the perspective of an individual agent. Hedonic coalition formation, on the other hand, presents organizational structure from a microscopic, non-transferrable utility perspective. It is too difficult to aggregate preferences into common, transferrable utilities; therefore, the preferences of a single leader or small group of leaders will be used as a proxy for the preferences of an individual agent.

The second factor considered in Table 12 is the information required to conduct the analyses for each method. The information required is a reflection of the type and depth of data that needs to be collected from the representative agent. The primary difference between methods is the need for either defined characteristic values or a set of solicited preference rankings. Collecting characteristic values (or effectiveness values) for analysis requires a quantitative evaluation over all feasible coalitions, which could potentially be very time intensive depending on the number of agents. Defining exact values to represent each coalition can also be challenging due to the extreme dependence on the criteria and methodology used for aggregation. Preference solicitation can sometimes be more easily derived through either qualitative or quantitative methods, but it typically represents more of a singular, subjective perspective than a quantitative evaluation over all feasible coalitions.

The third and fourth factors in Table 12 detail the benefits and limitations of using each method. While traditional cooperative game theory is a commonly accepted methodology for identifying fair and stable coalitions, it is computationally complex and lacks the ability to model more complex relationships between agents. Myerson graph theory and hedonic coalition formation provide more insight in unique situations, such as in the existence of dysfunctional linkages and multiple layers of preferences (e.g. size of coalition, agent expertise area, etc.), but do not add much value in structure analysis without these special circumstances.

The value of a comparison table manifests in the translation of real organizational structure characteristics into a representative sample capable of being analyzed from an agent-based perspective. While each method has advantages and disadvantages, this summary helps to capture the properties of each method to help the decision-makers and analysts in AFMC and external industry organizations alike examine organizational restructure from a different viewpoint.

4.5 Analysis of Alternative Test Instances

To better comprehend the complexities of each method and the resulting impact on preferred organizational structures, we deviate from our notational superadditive test instance and examine instances wherein additive and/or subadditive effectiveness relationships may exist. Considering the same alternative organizational structures and coalition structures, we first allow for subadditive, additive, or superadditive effects (i.e., all effectiveness values are generated randomly with no relationship between larger coalitions and contributing agents). This instance differs most from our previous analysis and illustrates important characteristics derived from alternative test instances. We subsequently examine an instance allowing for either additive or superadditive but not subadditive effects (i.e., effectiveness values for a given coalition are computed as the sum of the effectiveness values of the contributing agents in a coalition, with a random chance there will be a cooperation incentive or superadditive surplus added).

4.5.1 Instance with Subadditive, Additive, or Superadditive Effects

A randomly generated notional test instance allowing for subadditive, additive, or superadditive properties is detailed in Table 13.

Table 13. Test Instance with Subadditive/Additive/Superadditive Effects

Agent/Coalition	Effectiveness Value	Agent/Coalition	Effectiveness Value
1	21	4/6	11
2	4	4/7	18
3	18	5/8	25
4	20	5/9	25
5	19	6/7	18
6	5	8/9	3
7	6	2/5/8	25
8	14	2/5/9	1
9	9	2/8/9	11
10	3	3/4/6	4
2/5	13	3/4/7	9
2/8	10	3/6/7	21
2/9	23	4/6/7	16
3/4	14	5/8/9	14
3/6	18	2/5/8/9	20
3/7	21	3/4/6/7	20

Using this particular test instance, we compute the Shapley values for each coalition, as shown in Table 14.

