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The cost of commonality: assessing value in joint programs

Jessup, Rustin; Williams, Jamal

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THE COST OF COMMONALITY: ASSESSING VALUE IN JOINT PROGRAMS

December 2015

By: **Rustin Jessup**
Jamal Williams

Advisors: **Jesse M. Cunha**
John Dillard

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In the 21st century, Major Defense Acquisition Programs (MDAPs) have become increasingly joint efforts. This trend has led to expanding program complexities and interdependencies. The resulting cost, schedule, and performance risks often counterbalance, and potentially outweigh, the efficiencies gained through inter-service program designs. We define these risks as the *cost of commonality*.

Such costs are often unquantified in cost-benefit analyses in the defense acquisitions process. In this project, we first review the results of three joint MDAPs to evaluate ex-post indications of programmatic shortfalls resulting from commonality costs. We then propose a unique cost-effectiveness model to assess value in joint programs from a broader portfolio perspective. Finally, we apply our Joint Value Model to the Joint Light Tactical Vehicle program as a case study to validate the concept.

The Joint Value Model provides a means for managers to evaluate cost-effectiveness in the portfolio context and compare meaningful differences among program alternatives. We recommend use of this model as a tool for program analysis at all stages of system development.

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THE COST OF COMMONALITY: ASSESSING VALUE IN JOINT PROGRAMS

Rustin Jessup, Major, United States Army
Jamal Williams, Major, United States Army

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Approved by: Jesse M. Cunha

John Dillard

John Dillard
Academic Associate
Graduate School of Business and Public Policy

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LIST OF ACRONYMS AND ABBREVIATIONS

ABCT	armored brigade combat team
AoA	Analysis of Alternatives
BCT	brigade combat team
CAPE	Cost Assessment and Program Evaluation
CBA	cost-benefit analysis
CITA	cost informed trades assessment
DOD	Department of Defense
DOTMLPF-P	Doctrine, Organization, Training, Materiel, Leadership Development, Personnel, Facilities, and Policy
FCS	Future Combat Systems
FY	fiscal year
GAO	Government Accountability Office
GMV	Ground Mobility Vehicle
HMMWV	High Mobility Multipurpose Wheeled Vehicle
IBCT	infantry brigade combat team
JLTV	Joint Light Tactical Vehicle
JSF	Joint Strike Fighter
JTRS	Joint Tactical Radio System
KPP	key performance parameter
LCE	life cycle cost estimate
LRV	Light Reconnaissance Vehicle
LTV	light tactical vehicle
M-ATV	Mine-Resistant Ambush Protected All-Terrain Vehicle
MDAP	major defense acquisition program
MRAP	Mine-Resistant Ambush Protected
MS	milestone
OSD	Office of the Secretary of Defense
PAUC	program average unit cost
R&D	research and development
RDT&E	Research, Development, Test, and Evaluation

SBCT	Stryker brigade combat team
SWAP	size, weight, and power
TCE	transaction cost economics
TCM	Training and Doctrine Command capability manager
TD	technology development
TFX	Tactical Fighter, Experimental
USMC	United States Marine Corps

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I. INTRODUCTION

In 1907, the U.S. Army Signal Corps solicited for a heavier-than-air flying machine in a fixed-price incentive fee contract worth $30,000 (“Military Use of the Airplane,” 2015). The four-page contract was written such that the Army would pay incrementally more for improvements over a threshold speed of 36 miles per hour. Although the Army sought full and open competition for this contract, negotiations between the Army and the Wright Brothers began two years earlier, in 1905 (“Military Use of the Airplane,” 2015). Such arrangements are antithetical to competitive market strategies and illegal by modern standards. Yet, the Wright Brothers were one of the few inventors at the time who could meet the specifications. This procurement set a precedent for the government in balancing technological readiness with the urgency of user needs. It was also the first attempt to repurpose technologies across the services, becoming the foundation for modern joint programs: In 1911, the Navy purchased the Wright Model B in an attempt to modify it for water takeoff (“Military Use of the Airplane,” 2015). It is perhaps portentous that the first attempt at joint commonality for a major weapon system ended in failure. The Navy ultimately abandoned the Wright Brothers’ design for the prototypes of Glenn Curtis, which were made specifically for operating on water.

The concept that a single materiel solution could meet the requirements of multiple services is the fundamental principle of joint programs. The underlying rationale is that the benefits of inter-service commonality will outweigh the costs when properly executed. The pursuit of joint capabilities has become increasingly pervasive in the modern era. The fall of the Soviet Union ushered in the need for new national strategies to address emerging threats and non-state actors. The foundational document for this strategy was the *Joint Vision 2010,* published by the Office of the Joint Chiefs of Staff in 1996 (DOD, 1996). The principal concept was that no single military service would be able to defeat emerging asymmetric threats unilaterally. A synergistic capacity among agencies and departments would be necessary to accomplish national security objectives. To meet this intent, effective materiel solutions are often required to facilitate joint capabilities in the operational environment. This requirement has since driven the ever-increasing need for jointly developed solutions in defense acquisitions.

Despite the increasing necessity of joint solutions, a review of joint Major Defense Acquisition Programs (MDAPs) in the U.S. Department of Defense (DOD) reveals a history of extensive cost growth, schedule overruns, and performance shortfalls. These consequences result in part from the innate complexity of pursuing commonality on a large scale. In 2010, the Government Accountability Office (GAO) argued that many of the requirements for joint programs such as sharing domain information, policy and processes, technology, legal restrictions, and cultural barriers all impede the ability to benefit from joint capabilities. The decision to pursue a joint program begins with a cost-benefit analysis (CBA) and an Analysis of Alternatives (AoA) to ensure that joint commonality is the preferred solution. As the program evolves, managers consider trade-offs through a process of Cost Informed Trades Assessment (CITA). Despite these processes, underperformance remains prevalent in joint MDAPs.

We hypothesize that current analyses fail to account for inherent complexity risks, which often diminish or outweigh the economic and operational benefits of commonality in joint programs. We define this consequence as the cost of commonality. In this project, we review the results of three joint MDAPs to evaluate ex-post indications of programmatic shortfalls resulting from commonality costs. Additionally, in order to capture these hidden costs, we take a unique approach to evaluating cost-effectiveness by proposing a model that examines the value of joint programs from a broader portfolio perspective.

We observe that intrinsic tensions exist in combat systems among requirements for combat agility, which are driven by transportability and mobility needs, and requirements for combat power, which are defined in terms of force protection and lethality. Thus, the breadth of user requirements can be arrayed on a continuous agility–power spectrum, in which the attainment of functionality on one end often necessitates trade-offs on the opposite end. Joint and intra-service programs seek to incorporate a broad range of requirements on this spectrum with a common system or family of systems. However, programs often experience scope contraction over time as the range of included requirements narrows. Such contractions expose capability gaps in the force as peripheral requirements are left unmet by the common system. This generates negative externalities in the broader capabilities portfolio, increasing costs in other programs to address unmet requirements.

We theorize that scope contractions result, at least in part, from the inherent cost of commonality. Such costs often force programs to narrow the range of included requirements or increase funding investments over time to sustain original projections. Thus, our proposed cost-effectiveness model, which we term the Joint Value Model, seeks to capture these costs by evaluating the program in portfolio context. By including potential externalities in program assessments, the model can provide a means for better-informed decisions, resulting in improved cost-effectiveness in DOD acquisition portfolios. In order to validate the Joint Value Model as a concept, we apply it to the Joint Light Tactical Vehicle (JLTV) program as a case study. Our principal intent is not to evaluate the JLTV program specifically; rather, our goal is to assess the usefulness of the model as a tool for capturing the non-monetized costs of commonality and facilitating more comprehensive analysis in joint programs.

We find significant scope contraction in the JLTV program over the course of its development. Decisions to divest of several JLTV requirements were necessary and appropriate from the program perspective but resulted in reduced cost-effectiveness in the portfolio context. The Joint Value Model provides insight into the broader consequences of JLTV program decisions and offers a suitable tool for evaluating alternative courses of action throughout the development process.

While the scope of this project includes only one detailed case study, the Joint Value Model provides useful applicability in the assessment of large joint and intra-service programs by allowing managers to compare meaningful differences among program alternatives and assess value within capability portfolios. The model is also scalable, as it offers a means to compare value assessments among different portfolios, informing funding decisions at the highest levels. However, incorporation of the Joint Value Model requires a paradigm shift with respect to how programs are currently assessed and funded. The responsibility of program managers increases as the required scope of consideration in the decision-making process widens. As such, managers should be granted greater authority and funding flexibility in order to maximize value for the DOD.