Table 14. Shapley Value Solutions for Instance with Subadditive/Additive/Superadditive Effects

Agent	Eff Value	2/5	2/8	2/9	3/4	3/6	3/7	4/6	4/7	5/8	5/9	6/7	8/9
1	**21**												
2	4	-1.0	0.0	**9.0**									
3	**18**				6.0	15.5	16.5						
4	**20**				8.0			13.0	16.0				
5	**19**	14.0								15.0	17.5		
6	5					2.5		-2.0				**8.5**	
7	6						4.5		2.0			**9.5**	
8	**14**		10.0							10.0			4.0
9	9			**14.0**							7.5		-1.0
10	**3**												

Agent	Eff Value	2/5/8	2/5/9	2/8/9	3/4/6	3/4/7	3/6/7	4/6/7	5/8/9	2/5/8/9	3/4/6/7
1	**21**										
2	4	-0.3	-5.4	5.6						1.5	
3	**18**				4.8	4.5	11.6				6.3
4	**20**				2.3	4.0		9.0			3.5
5	**19**	14.6	3.2						14.5	10.3	
6	5				-3.1		3.7	1.5			3.3
7	6					0.5	5.7	5.5			6.9
8	**14**	10.7		0.7					1.0	7.9	
9	9		3.2	4.7					-1.5	0.3	
10	**3**										

One of the most striking aspects of this result is the emergence of negative Shapley values. Negative Shapley values can be interpreted as an agent having to "pay" the other agents to cooperate in a particular coalition because their participation degrades the overall value of the coalition (i.e., the coalition has subadditive properties). As a result of subadditive properties, there is a tendency for most agents to prefer working alone to cooperating and receiving a lesser payoff. These Shapley values can be converted into preferences in terms of our three motivating alternative structures.

Table 15. Shapley Value Preferences for Subadditive/Additive/Superadditive Instance

Agent	Org Structure #1	Org Structure #2	Org Structure #3
1	**21.0**	**21.0**	**21.0**
2	-1.0	**4.0**	1.5
3	**18.0**	15.5	6.3
4	**20.0**	16.0	3.5
5	14.0	**14.5**	10.3
6	**8.5**	2.5	3.3
7	**9.5**	2.0	6.9
8	4.0	-1.5	**7.9**
9	-1.0	-1.5	**0.3**
10	**3.0**	**3.0**	**3.0**

Unlike the original superadditive test instance, most agents in this test instance prefer Organizational Structure #1. However, in Organizational Structure #1, agents $\{2\}$ and $\{9\}$ both receive negative Shapley values, indicating that they are forced to cooperate in structures with subadditive properties. This type of structure likely lacks stability since agents will have an incentive to deviate to a structure yielding a positive payoff for all agents, such as Organizational Structure #3. Yet Organizational Structure #3 lacks stability as well because agents such as $\{2,3,4,6,7\}$ have the incentive to deviate and form smaller sub-coalitions or operate autonomously. This tendency to not cooperate is an interesting byproduct of the existence of subadditive coalitions and is noteworthy when developing effectiveness values and analyzing alternative organizational structures.

Similar to the Shapley value analysis, the core analysis also yields thought-provoking insights. We are unable to represent the core solutions graphically because subadditive coalitions cannot be effectively normalized, but linear programming software indicated that all coalition structures with two or more agents are unstable, with the exception of coalitions $2/9$, $6/7$, $2/5/8$, $3/4/6$, and $3/4/7$. This supports Shapley value indication that all three of our motivating alternative organizational structures are not stable in this test instance.

As discussed in Section 4.2, the Myerson value solutions will yield the same distribution of payoffs to agents as the Shapley value method. Again assuming a dysfunctional linkage between agents {5, 9}, the preferred organizational structures for each agent are shown in Table 16.

Table 16. Myerson Value Solutions for Subadditive/Additive/Superadditive Instance

Agent	Org Structure #1	Org Structure #2	Org Structure #3
1	**21.0**	**21.0**	**21.0**
2	-1.0	**4.0**	3.6
3	**18.0**	15.5	6.2
4	**20.0**	16.0	3.6
5	**14.0**	10.3	8.2
6	**8.5**	2.5	3.3
7	**9.5**	2.0	6.9
8	4.0	9.3	**9.9**
9	**-1.0**	-5.6	-1.7
10	**3.0**	**3.0**	**3.0**

Using this methodology, almost all agents prefer Organizational Structure #1, with the exception of agents {2} and {8}. However, the structure is still not stable because agent {2} is incentivized to deviate and operate autonomously. Therefore, similar to the traditional game theory method results, Organizational Structure #1 is preferred by most, but ultimately no single organizational structure is stable.

Finally, the hedonic coalition formation method is examined for this instance allowing for subadditivity. The preference structure derived from the Shapley values (without any added preferences towards size of a coalition or other factors) is detailed in Table 17.

Table 17. Hedonic Preferences for Subadditive/Additive/Superadditive Instance

Agent	Coalition Preferences
1	1
2	2/9 > 2/8/9 > 2 > 2/5/8/9 > 2/8 > 2/5/8 > 2/5 > 2/5/9
3	3 > 3/7 > 3/6 > 3/6/7 > 3/4/6/7 > 3/4 > 3/4/6 > 3/4/7
4	4 > 4/7 > 4/6 > 4/6/7 > 3/4 > 3/4/7 > 3/4/6/7 > 3/4/6
5	5 > 5/9 > 5/8 > 2/5/8 > 5/8/9 > 2/5 > 2/5/8/9 > 2/5/9
6	6/7 > 6 > 3/6/7 > 3/4/6/7 > 3/6 > 4/6/7 > 4/6 > 3/4/6
7	6/7 > 3/4/6/7 > 7 > 3/6/7 > 4/6/7 > 3/7 > 4/7 > 3/4/7
8	8 > 2/5/8 > (2/8 = 5/8) > 2/5/8/9 > 8/9 > 5/8/9 > 2/8/9
9	2/9 > 9 > 5/9 > 2/8/9 > 2/5/9 > 2/5/8/9 > 8/9 > 5/8/9
10	10

The core stable structure from these preferences is $\{1\}\{2/9\}\{3\}\{4\}\{5\}\{6/7\}\{8\}\{10\}$, which is unique to all of our motivating alternative structures, but most similar to Organizational Structure #1. This structure is also the Nash stable structure because all agents are better off in cooperating in this structure than by joining one of the other coalitions in the partition Π, and individual stability is satisfied by the relation between Nash stability and individual stability as described in Chapter 3. Superimposing the size preference structure of Table 10 on the payoff distribution preferences of Table 17, we derive a new preference structure with an emphasis on size in Table 18.

Table 18. Hedonic Preferences with Size for Subadditive/Additive/Superadditive Instance

Agent	Coalition Preferences
1	1
2	2/9 > 2/8 > 2/5 > 2/8/9 > 2/5/8 > 2/5/9 > 2 > 2/5/8/9
3	3/6/7 > 3/4/6 > 3/4/7 > 3/7 > 3/6 > 3/4 > 3 > 3/4/6/7
4	4 > 4/7 > 4/6 > 3/4 > 4/6/7 > 3/4/7 > 3/4/6 > 3/4/6/7
5	2/5/8/9 > 2/5/8 > 5/8/9 > 2/5/9 > 5/9 > 5/8 > 2/5 > 5
6	3/6/7 > 4/6/7 > 3/4/6 > 3/4/6/7 > 6/7 > 3/6 > 4/6 > 6
7	3/4/6/7 > 3/6/7 > 4/6/7 > 3/4/7 > 6/7 > 3/7 > 4/7 > 7
8	2/5/8 > 5/8/9 > 2/8/9 > (2/8 = 5/8) > 8/9 > 2/5/8/9 > 8
9	2/9 > 5/9 > 8/9 > 2/8/9 > 2/5/9 > 5/8/9 > 9 > 2/5/8/9
10	10

With the addition of a size preference, the new core stable organizational structure is {1}{2/9}{3/6/7}{4}{5/8}{10}, which is also individually stable since no agent can leave to join another coalition in a stable partition and still be better off. Agent {4} blocks a Nash stable structure since agent {7} would prefer the coalition 3/4/6/7 but cannot incentive agent {4} to cooperate. This structure is unique to our motivating alternative structures, but is exactly the same result as in the original test instance imposing strict superadditivity. This insight emphasizes the importance of understanding the ranking of preferences (e.g., size, payoff distribution, etc.) since the primary preferences can potentially supersede even a unique effectiveness value distribution and result in the same preferred organizational structure.