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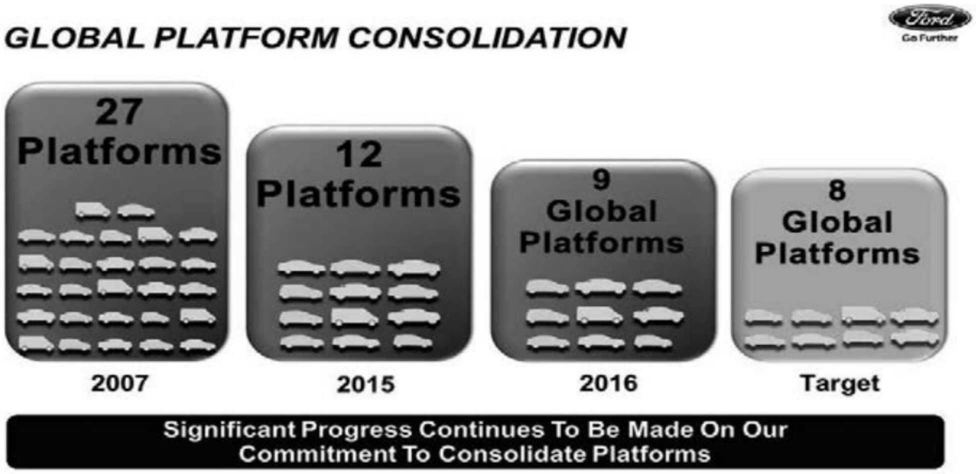
II. THE VALUE OF COMMONALITY

A. THE BENEFITS OF COMMONALITY

The economic concept of division of labor, to the extent it can be achieved, generates a proportional increase in productivity (Smith, 1775). This is the concept for economies of scale, which defines the improvements in efficiency that result from increased production volume. The automotive industry has been one of the greatest beneficiaries of this principle. However, these commonality benefits are not easily transferrable to the defense industry. Even for platform-centric systems like the JLTV, economies of scale are limited by small quantities (49,550 vehicles from 2015 to 2035 with 4 variants). In comparison, the Ford Motor Company, which continues to decrease their overall number of global platforms (see Figure 1), reported global annual sales volumes of 5.6 million to 6.3 million[1] vehicles from 2012 to 2014 (Ford, 2014).

Figure 1. Ford Global Platform Consolidation



Source: Ford Motor Company. (2014). *Annual Report Form 10-K.* Retrieved from http://corporate.ford.com/annual-reports/annual-report-2014/files/201_Ford_Annual_Report_sm.pdf

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[1] Ford vehicle sales volume numbers were calculated using the Ford Motor Company Form 10-K and their estimates of (1) global sales volumes and (2) Ford's estimated global market shares.

The auto industry relies on a competitive market that allows consumers to choose among several automakers. Consumer selectiveness, however, is tempered by a market dominated by the few players who can achieve significant economies of scale in order to provide cheaper goods. When those economies of scale are not realized, as was the case with the U.S. auto market “Big Three” during the 2008–2010 automotive industry crisis, it is not profitable to simply produce goods with common parts. Specifically, fuel-inefficient sport utility vehicles and pickup trucks, which had previously flourished under General Motors, Ford, and Chrysler, were no longer in high demand, and thus no longer profitable (Vlasic, 2011). Ultimately, production quantities remain an important consideration for military procurement, driving central aspects of program acquisition strategies.

While the military may not benefit greatly from high production volumes, there are shared operational and economic benefits when U.S. forces conduct joint operations. The cost savings of supporting and maintaining the equipment and vehicles of multiple services with a common logistical trail is substantial. Logistically burdensome items, such as tires, tracks, engines, and transmissions, tend to dominate bulk storage, creating a tremendous footprint and driving up life-cycle costs (Held, Newsome, & Lewis, 2008). Common logistics warehouses and distribution centers that support system sustainment are important mechanisms for lowering costs. Further, inter-service commonality generates operationally synergistic effects in the joint environment. Organizations thus achieve greater efficiency through higher system interoperability, resulting in improved combat effectiveness.

Commonality also provides training benefits to operations and maintenance personnel. Specifically, when commonality is implemented in the design phase, common components can reduce training demands for operators and armament crews if the components or systems they intend to replace are relatively complex (Held et al., 2008). Increased commonality also leads to a reduction in the number of specialized operators necessary for equipment. In the airline industry, budget carriers such as Southwest Airlines and Ryanair have accomplished this by operating a single airframe (Treacy & Wiersema, 1995). This reduces the amount of training and the number of specialized licenses required. In the military, such consolidation strategies can result in fewer necessary certifications and potentially fewer military occupational specialties needed for operators and maintainers (Held et al., 2008).

Risk pooling is a further advantage of commonality (Chopra & Meindl, 2001). By combining the funds of multiple services, the DOD can disperse programmatic risk while permitting access to greater resources. By expanding the scope of stakeholders, joint programs broaden the operational, economic, and political consequences of failure. This raises the priority and visibility of a program, often ensuring its survival in the wake of budget fluctuations. Regardless of program performance, vested stakeholders will inevitably act to secure interests and prevent organizational failure.

Finally, commonality within a system or family of systems can provide reduced research and development (R&D) costs when deliberately implemented from early design stages. Ultimately, if the components of a new system consist of items within the existing inventory, R&D costs for that component are reduced to zero (Held et al., 2008). For the military, while common engines and transmissions may be difficult to reuse during development due to unique and diverse mission sets, utilization of existing test equipment and maintenance facilities become significant cost savers.

B. THE COSTS OF COMMONALITY

The costs of commonality manifest in numerous ways but derive principally from the innate complexities demanded by the pursuit of large-scale programs. The DOD is pursuing joint solutions with perhaps insufficient insight into the associated risks of these complexities (Brown, 2011). This paradigm is not unique to defense acquisitions. Ninety percent of "megaprojects" throughout the world run over schedule and/or over budget, while delivering less in terms of performance than original estimates.[2] This reality places at risk the viability of projects and often hinders economic growth in affected populations. Proponents of megaprojects are incentivized to disguise such risks from

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[2] A "megaproject" is defined as an exceptionally large-scale venture, typically costing more than U.S. $1 billion in total investment. Megaprojects are categorized by extreme complexity with significant impacts on affected environments, communities, and budgets (Flyvbjerg, Buzelius, & Rothengater, 2003).

public and private decision-makers to ensure project approval. As a result, leaders are disposed to agree to unrealistic project objectives at the outset. Due to the enormous investment required to pursue megaprojects, government balance sheets can be affected for many years by the outcome. Failure can result in the collapse of firms and even government entities (Flyvbjerg, Buzelius, & Rothengater, 2003).

One notorious example is Boston's Central Artery Tunnel Project, also known as the Big Dig. This megaproject was the most expensive highway construction effort in U.S. history. It was finally completed in 2007, 190% over budget and nine years behind schedule. The ultimate economic cost to Boston for the Big Dig is staggering. The final sum of $22 billion in principal and interest will not be paid off until 2038 (Moskowitz, 2012). The F-35 Joint Strike Fighter (JSF) is a comparable example within the DOD. Similarly plagued with cost overruns, schedule delays, and performance shortfalls spanning two decades, JSF remains an active program. Like other megaprojects, the success of JSF has become critical for its sponsors. Despite numerous costly setbacks, the DOD has reinvested continuously to prevent JSF program failure. Megaprojects require an intense focus on risk management to mitigate negative consequences. Where possible, managers should instead limit project scope and partition objectives into separate projects of manageable scale (Flyvbjerg et al., 2003).

While no other joint MDAP has reached the scale of JSF, the megaproject phenomenon is broadly applicable in defense acquisitions. As MDAPs become increasingly joint endeavors, the resulting expansion of scale and scope broaden the aperture of risk, typifying megaprojects worldwide. Such risks in the complexity of joint MDAPs are critically under-examined. The defining nature of "jointness" is the resulting amount of interdependencies among stakeholders and programs. Without a deeper understanding of the risks that such largely interdependent efforts encounter, it is impossible to isolate critical governance mechanisms that can mitigate cost, schedule, and performance shortfalls (Brown, 2011).