As an overarching theme, a test instance allowing for the properties of subadditivity, additivity, and superadditivity leads to greater reluctance to cooperate and stronger tendencies for autonomy to avoid negative or smaller payoffs. In terms of our motivating alternative structures, agents generally prefer Organizational Structure #1 for all methods, with the exception of the hedonic coalition formation analysis with size preference.

4.5.2 Instance with Additive or Superadditive Effects

A randomly generated notional test instance for organizational agents with only additive or superadditive properties is shown in Table 19.

Table 19. Test Instance with Additive/Superadditive Effects

Agent/Coalition	Effectiveness Value	Agent/Coalition	Effectiveness Value
1	6	4/6	18
2	5	4/7	21
3	10	5/8	14
4	8	5/9	16
5	2	6/7	21
6	10	8/9	22
7	10	2/5/8	21
8	10	2/5/9	22
9	10	2/8/9	26
10	4	3/4/6	33
2/5	9	3/4/7	31
2/8	20	3/6/7	35
2/9	18	4/6/7	29
3/4	30	5/8/9	27
3/6	21	2/5/8/9	31
3/7	20	3/4/6/7	43

Using this particular test instance, we compute the Shapley values for each coalition, as shown in Table 20.

Table 20. Shapley Value Solutions for Instance with Additive/Superadditive Effects

Agent	Eff Value	2/5	2/8	2/9	3/4	3/6	3/7	4/6	4/7	5/8	5/9	6/7	8/9
1	**6.0**												
2	5.0	6.0	**7.5**	6.5									
3	10.0				11.0	10.5	10.0						
4	8.0				9.0			8.0	9.5				
5	2.0	3.0								3.0	**4.0**		
6	10.0					10.5		10.0				10.5	
7	10.0						10.0		**11.5**			10.5	
8	10.0		**12.5**							11.0			11.0
9	10.0			11.5							12.0		11.0
10	**4.0**												

Agent	Eff Value	2/5/8	2/5/9	2/8/9	3/4/6	3/4/7	3/6/7	4/6/7	5/8/9	2/5/8/9	3/4/6/7
1	**6.0**										
2	5.0	6.8	6.2	6.0						5.7	
3	10.0				**12.2**	10.4	11.5				12.0
4	8.0				9.6	**9.8**		8.5			9.0
5	2.0	2.4	3.6						**4.0**	3.8	
6	10.0				11.2		**12.0**	9.5			11.2
7	10.0					10.8	**11.5**	11.0			10.8
8	10.0	11.8		10.5					11.0	10.6	
9	10.0		**12.2**	9.5					12.0	10.9	
10	**4.0**										

While there are no negative Shapley values in the results of this particular test instance, there is potential for negative Shapley values to exist if the effectiveness value of an agent joining a coalition does not exceed the cooperation incentive bonus of the coalition without the joining agent (e.g., the effectiveness value of coalition $2/5/8$ could be lower than the effectiveness value of $5/8$ if the effectiveness value of agent $\{2\}$ alone is less than the additional cooperation incentive bonus added to the sum of effectiveness values of agents $\{5, 8\}$). Similar to previous analyses, these Shapley values can be converted into preferences in terms of our 3 motivating alternative structures.