Complex interdependence leads to a value chain in joint programs that is "laden with junctions and bifurcations where delay, defection or shirking can occur" (Brown, 2011, p. 7). The pursuit of joint capability expands the intricate network of stakeholders in which open and permeable boundaries are necessary to achieve common objectives. Yet, the open-boundary structure makes it difficult to coordinate and safeguard exchanges in complex environments. Social exchange theory holds that uncertainty is often the result of interdependence within organizations. Shirking or defection of a single network member can have dire consequences for the survival and performance of the network as a whole (Emerson, 1976). Military services are independent stakeholders who join in strategic alliance for joint programs. Thus, interdependence develops among services that typically have competing goals and requirements. This creates a challenging environment for system development and program management. As a result, joint programs tend to experience higher research, development, testing, and evaluation (RDT&E) costs and extended schedules (Brown, 2011).

Performance optimization is difficult to achieve in complex environments. The field of behavioral science is useful in explaining the rational choices of stakeholders as members of interdependent networks. As environmental complexity increases, the ability of an organization to optimize performance wanes. In a simplistic environment, such as a single-service or single-branch acquisition program, the organization requires no utility function or complicated algorithm to determine the best course of action. As the number of competing goals increases, the ability of an organization to maximize need-fulfillment through a process of optimization diminishes. It is most often replaced with satisficing—a solution that permits the satisfaction of all needs at a minimum specified level. Ultimately, common denominators among diverse requirements may not exist or may exist only in rudimentary form. Thus, organizations should be skeptical of elaborate mechanisms to find converging (or joint) solutions (Simon, 1956). As such, the effort required to achieve incremental improvements in optimization is extensive and costly, if productive at all.

Many of the barriers to optimization in complex environments are well documented in theories of individual and organizational behavior. The theory of bounded rationality describes the fundamental limitations of decision-makers in these environments, where a gap exists between reality and perception. While stakeholders are generally rational actors, individual cognitive capacities, time constraints, and the limited availability of information hinder decision-making abilities. As environmental complexity increases, the interrelated and compounding consequences associated with various courses of action outpace the ability of actors to process them acutely. The result is a largely intuitive decision-making process in which actors perceive acceptable thresholds (Simon, 1978). This leads to satisficing outcomes for the broader organization.

Within the construct of bounded rationality, we can examine the dynamics of interdependent networks using game theory. Stakeholders in such networks share a common but not identical range of objectives. Parochial interests prevent joint synergy as stakeholders seek to maximize provincial outcomes at the expense of collective optimization. Thus, rational actions within the network are often undertaken irrespective of common goals. This consequence is a social dilemma known as the tragedy of the commons. The program structure incentivizes service proponents to exploit common resources by insisting on the development of custom requirements. This increases development costs and schedule demands while forcing undue performance trades (Moore, Novak, Collins, Marchetti, & Cohen, 2014).

Opportunistic behavior and suboptimization also result from transaction costs in complex systems. The field of transaction cost economics (TCE) arose from the notion that markets and systems are not frictionless environments. Transaction costs arise through exchanges among internal and external actors. Primarily, these costs are associated with coordination and motivation problems such as search and information, bargaining and decision, and policing and enforcement. They also manifest in the promotion of productive effort and deterrence of opportunistic behavior. TCE can provide substantive input into the development of MDAP cost estimates. An important insight of TCE is that firms should consider both production and transaction costs in business decisions. The current DOD analysis structure uses work breakdown structures to evaluate costs and does not account for relationship-oriented dynamics. Thus, it overlooks transaction costs. This contributes to overly optimistic estimates. Therefore, program cost growth will have ex-ante indicators that relate to TCE. Inversely, cost growth is an ex-post indication of hidden or unanticipated transaction and production costs. By including TCE considerations, the DOD can improve cost-estimation methodologies and mitigate program cost growth (Angelis, Dillard, Franck, & Melese, 2008).

Behavioral and transaction cost theories only partially explain the program dynamics that erode joint commonality. Conceptual designs for complex systems in industries such as aviation, satellites, automobiles, and semiconductors often exhibit high degrees of commonality. However, as designs progress, small alterations force a continual drift away from commonality, a phenomenon termed “divergence.” The net effect of divergence can be substantial; intended commonality across large subsystems can devolve into commonality only among low-level and lower-cost components. There are multiple contributing factors. Commonality breaks down as user needs evolve and refine, development teams fail to adequately coordinate and synchronize, and new technologies integrate into the system. These factors are most prevalent and consequential in projects with greater complexity and economic scale, such as joint MDAPs. To mitigate divergence and extract the benefits of commonality, managers must emphasize four concepts. First, shift organizational focus from individual products to product families and modify the development process accordingly. Second, align incentives toward beneficial commonality rather than individual products and requirements. Third, actively manage commonality over the course of the entire life cycle. Finally, be realistic and do not pursue commonality as an end in itself. Managers should consider the associated trade-offs and consequences in all business and production decisions (Boas, 2008).

The pursuit of commonality in large-scale programs may also diminish product value to the user. In the commercial market, design configurations with commonality are desirable when net savings accrue in manufacturing and design. However, such designs can inhibit the capacity to extract price premiums though product differentiation. This can manifest as a real or perceived value disparity. Thus, substantial coordination among system stakeholders is critical to evaluating the value of common configurations and informing sound business decisions (Desai, Kekre, Radhakrishnan, & Srinivasan, 2001). While revenues and profitability are not the objectives of defense acquisitions, the commonality–differentiation trade-off is a transferable principle. Product utility, or value, with respect to the warfighter may diminish when common solutions fail to address diverse needs adequately. Intuitively, the more functions that a common system seeks to achieve, the less effective it becomes at any given function. This may induce suitability concerns in the operational environment if development efforts do not adequately incorporate the user community.

To summarize, the costs of commonality pervade all aspects of large-scale projects and programs, diminishing product value. The pursuit of large-scale commonality results in complex interdependencies among stakeholders. Such networks generate considerable risk in the value chain as parochial interests create incentives for opportunistic behavior at the expense of collective optimization. The associated transaction costs and suboptimal performance can have dramatic adverse effects. These conditions often lead to divergence over time, in which the commonality of original designs, and thus the intended benefit, is diluted. Where achieved, commonality benefits can be further offset by the reduced utility of non-specialized products.

C. ASSESSMENT OF COMMONALITY IN JOINT PROGRAMS

These theories of commonality bear relevance to joint MDAPs in the modern era. We examine the results of three joint MDAPs through the lens of academic theory in order to determine ex-post indications of unanticipated commonality costs. While the full CBAs associated with these programs are beyond the scope of this project, the examples below illustrate the challenges of pursuing joint commonality on a large scale. These case studies provide a basis for our more comprehensive examination of the JLTV program and our logic for the application of similar metrics.

1. Tactical Fighter, Experimental

Secretary of Defense Robert McNamara’s Tactical Fighter, Experimental (TFX) program demonstrates acutely the challenges of pursuing joint commonality (Boas, 2008). In 1961, initial optimism fostered a common goal of one aircraft to meet the requirements of all four services (Art, 1968). Within five months, the DOD narrowed the program’s scope to include only Air Force and Navy specifications (Art, 1968).

McNamara later gave a directive to maintain commonality with an emphasis on Air Force requirements. As a result, the Air Force eventually procured 562 of the initially anticipated 1,762 aircraft while the Navy program was canceled due to an inability to meet user requirements. The direct costs attributed to the Navy program's cancellation are estimated at $400 million in fiscal year (FY) 1969 dollars, or $2.6 billion in FY2015 dollars. Additionally, the DOD incurred tremendous operational and economic costs in subsequent years as a result. Each service developed unique platforms, and the residual lack of commonality in the joint environment perpetuated operational inefficiencies (Boas, 2008). Thus, not only did the DOD not achieve the intended benefits of joint commonality in the F-111A, but the assessed program value was also outweighed by the opportunity costs of alternative single-service acquisition strategies. Congressional investigations of the TFX contract later revealed that the Air Force received a compromised and dramatically less capable system in the F-111A than if an independent program had been pursued from the outset (Boas, 2008).

Congressional hearings further concluded that critical failures in the TFX program resulted from divergence, which evolved from a lack of proven commonality at inception. In order to justify moving forward with a joint program, a rigorous systems engineering process must be applied to show that significant system commonality will exist at the time of production. During the investigation, Senate committee chairman John McClellan remarked that "to make 80 percent of the parts common and build planes for all these missions … I don't believe anyone can say that was a proven judgment" (*TFX Contract Investigations*, 1963, p. 971). Failing to satisfy component commonality to a predetermined level will result in increased program costs. As with the TFX, when the commonality of parts falls below a specified threshold, the systems are no longer common. The program is then de-scoped and partitioned into multiple programs. The earlier in the life cycle this decision can be made, the greater the costs savings to the program and the broader portfolio. It is incumbent upon program leadership to present this information to decision-makers early enough in the life cycle to facilitate these savings.

2. Joint Strike Fighter

The issue of divergence has also plagued the JSF program. The goal of the JSF is to "develop and field an affordable, highly common family of next-generation strike aircraft for the United States Navy, Air Force, Marine Corps, and allies" (DOD, 2015, para. 1). The DOD initially intended to incorporate 11 stakeholder nations and replace 13 individual aircraft with the JSF (Boas, 2008). It anticipated significant operational and logistical cost savings through design of a common airframe. The DOD envisions further efficiencies as a result of international cooperation, relying on a global logistics footprint common to allied partners. The success of this strategy is contingent upon the achievement of commonality among major subsystems and effective integration thereof.

> Through consolidation or cancellation of existing programs and the creation of the tri-variant JSF program, the U.S. Government drove significant savings relative to the alternative of three independent development programs. The high-level vision of a common air vehicle, a common engine, and a common manufacturing line created the proper starting point. (Boas, 2008, p. 95)

While the economies of scale and the logistics savings will not be recognized until the system is fully fielded, the current status of several program metrics has generated significant concerns from Congress. Program challenges have forced decisions affecting overall procurement quantities, system configurations, and the number of participating allies. In oversight of the program, the GAO reports significant cost, schedule, and performance problems (GAO, 2015). The JSF has become the most expensive and ambitious DOD acquisition program in history with estimated acquisition costs of nearly $400 billion (GAO, 2015). Much of the cost increases have come through a differentiation of technology needs for the three variants, such as the United States Marine Corps (USMC) requirement for short take-off and vertical landing (STOVL) and the individual software requirements to support all variants (Boas, 2008).

As the JSF proceeded to the engineering, manufacturing and development phase, the program office realized that in order to meet STOVL requirements, significant size, weight, and power (SWAP) modifications from the base design would be needed. Concerned about the resulting program risk, the Secretary of Defense placed the STOVL variant on a two-year probation and decoupled the program variants in 2011 (GAO, 2015). The GAO concludes that while this restructuring caused cost increases and schedule growth, the decision was necessary in order to achieve overall program success and ultimately recouple the program variants. The required modifications, however, ultimately correspond to a decrease in commonality among the variants and a significant increase in the complexity of the USMC variant (Boas, 2008).

The primary cause of system divergence due to software is the commonality metric selected during the system demonstration phase. In short, the commonality metrics for the JSF during system demonstration did not include software, while the primary design metric, airframe weight, did not adequately account for disparate software requirements (Boas, 2008). As a result, software became and continues to be a major driver of cost growth. JSF software designs and integration requirements have increased complexity and decreased system commonality. Specifically, while the program anticipated 45% growth in software testing for 2014, the GAO observed 90% system growth (GAO, 2015).

These realities have made system-optimization efforts extremely challenging, which has led to satisficing solutions. Further, the enormous organizational bureaucracy necessary to accommodate all service and international stakeholders has resulted in substantial transaction costs. This has contributed to increasing divergence and climbing program costs as the DOD continues JSF development.

3. Joint Tactical Radio System

The DOD Joint Tactical Radio System (JTRS) Ground Mobile Radio program was intended to provide a radio that would be interoperable with both advanced networking and legacy waveforms to support operations in an “Internet-like environment for battle command, sensor-to-shooter, and survivability applications” (Kendall, 2011, p. 1). The priorities for this program were to address capability gaps in information warfare and to facilitate the goal of a fully digitized battlespace (DOD, 1997). The complexity of the JTRS program is epitomized by its description as the “backbone of the Future Combat System” and its requirement to link 18 manned and unmanned systems across the battlespace (Feickert, 2005). The original program organization relied on the simultaneous development of five different systems, or “clusters,” by four different service leads, as identified in Table 1 (Feickert, 2005).

Table 1. JTRS Clusters

Chapter	**One**	**Two**	**Three**	**Four**	**Five**
Description	Ground Vehicle and Helicopter Radios	Hand-Held Radios	Fixed Site and Maritime Radios	High Performance Aircraft (Fixed Wing) Radios	Handheld, Dismounted, and Small Form Factor Radios
Service Lead	U.S. Army	U.S. Special Operations Command (USSOCOM)	U.S. Navy	U.S. Air Force	U.S. Army

Adapted from: Feickert, A. (2005). *The Joint Tactical Radio System (JTRS) and the Army’s Future Combat System (FCS): Issues for Congress* (CRS Report No. RL33161). Washington, DC: Congressional Research Service, p. 2.

Additionally, the requirement existed for overall integration of capabilities and products from Boeing, Northrup Grumman, Rockwell Collins, BAE Systems, Harris Communications, General Dynamics, and Thales Communication (Feickert, 2005). Based on these metrics, it is clear that the number of stakeholders adding to the complexity of the program architecture presented a formidable management challenge that compounded program risk. Yet, this reality was independent of assessments for JTRS technology maturation and cost goals, and thus was not included in cost analyses. Acting Undersecretary Frank Kendall cancelled the program in 2011 due to “inadequate affordability analysis at inception” and “the technical challenges of mobile ad hoc networks and scalability” (Kendall, 2011, p. 1). The JTRS program clearly demonstrates the impact of complexity and interdependency, as well as the need for better evaluation metrics in joint MDAPs.

III. THE JOINT VALUE MODEL

A. A NEW APPROACH

The value of a program can be measured by examining the effectiveness with which it meets the breadth and depth of user needs. In order for a program to meet a specified requirement, it typically must make trade-offs with respect to resources or design that limit its ability to meet other requirements. Budgetary constraints often limit development to a narrow range of objectives, while physical realities may prohibit the attainment of competing requirements within a common system. This is the fundamental principle that defines the scope of a program. Thus, the goal in all programs is to balance competing objectives in order to achieve an optimized capability for broad and effective application in the operational environment. As noted, optimization is increasingly challenging as the scale of complexity rises. This constitutes the fundamental challenge of joint MDAPs, to incorporate a diverse range of requirements through system commonality. Joint programs emerge when the inter-service community assesses the optimal range of requirements to be feasible within a common system or family of systems.

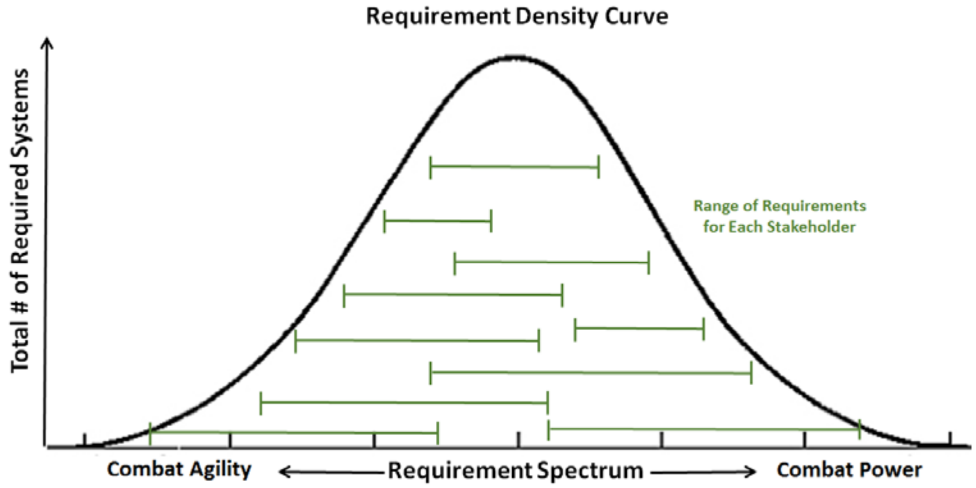
In commercial industries, a broad array of trade-off dynamics can influence system development. Attributes such as the level of reliability, the extent of interoperability, or the scale of produceability may dictate design parameters. While such tensions are applicable in combat systems as well, the nature of the expeditionary environment in the context of ground, air, and maritime warfare tends to define and distribute critical capability requirements across a broad spectrum. On one end, requirements reflect the need for combat agility: speed, mobility, transportability, and so forth. On the other end, requirements prescribe combat power: lethality, protection, survivability, and so on. This agility–power spectrum is ubiquitous in defense acquisitions. It is applicable and scalable to nearly all combat systems, from soldier-carried equipment and armored vehicles to fighter aircraft and combat ships. The Army organizes its force structure with respect to this capability spectrum. It optimizes Infantry

Brigade Combat Teams (IBCT) for combat agility and Armor Brigade Combat Teams (ABCT) for combat power. Stryker Brigade Combat Teams (SBCT) offer capabilities in the middle range of the spectrum. Within the portfolios of each brigade combat team (BCT), the Army seeks to balance capabilities to maximize combat effectiveness.