Table 21. Shapley Value Preferences for Additive/Superadditive Instance

Agent	Org Structure #1	Org Structure #2	Org Structure #3
1	**6.0**	**6.0**	**6.0**
2	**6.0**	5.0	5.7
3	10.0	10.5	**12.0**
4	8.0	**9.5**	9.0
5	3.0	**4.0**	3.8
6	10.5	10.5	**11.2**
7	10.5	**11.5**	10.8
8	**11.0**	**11.0**	10.6
9	11.0	**12.0**	10.9
10	**4.0**	**4.0**	**4.0**

In this particular test instance, most agents prefer Organizational Structure #2. The agents who prefer alternative structures will not be able to incentivize other agents to deviate, thereby stabilizing the preferred Organizational Structure #2. An analysis of the core supports this conclusion because, by linear programming methods, core solutions exist for every coalition in the test instance except coalitions $3/6/7$, $4/6/7$, $2/5/8/9$, and $3/4/6/7$, which also renders Organizational Structure #3 as an infeasible alternative.

The results of the Myerson graph theory analysis, with the assumption of a dysfunctional linkage between agents $\{5, 9\}$ is provided in Table 22.

Table 22. Myerson Value Solutions for Additive/Superadditive Instance

Agent	Org Structure #1	Org Structure #2	Org Structure #3
1	**6.0**	**6.0**	**6.0**
2	6.0	5.0	**7.1**
3	10.0	10.5	**12.0**
4	8.0	**9.5**	9.0
5	**3.0**	1.4	2.4
6	10.5	10.5	**11.2**
7	10.5	**11.5**	10.8
8	11.0	**16.3**	11.9
9	**11.0**	9.3	9.6
10	**4.0**	**4.0**	**4.0**

The addition of a dysfunctional linkage leaves no clear preferred organizational structure. This result emphasizes the nature of an additive/superadditive test instance to be very sensitive to the individual effectiveness values of each particular agent for preferred structures. A blend of all three alternative organizational structures will ensue in this instance.

The hedonic preferences of this additive/superadditive test instance, as derived from Shapley value solutions, is shown in Table 23.

Table 23. Hedonic Preferences for Additive/Superadditive Instance

Agent	Coalition Preferences
1	1
2	2/8 > 2/5/8 > 2/9 > 2/5/9 > (2/5 = 2/8/9) > 2/5/8/9 > 2
3	3/4/6 > 3/4/6/7 > 3/6/7 > 3/4 > 3/6 > 3/4/7 > (3 = 3/7)
4	3/4/7 > 3/4/6 > 4/7 > (3/4 = 3/4/6/7) > 4/6/7 > (4 = 4/6)
5	(5/9 = 5/8/9) > 2/5/8/9 > 2/5/9 > (2/5 = 5/8) > 2/5/8 > 5
6	3/6/7 > (3/4/6 = 3/4/6/7) > (3/6 = 6/7) > (6 = 4/6) > 4/6/7
7	(4/7 = 3/6/7) > 4/6/7 > (3/4/7 = 3/4/6/7) > 6/7 > (7 = 3/7)
8	2/8 > 2/5/8 > (5/8 = 8/9 = 5/8/9) > 2/5/8/9 > 2/8/9 > 8
9	2/5/9 > (5/9 = 5/8/9) > 2/9 > 8/9 > 2/5/8/9 > 9 > 2/8/9
10	10

This set of agent preferences has two unique core stable solutions: $\{1\}\{2/8\}\{3/4/6\}\{5/9\}\{7\}\{10\}$ and $\{1\}\{2/8\}\{3/4/7\}\{4\}\{5/9\}\{10\}$. The determination of a prevailing structure largely depends on the order of coalition formation. Due to the existence of two core stable solutions, both Nash stability and individual stability are blocked, since agents $\{3, 4, 6, 7\}$ do not all share a preferred structure. The inclusion of size preferences for agents as defined in Table 10 results in the following preferences for this test instance.

Table 24. Hedonic Preferences with Size for Additive/Superadditive Instance

Agent	Coalition Preferences														
1	1														
2	2/8	>	2/9	>	2/5	>	2/5/8	>	2/5/9	>	2/8/9	>	2	>	2/5/8/9
3	3/4/6	>	3/6/7	>	3/4/7	>	3/4	>	3/6	>	3/7	>	3	>	3/4/6/7
4	4	>	4/7	>	3/4	>	4/6	>	3/4/7	>	3/4/6	>	4/6/7	>	3/4/6/7
5	2/5/8/9	>	5/8/9	>	2/5/9	>	2/5/8	>	5/9	>	(2/5	=	5/8)	>	5
6	3/6/7	>	3/4/6	>	4/6/7	>	3/4/6/7	>	(3/6	=	6/7)	>	4/6	>	6
7	3/4/6/7	>	3/6/7	>	4/6/7	>	3/4/7	>	4/7	>	6/7	>	3/7	>	7
8	2/5/8	>	5/8/9	>	2/8/9	>	2/8	>	(5/8	=	8/9)	>	2/5/8/9	>	8
9	5/9	>	2/9	>	8/9	>	2/5/9	>	5/8/9	>	2/8/9	>	9	>	2/5/8/9
10	10														

This result reinforces the notion that while size preference does heavily influence the preferred organizational structure, the effectiveness value distribution still is important. The core stable partitioning of this test instance is unique from all other analyses and results in the structure $\{1\}\{2/8\}\{3/6/7\}\{4\}\{5/9\}\{10\}$, which is also individually stable. There does not exist a Nash stable partition for this test instance with size preferences.

The preferred organizational structure of instances with additive and superadditive effectiveness values is much more difficult to perceive since preferences can dramatically change based on different relationships between individual agents. The traditional cooperative game theory analyses suggested that Organizational Structure #2 would be preferred for this test instance, but dysfunctional linkages and size preferences created complexities which resulted in no single dominating structure. While alternative test instances provided insight into the relationship between effectiveness value structures and organizational structures, this analysis supported the results of Section 4.4 in that the viewpoint for analysis, the information required, and the advantages/disadvantages corresponding to each method remained constant for all test instances. Therefore, we can assert that our analysis and representation of three alternative agent-based methods for evaluating organizational structure is not dependent upon particular test instance structure.

IV. Conclusions

5.1 Summary

Regardless of commercial, private, or governmental mission, organizations must constantly adapt to meet the needs of a changing environment. AFMC, as a representative AF business unit, has dramatically evolved over the past few decades to continue to execute its mission in the most effective way. Public and private industry organizations (e.g., Cardinal Health and P&G) have experienced similar transitions in recent years to stay competitive and relevant in a dynamically changing world. Building upon the need for effective organizational restructure, this thesis makes the following contributions to the discipline of cooperative game theory.

1. Via a survey of the literature, it identifies organizational effectiveness measures that can be used to assess the value of an organizational structure, and it identifies a subset thereof that is more readily quantifiable. Whereas some of these are directly quantifiable from a macroscopic view, the majority of such measures are more typically assessed via survey methodologies.
2. Using an instance representative of an Air Force organization's staff elements (but also notionally representative of commercial, public, or private subordinate organizations), it illustrates the use of three methods from cooperative game theory to assess the relative viability of alternative organizational structures. For both the application of Myerson graph theory and hedonic coalition formation analyses, this is the first demonstration of their use for a practical scenario to date, based on an extensive survey of the literature.

3. It provides a comparative analysis of the three cooperative game theory analysis methods for use in organizational structure analysis. With a view toward helping a decision-maker identify an appropriate cooperative game theory method to consider, this analysis specifically identifies and compares, across methods, the presumptive viewpoint for analysis (e.g., macroscopic or agent-based), the required information to facilitate analyses, the benefits derived from utilizing each particular method, and the limitations inherent in each type of analyses.

5.2 Limitations

This research makes some assumptions that merit further scrutiny to ensure they hold for a given application under consideration. Fundamentally, an organization must be concerned with the perspective of subordinate organizations/agents to even consider the methods examined herein. Assessing the metrics and/or preferences requires considerable deliberation and effort, and doing so would require that an organization's leadership values such input and perspective.