When a system or portfolio becomes unbalanced on this spectrum, the result is reduced combat effectiveness. The U.S. Army Training and Doctrine Command's Capability Manager for the IBCT (TCM-IBCT) has identified this imbalance as a critical concern. The ever-increasing weight of combat equipment in infantry units has led to an excessive physical burden for dismounted soldiers. This has diminished the ability of IBCT units to maneuver effectively. TCM-IBCT cites this concern as the most critical capability gap for the formation. Conversely, LTG H. R. McMaster, Director of the Army Capabilities Integration Center, believes that recent trends in maneuver portfolios have driven capabilities too far to the agile end of the spectrum in many cases. He advocates for renewed emphasis on combat power in ground combat systems (Freedberg, 2015).

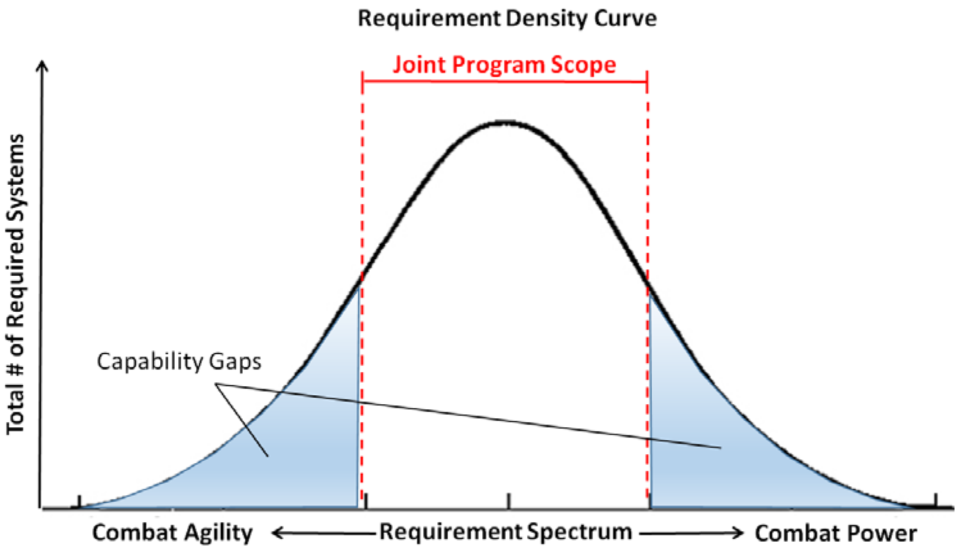
To assess the effectiveness with which programs address the spectrum of user needs, we propose a quantitative evaluation model. Each user need in a capability portfolio can be examined individually to determine how many total systems in the force require that specification. The summation of these needs across users is a measure of requirement density, quantified in number of systems. This is not simply a calculation of the number of total systems required by the force; rather, it is an assessment of each individual requirement to determine how many systems need that specification. For example, unit A may require 100 systems to meet its needs, but only 70 of those systems require specification X and 80 require specification Y. In this case, the densities of specification X and Y for unit A are 70 and 80, respectively. This assessment is repeated for each relevant unit in the force. The summation of these values represents the total requirement density for each portfolio specification. If these results are arrayed on the agile–power spectrum relative to one another, the result is a graphical distribution of requirement densities. On this spectrum, capabilities positioned at the center reflect the most common functions in the most probable environments, while peripheral requirements represent unique capabilities for more extreme or specialized scenarios and missions. Therefore, the density graph for a given portfolio will likely depict a bell-shaped curve resembling a normal distribution (see Figure 2). Thus, while a joint or intra-service program will seek to capture the broadest possible range of requirements, potential commonality benefits are highest at the center of the spectrum where density is greatest.

Figure 2. Portfolio Requirements Density Curve on the Agile–Power Spectrum



However, we speculate that physical, programmatic, and economic realities invariably limit the scope of joint programs to a narrow range of user needs. Beyond this limit, common systems are inadequate to meet the diversity of requirements. Thus, at the periphery of the curve are requirements that must be met by other programs or remain unfulfilled (see Figure 3). If a program fails to meet the intended range of requirements, these capability gaps constitute negative externalities for the broader portfolio. As such, the breadth of program scope dictates the economic and operational benefits of product commonality. If the scope is broad, production and logistics cost savings will be high, but the attempt to incorporate a wider range of requirements will increase development costs. Suitability issues may also arise with less system specialization. If the scope is narrow, the inverse will result, and negative externalities will increase.

Figure 3. Portfolio Requirements Density Curve: Joint Program Scope



The agile–power spectrum does not fully encapsulate the diversity of user requirements. Unique specifications will invariably exist in parallel to the spectrum, extending this diagram to a multidimensional model. For example, reliability, availability, and maintainability attributes will drive resource and performance trades across the spectrum. However, such requirements are typically not distinguishing characteristics dictating program scope. Thus, for the purposes of this study, we project the distribution of requirements on a single-dimensional scale, the agile–power spectrum.

The effectiveness of a given portfolio, as defined in the context of this model, is the total utility of meeting all requirements in the portfolio. The magnitude of this utility is dictated by the number of weapon systems in the entire force possessing each requirement on the spectrum. Thus, the effectiveness value can be viewed as a measurement of the overall capability provided by the portfolio when all user needs are satisfied. We conclude that effectiveness is a volumetric measurement of requirement densities. For our two-dimensional model depicted in Figure 3, we define this as the area under the requirement density curve. In practical terms, the density of each requirement can be measured discretely. Therefore, this model (shown in Equation 1) calculates effectiveness (E) as the sum of requirement densities across the requirement spectrum, where D_x = the density of requirement x, measured in number of systems.

$$E = \sum_{x=1}^{n} D_x \tag{1}$$

The unseen costs of commonality heavily influence program scope. Inherent complexities and interdependencies, organizational satisficing, and transaction costs contribute to commonality divergence and sub-optimal solutions. This affects program boundaries in a meaningful way. In general, these consequences act as programmatic constraints, forcing a contraction in the breadth of scope over time. The result is reduced product utility from original designs. Programs can mitigate scope contraction with increased resource investment. Yet, such strategies intensify complexity, resulting in higher marginal costs and diminishing returns. Consequently, cost growth and underperformance are pervasive in joint MDAPs.

Traditional methods in CBAs and CITAs define program scope as a constant parameter within the context of the program rather than as a dependent variable as we have described. The initial CBA and AoA establish the program baseline for requirement scope. As noted, this scope rarely expands as the program evolves but often contracts over time. Programs often divest of requirements by reducing the number of product variants. Managers typically evaluate these decisions based on programmatic concerns without regard for externalities in the broader portfolio. The outcome of a CITA is a new scope baseline, against which program success is measured. This practice conceals the inherent costs of commonality that contribute to scope contraction. Thus, we reason that by incorporating externalities into the analysis, such costs are appropriately considered in the decision-making process.

It follows that the monetary cost of portfolio externalities for the DOD is the program cost of meeting excluded requirements by alternate means. Therefore, the cost parameter of this model is calculated (shown in Equation 2) with estimates of Program Average Unit Cost (PAUC) for each weapon system in the portfolio. The model weights each PAUC based on the total number of systems to be produced, or the Acquisition

Objective (AO) of each system. Each weight is determined by calculating the AO of the respective program divided by the sum of all program AOs in the portfolio. Therefore, the total cost (*C*) is calculated as the weighted average of PAUCs within the portfolio where A_i = the AO of system *i*, and P_i = the PAUC of system *i*.

$$C = \frac{\sum_{i=1}^{n} A_i P_i}{\sum_{i=1}^{n} A_i} \tag{2}$$

The cost-effectiveness of a portfolio can then be defined as total cost divided by calculated effectiveness, or the weighted average of PAUCs divided by the sum of requirement densities (shown in Equation 3). It denotes the cost per calculated value of utility (or effectiveness). Thus, lower values represent better cost-effectiveness than higher values.

$$\frac{C}{E} = \frac{\sum_{i=1}^{n} A_i P_i}{\left(\sum_{x=1}^{n} D_x\right)\left(\sum_{i=1}^{n} A_i\right)} \tag{3}$$

The Joint Value Model provides a tool for comparative analysis of program alternatives that incorporates the costs of externalities generated by scope contraction. We propose that it can be incorporated into analyses at all phases of a joint program from inception to production. The model is applicable for use in the initial program CBA to develop the appropriate baseline for requirement scope. As the program evolves, the model can be particularly useful in evaluating alternatives during CITA. It offers the DOD a means to address affordability metrics from a broader perspective, whereby capturing the true value of programmatic decisions.

As an ex-post analysis tool, the model can provide an objective metric for measuring an improvement or decline in cost-effectiveness over time. This is the calculated difference between cost-effectiveness results at two (or multiple) points in time. We theorize that a decline in portfolio cost-effectiveness from program initiation to system production is, at least in part, a manifestation of inherent commonality costs. Such differences can be further dissected to isolate root causes, which can be related where appropriate in analyses of other programs. As a case study, we apply this approach to the JLTV program in order to evaluate changes in cost-effectiveness from Milestone (MS) A to MS C. We then examine this variance through the lens of academic theory to identify causal relationships and draw conclusions, where pertinent, for other joint MDAPs.

B. APPLICATION IN CURRENT PRACTICE

The military CBA has become an indispensable tool for evaluation of acquisition programs. The general guidelines of the CBA are designed to promote the efficient allocation of limited resources via well-informed decisions by key leaders of the federal government (White House Office of Management and Budget, 1992). The CBA is the recommended technique for formal government economic analysis of programs and is directed toward executive leaders. While the CBA provides an objective economic approach, current practices lack a consistent and holistic approach for evaluating the undefined costs and benefits of programs, particularly in joint MDAPs. An alternative, or complementary, approach to the CBA process is a cost-effectiveness analysis, which compares costs and benefits in situations where benefits cannot be easily monetized (Everly, Limmer, & MacKenzie, 2015). Yet this approach, while useful, fails to incorporate the inherent costs of commonality. The relative subjectivity of benefits and often-ambiguous nature of cost dynamics make value determinations difficult. Consequently, reliable metrics for program cost-effectiveness are unavailable to acquisition decision-makers. The Joint Value Model augments these methods to provide greater understanding of hidden costs and thus better-informed analysis of program alternatives.

C. ASSUMPTIONS AND LIMITATIONS

The principal assumption of this model is that the customer’s preferences accurately reflect the value of requirements to the organization, and thus to society. All specified requirements are valid user needs, necessitating materiel solutions to mitigate critical capability gaps. In addition, the model is a data-intensive construct. The costs of collecting and synthesizing necessary data must be compared to the potential benefits of a more optimal policy. The value of the model can also be limited by the accuracy and data and cost estimates. Therefore, the degree of confidence in data inputs should be taken into consideration by producing multiple model variations, accounting for best, most likely, and worst-case scenarios. Another inherent limitation is related to calculations of effectiveness. The magnitude of utility is reflected in the quantity of user needs; this is the requirement density value. The model does not account for the relative importance of requirements within the portfolio. In reality, some needs may be more critical for the user than others, despite smaller density values. However, such assessments are variable and subjective in nature. Thus, in this regard, all approved requirements offer equal utility in the model.

The model injects a paradigm shift with respect to program analysis, requiring a broader analytical aperture with greater empowerment and funding flexibility for program managers. There are costs associated with such shifts that must be taken into account as well. We also acknowledge that a portion of commonality benefits are gleaned during sustainment and are not reflected in PAUC estimates. Where possible, Life cycle Cost Estimates (LCEs) should be used in place of PAUCs for all systems in the model. The accuracy and availability of LCE in early stages of system development are minimal. Therefore, life cycle considerations must be applied, in most cases, to broader external evaluation criteria. Additionally, the model does not address issues of suitability that may reduce system effectiveness. This aspect of the model is examined as a binary variable; the program either does or does not meet threshold requirements. In reality, systems designed exclusively for a singular purpose or subset of requirements will often provide greater utility to the user for that task.

IV. JLTV CASE STUDY

The JLTV program has experienced significant scope contraction over the course of its 10-year development, exposing peripheral capability gaps in the LTV portfolio and necessitating investment in other platforms to meet the breadth of user needs. This has altered portfolio cost-effectiveness for the DOD. We first apply an overview of the JLTV program and then proceed to apply the Joint Value Model for analysis.

A. PROGRAM OVERVIEW

The genesis of JLTV dates back to a 2005 Army and USMC Light Tactical Vehicle Functional Area Analysis. This analysis found that the aging Highly Mobile Multipurpose Wheeled Vehicle (HMMWV) fleet was inadequate to meet many of the new light-wheeled vehicle requirements of force protection, survivability, payload, and transportability (Grgurich, 2013). The Joint Chiefs of Staff thus approved the JLTV program in November 2006 (Feickert, 2011). The Army and Marines intended to initiate the Technology Development (TD) phase of the program as early as October 2007. However, John Young, the Defense Acquisition Executive, expressed reservations about the maturity of required technologies, writing, “There are several aspects of the strategy that raise doubts about our ability to develop and acquire this vehicle fleet in an affordable and timely manner” (Sherman, 2007, para. 4). The revised Army and Marine TD plan was executed by Request for Proposal (RFP) in February 2008. The JLTV timeline was delayed again in 2011 when the Army insisted on equivalent underbody protection to the Mine-Resistant, Ambush-Protected All-Terrain Vehicle (M-ATV; Feickert, 2015). This requirement had a substantial impact on overall divergence of the system from its original design. In short, the increased protection requirements drove significant weight increases. Most notably, it resulted in elimination of the long wheelbase Category B variant (Feickert, 2015). The remaining variants include two- and four-passenger designs with sub-variants, supporting add-on armor and weapons carrier configurations. Joint Program Office JLTV ultimately awarded three engineering, manufacturing, and design contracts in 2012 and one production contract in 2015.

The Army's vision for JLTV has evolved over time. The 2014 Tactical Wheeled Vehicle Strategy identifies the overall Light Tactical Vehicle (LTV) fleet as a multipurpose platform, focusing on light, tactical, protected mobility (U.S. Army Deputy Chief of Staff, G-3/5/7, 2014). This fleet is specifically identified as a mix of HMMWVs, Up-Armored HMMWVs, and JLTVs. Original estimates for the JLTV included an Army plan in which approximately 85,000 of its estimated 160,000 HMMWVs would remain in service through 2025 (Feickert, 2011). Revised JLTV acquisition quantities call for the procurement of 49,909 JLTVs for the Army from FY2015 to FY2040 and 5,500 JLTVs for the USMC from FY2015 to FY2021 (Feickert, 2015). The current strategy also identifies a need for MRAP vehicles to meet the current gap in capabilities from the HMMWV to the JLTV. Specifically, the MRAP fleet will "enable mobility in high threat improvised explosive devise environments, serve as key leader vehicles, and provide medical evacuation" (U.S. Army Deputy Chief of Staff, G-3/5/7, 2014, p. 15). Additionally, the Maneuver Center of Excellence is developing requirements for an ultralight Ground Mobility Vehicle (GMV) and a six-passenger Light Reconnaissance Vehicle (LRV) to fill other capability gaps in the LTV portfolio that JLTV was unable to meet.