We can only analyze what we can measure. Certain methodologies may seem appealing in theory but reveal themselves to be too academic and are challenging to apply. For example, decision-makers might be uncomfortable identifying criteria to aggregate to attain a single measure of organizational effectiveness. I.e., the hedonic coalition formation methodology could be the only viable alternative for examining organizational structure from an agent-based view.

We can only analyze *effectively* what we can measure *appropriately*. Each of the three methods examined herein relies on the identification of a subordinate unit/agent, an identity that may alternatively represent an aggregation of units and people within it, or perhaps be represented by the leadership of it. Each organization must consider and define what constitutes such a subordinate unit/agent. Resolving this potentially ambiguous definition complicates further the challenge of determining characteristic values and preferences for the respective methods.

We can only analyze *well* what we can measure *accurately*. Given the differences in organizational structure assessments demonstrated by the test instances we examined, which respectively included different types of inter-agent relationships, it is important to accurately quantify the effects of different coalition structures. Such metrics are informed by the literature, but quantitative assessment techniques are not readily found (or at least published) in the literature. As such, measuring characteristic functions is a creative endeavor, which portends a likely preference towards the hedonic preference analysis, which can be informed by survey instruments.

We do not want to reduce organizational effectiveness while assessing it. Another limitation of this research is the political sensitivity of deriving effectiveness values for various organizational structures and soliciting hedonic preferences. Both induce the need to safeguard the existence of characteristic value tables and/or preference tables to prevent potential discord within the organization.

5.3 Future Research

For future research, we recommend conducting sensitivity analyses on both the characteristics of alternative motivating organizational structures and the subadditive, additive, and superadditive properties of test instances. Further exploration regarding the effects of these variables might identify patterns that help explain variation between preferred coalition structures. We also recommend initiating the process from start to end on a small sample of real agents. In other words, the real development of characteristic values and solicitation of preferences from a small sample of representative subordinate organization agents would reveal more insight into the process of performing an agent-based analysis. Many of the limitations discussed above may manifest more or less prominent than expected. Finally, we recommend comparing the results of a macroscopic, top management-based analysis relative to the perspective of subordinate organization agents. Doing so would ascertain whether the agent-based analyses are complementary to or redundant with the analysis from the perspective of an organization's executive leader(s).

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14. ABSTRACT

Due to dynamically changing fiscal and operational environments, the Air Force is seeking a deeper understanding of organizational structure and its impact on organizational effectiveness; however, the issue of identifying an effective organizational structure is a concept constantly revisited by organizations in public, private, and governmental sectors alike. Current methodologies for measuring organizational effectiveness, and thereby evaluating organizational structure, tend towards a point in time perspective from an organization's top management. In this research, we propose analyzing organizational structure from a subordinate organization's or representative agent's perspective using coalitional game theory, with particular emphasis on the methodologies of traditional coalitional game theory, Myerson graph theory, and hedonic coalition formation. Upon surveying the literature to assess whether methods exist to classify and analyze contributing elements of organizational effectiveness, we identify three viable alternative methodologies for quantifiably evaluating alternative organizational structures. Considering a representative scenario, we extend the published work by applying and comparing these methodologies. The results of the analysis indicate that, in traditional usage, all three coalitional game theory methodologies perform similarly. However, in cases with situational factors, such as dysfunctional linkages between agents, multi-dimensional levels of preferences, or limitations in the solicitation of effectiveness values or preferences, unique differences emerge between methodologies. We conclude by providing a comparative analysis and discussion with recommendations to help decision-makers and analysts determine the best strategy for evaluating organizational structure from the agent-based view, followed by an examination of the value of respective methodologies when primary assumptions about agent-to-agent relationships do not hold.

15. SUBJECT TERMS

Cooperative game theory, organizational structure, agent-based analysis

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