B. JLTV COST-EFFECTIVENESS

The intent of this analysis is not to deliver precise or robust measurements for evaluation of the JLTV program, but rather to demonstrate a proof of concept with respect to the model. To this end, we obtained sufficient data to populate the model and make appropriate calculations for assessment.[3] Much of the collected data represents sensitive information, designated For Official Use Only and inappropriate for open release. As such, this study provides a descriptive rather than detailed presentation of input values. Only derivative values calculated in the model are presented in full. Similarly, we distribute relevant key performance parameters (KPPs) as appropriate on

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[3] Our calculations for this case study are based on available data at the time of analysis. As external evaluators, we are not privy to all of the relevant and most current data pertaining to this assessment. Thus, we acknowledge that the accuracy of our calculations is subject to a wider margin of error than should be expected for an internal program evaluation.

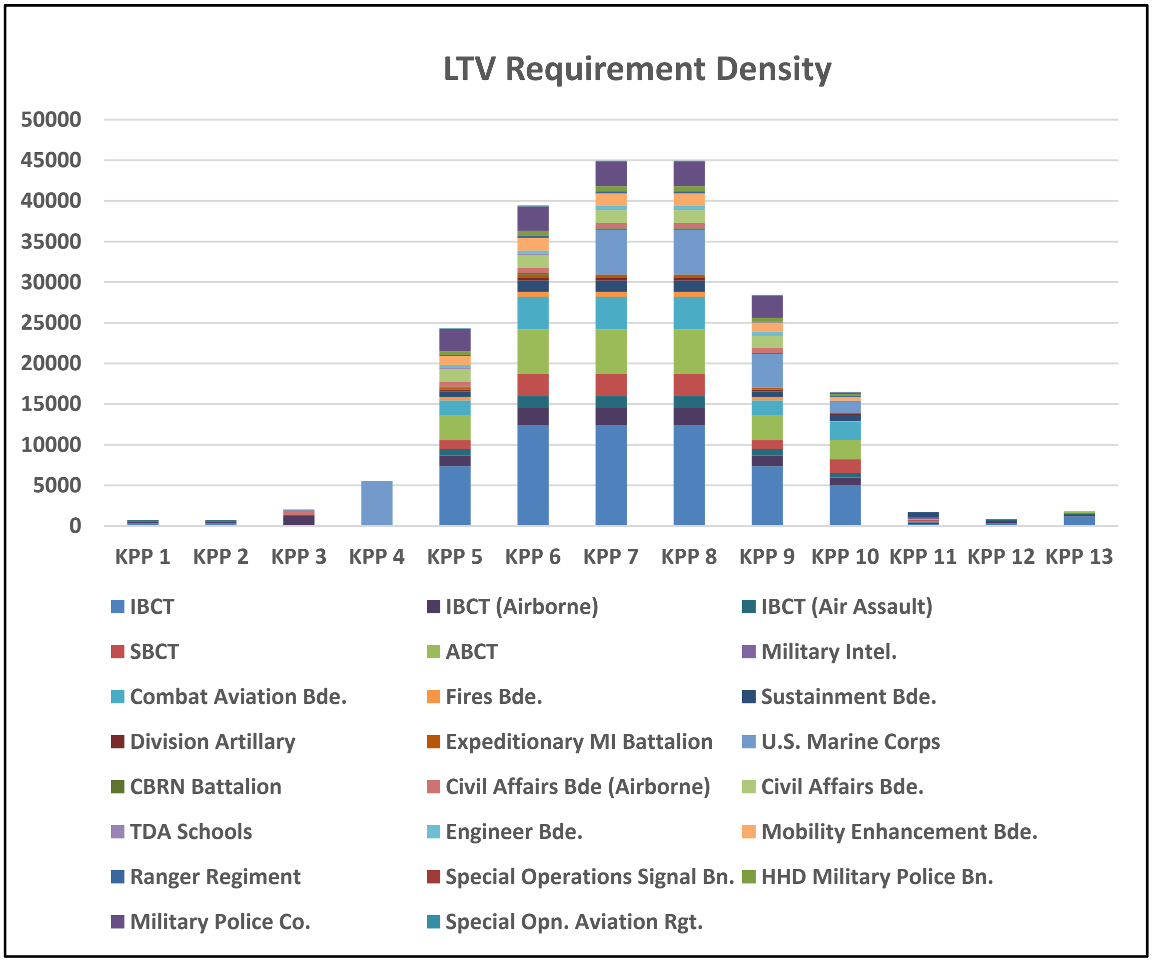
the agility–power spectrum and calculate requirement densities accordingly, but we do not detail the specific nature of each KPP in this study.

To assess the temporal change in cost-effectiveness, we apply the Joint Value Model to the LTV portfolio at two points in time, corresponding with the JLTV program at MS A and MS C. In measuring the requirement density of the portfolio, we determined that while KPP threshold and objective values evolved over time, the fundamental requirements remained consistent throughout development. For example, the most dramatic change in KPP values was with respect to underbody protection as described previously. While this change had a dramatic impact on the program, including requirement scope, it did not change the number of vehicles in the fleet requiring underbody protection. It only increased the level of protection that each vehicle required. Thus, the sum of requirement densities, which represents the calculated effectiveness of the portfolio, remained unchanged from JLTV MS A to MS C. A constant value for effectiveness will not result in all circumstances, and the model does not require this in order to produce valid calculations. In many cases, evolving requirements will generate new KPPs or alter densities for existing KPPs. This has not generally been the case for the LTV portfolio. Further, the study includes only those requirements that constitute distinguishing characteristics of the platform. Requirements for reliability, availability, maintainability, trafficability, and so forth are applicable to all vehicles in the portfolio and are thus excluded from consideration.

The model incorporates 13 KPPs on the LTV requirement spectrum. KPPs at the agile (left) end of the scale represent requirements for rotary-wing, fixed-wing, and seaborne transportability and deployment as well as mobility. On the power (right) end of the spectrum, KPPs dictate force protection and payload capacities for cargo, reconnaissance, heavy weapons, and mission command requirements. We derived the density of each KPP by analyzing current tables of organization and equipment, Army tactical wheeled vehicle strategies, approved and developing capability development documents, and the published basis of issue plans. These documents provided sufficient data to identify, with reasonable confidence, how many vehicles within a formation require each specification.

The arrangement of requirement densities on the agility–power spectrum reflect a generally bell-shaped distribution, with KPPs at the center of the scale exhibiting greatest density (see Figure 4). Using these values, we calculated LTV portfolio effectiveness to be 211,812. Again, this value is not the number of total vehicles needed in the fleet. It is the sum of requirement densities for all KPPs in the portfolio as previously defined.

Figure 4. LTV Requirement Density of KPPs by Formation



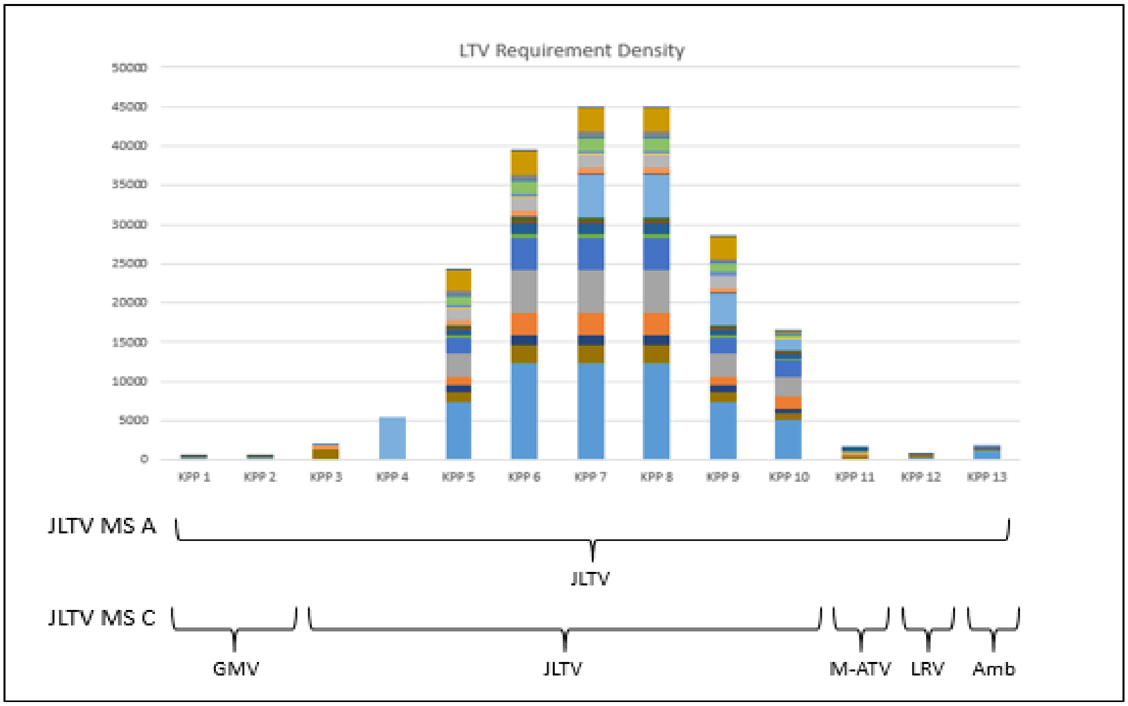
At JLTV MS A, the Army and USMC envisioned that the JLTV would replace a large portion of the HMMWV fleet and assume their associated mission roles. The intent was to meet threshold values for all 13 KPPs with multiple variants of a common platform. Over the course of development and as a result of a program CITA prior to MS

B, the services narrowed functional objectives for the JLTV to include only the requirements represented as KPP 3–10 in this model. The services designated KPP 1–2 and 11–13 to be met with other platforms or later unplanned increments of JLTV. Four separate platforms have been identified to meet these five remaining KPPs.

The GMV is in development to meet KPP 1–2, facilitating airborne and air assault operations in the IBCT. This vehicle will provide a highly maneuverable and transportable platform to enhance tactical mobility for light infantry units. The Army also currently uses M-ATVs to serve as key leader vehicles across the force. While less maneuverable and transportable than the GMV or JLTV, the M-ATV offers greater size, weight, and power capacities to facilitate command and control networking (KPP 11), which the JLTV is currently unable to integrate. IBCTs also require the LRV to enable organic cavalry scout squadrons. This requirement, represented as KPP 12 in the model, drives further capacity needs to support equipment and force structures specific to the reconnaissance mission. Similarly, KPP 13 dictates requirements for a battlefield ambulance with force protection, mobility, and transportability attributes equivalent to the JLTV. There is no current initiative to address the ambulance capability gap. Thus, it remains an unmet requirement within the LTV portfolio. The mitigation strategy includes a recapitalization of the HMMWV ambulance fleet and fielding of MRAP variants in prepositioned stock to facilitate contingency operations.

As the designated joint program, JLTV retains primacy in the model. This means that where capabilities overlap among programs, the model selects JLTV as the assigned solution. For example, GMV is required to meet KPP 1–7. However, since JLTV meets KPP 3–10, GMV is aligned only with KPP 1–2 in the model. The LTV portfolio structure at JLTV MS A and MS C is depicted in Figure 5.

Figure 5. LTV Portfolio Structure at JLTV MS A and MS C



To calculate portfolio cost, we used estimates of program average unit cost (PAUC) for each relevant program. PAUC is defined as total program cost divided by the acquisition objective (AO), or the total number of systems to be procured. For JLTV, the model incorporates reported PAUC values at MS A and MS C. Since JLTV was the only designated platform at MS A, this value represents portfolio cost for the model at that point in time. For MS C, the model averages PAUC values for each program, weighted with respect to AO. The published M-ATV PAUC value is also incorporated in the model. The GMV, LRV, and Ambulance platforms are in early stages of development and do not have approved PAUC estimates. We derived these values using available cost estimate data and projected procurement quantities. In a more detailed assessment of the JLTV using this model, a thorough sensitivity analysis should be included to evaluate variability in these values. For the purposes of this study, we exclude variability assessments, incorporating one estimated value for each PAUC. The calculated portfolio costs for our model at JLTV MS A and MS C are $250,000 and $433,512, respectively.

C. RESULTS AND FINDINGS

With these portfolio values, we calculated the cost-effectiveness of the LTV portfolio to be 1.18 at JLTV MS A and 2.05 at MS B. These values represent the cost to attain a single value of utility, or effectiveness. In itself, the cost-effectiveness number holds no useful meaning. However, as a tool for comparative analysis, it provides a valuable measurement for evaluating courses of action and assessing portfolio value over time. In the LTV portfolio, our calculations reveal a decline in cost-effectiveness from JLTV MS A to C as it became more expensive to deliver required capabilities than originally estimated. This can be also viewed as a reduction in portfolio value.

As a well-managed and successful program, JLTV is an ideal case study for analysis. In the course of development, program leadership made necessary and appropriate decisions to divest unattainable requirements and unaffordable platform variants. While logical for the program, such decisions were made without consideration for the broader portfolio and the potential negative externalities imposed. For example, the decision to cancel the Category B variant that supported LRV and ambulance platforms generated capability gaps and unfunded requirements in the portfolio. If the Joint Value Model had been applied in the decision-making process, it may have afforded a better-informed analysis of alternatives. The model would have provided the means to evaluate portfolio value by estimating the cost of including the variant in the program as compared to the cost of externalities in the portfolio as a result of exclusion. While inclusion would have increased JLTV PAUC estimates, it may have produced a more favorable cost-effectiveness assessment for the portfolio. If analysts are able to use LCEs to evaluate portfolio cost, the model can provide further insight into such alternatives. We can reasonably predict that logistical savings through commonality in the JLTV program would perhaps make inclusion of the long wheelbase variant more attractive from a portfolio perspective.

The model effectively captures the consequences of scope contraction and the hidden costs of commonality. Although a joint MDAP, JLTV experienced contraction largely as a result of competing intra-service Army requirements. Yet, the model is still useful in assessing the value of jointness in the program. The JLTV was able to incorporate USMC-driven requirements for seaborne transportability and mobility while achieving Army force protection needs. It is unclear to what extent, if any, these requirements drove development cost increases or schedule delays. Further, the transaction costs of accommodating the bureaucracies of both services in the development process are also not monetized in program estimates. Suitability concerns are relevant as well if suboptimal solutions result from USMC-unique requirements. Given the small quantity of procurement for the USMC—10% of the AO—even slight cost increases resulting from USMC specifications could have a definitive impact on cost-effectiveness. The cost to accommodate 10% of the fleet may outweigh the benefits of joint commonality. Here again, the Joint Value Model can be applied to evaluate alternatives in the portfolio context and determine if a joint solution is the optimal course of action.

V. CONCLUSION AND RECOMMENDATIONS

Current military CBAs and other DOD analyses fail to account for inherent complexity risks, which often diminish or outweigh the economic and operational benefits of commonality in joint programs. This cost of commonality, when overlooked, leads to suboptimal program solutions with detrimental effects on cost, schedule, and performance parameters. The JLTV case study provides initial validation of the Joint Value Model as a mitigation tool for program assessment. By capturing the cost of commonality and broadening the aperture of analysis, our model provides a useful methodology to reinforce the current suite of analyses and optimize requirement satisfaction. Ultimately, incorporation of the Joint Value Model can contribute to more cost-effective solutions and greater value in joint capability portfolios.

Examining requirements through the lens of a portfolio is not a new concept. Capability portfolio reviews have yielded service-centric strategies to include the current Army Tactical Wheeled Vehicle Strategy. However, decisions associated with these strategies tend to be focused at a senior executive level and are rarely delegated to a program or project level. Additionally, these decisions often have negative impacts for program and project leadership when divergence occurs from initial baselines. Current legislation for acquisition reform, and its role in the future of the National Security Strategy, attempts to address cost overruns and technical risk through several statutory changes. Language in the 2016 National Defense Authorization Act proposes further empowerment of services and program managers with respective penalties to accompany the new authorities. If this legislation is approved, tools such as the Joint Value Model may provide program managers with additional insight at the portfolio level. While the ultimate decision authority for joint programs remains at the DOD level, analysis conducted by the program manager has a tremendous impact on the overall success of the program. Our analysis indicates that the Joint Value Model has beneficial applicability at all stages of program development in assessing alternative courses of action. It is also scalable in nature. A comparison of cost-effectiveness figures among portfolios can reveal which investments produce the greatest value with respect to warfighter needs. Such analysis can inform budgetary considerations at the highest levels.

We recommend additional research to provide further validation of the Joint Value Model construct. The scope of this project incorporates only one detailed case study as a proof of concept. While this study indicates the usefulness of the model beyond the examined program, follow-on research should be conducted to determine the breadth of valid applicability.

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