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The Costs of Commonality: Examination of the JLTV as a Case Study

15 July 2016

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Abstract

In the 21st century, Major Defense Acquisition Programs (MDAPs) have become increasingly joint service efforts. The concept of a single materiel solution that can meet the requirements of multiple services is the fundamental principle of joint programs, with a concurrent objective of attaining economies of scale. But this trend has also 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. Even more important, perhaps, are the eventual, less obvious costs to attain unmet service requirements across a broader portfolio. We define these risks as the costs of commonality. Such costs are unquantified in cost–benefit and cost-informed trade analyses. Thus, they remain concealed in the defense acquisition process. Additionally, in order to capture these hidden costs, we propose a unique cost-effectiveness model that examines the value of joint programs from a broader portfolio perspective. We apply this Joint Value Model to the Joint Light Tactical Vehicle (JLTV) program as a case study to validate the concept. We conclude from our analysis that the Joint Value Model has useful applicability for assessing value in joint and intra-service MDAPs. It 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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Table of Contents

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I. The Value of Commonality

Parts standardization, or commonality, is a fundamental element of lean production for economic benefits. The practice extends to purchasing, overhead, manufacturing processes, support equipment, and tools, with every cost savings at even the lowest levels of parts and raw materials going straight to the bottom line of profitability. In the initiation of a product line commonality strategy, either a zero-based approach (bottoms up) or a parts reduction (top down) approach can be used. While the zero-based approach adds and uses only parts and modules deemed to be needed in terms of requirements, features, or parts functionality to a product design, the parts reduction approach instead seeks to reduce from an existing list and is thus more difficult or time-consuming to implement.

Economic benefits are especially realized when volumes are extremely large, such as in the automotive industry. Beginning in 2007, Ford Motor Company famously undertook a consolidation from 27 core platforms to a target of just nine in 2016 to leverage the company's global assets (Ford Motor Company, n.d.). Such part-type reduction benefits extend to not only spares inventory but diagnostics, maintenance, and even training of operators and maintainers.

The strategy is not without risk, however, because different product lines may require different tolerances and strengths to avoid component failure risk. Parts commonality also seems to be somewhat time-dependent. The initial pursuit of product line parts commonality often devolves into design divergence (reduction of commonality) as products evolve through development into final configuration, stemming from differences in the products' market positioning and their timelines for completion. It has also been realized that savings from predominantly common low-cost parts can be more than offset negatively by major subcomponents that are not common, and likewise shown that the lure of modularity and the benefits of standardization can often fail to emerge. Modularity often constrains form, fit, and function of components to a single, standard interface, and whether involving common modules of hardware or software, unintended interactions can occur as complexity grows. Design modifications and standards continuously evolve, coupled with an often sporadic demand upon release. Thus, benefits after initial provisioning can become smaller over the product life cycle.

Scaling up the positive aspects of this principle brings the concept of joint systems for use across the military services performing similar roles. Fleet commonality cost savings are envisioned as coming from spares provisioning, crew training, maintenance support, fault identification, and support equipment. Through the last century, as Department of Defense (DoD) sought joint service integration in its weapon systems in hopes of achieving economic benefits from multi-use platforms and parts commonality, many promised benefits have failed to arrive. Several others have noted that, in some ways, the Defense Department represents three niche markets derived from their distinct and unique operating environments.

Still a growing trend in defense acquisition, and required by DoD regulations, joint programs have revealed expanding program complexities and interdependencies. Brown (2011) made important distinctions between joint acquisition program effectiveness versus efficiency. Joint service acquisitions have been shown to involve more stakeholders, often having diverging and/or competing requirements, adding to program interdependencies and resulting scale of complexity. Further, these conflicting objectives have led to difficult and contentious tradeoffs, diffused authority, negotiated budget arrangements, complex project management structures, and so forth. This increased interdependence is generally reflected in greater transaction costs, that is, higher “coordination costs” from increased complexity and uncertainty. But the persistent intuitive rationale is that the benefits of inter-service commonality will outweigh the costs when properly executed.

The pursuit of joint capabilities has become increasingly emphasized in the 21st century. Materiel solutions are required to facilitate joint capabilities in the operational environment, which has driven an increasing need for jointly developed defense acquisition programs. However, a review of joint Major

Defense Acquisition Programs (MDAPs) in the DoD reveals a history of extensive cost growth, schedule overruns, and performance shortfalls. These consequences may result in part from the innate complexity of pursuing commonality on a very large scale across multiple roles and missions. In 2010, the Government Accountability Office (GAO) argued that many of the requirements for joint programs such as sharing domain information, business 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) to recommend the pursuit of a materiel or non-materiel solution to an identified capability gap in order to best meet an established capability need, followed by an Analysis of Alternatives (AoA) (cost–benefit analysis) to ensure that joint commonality is considered as the preferred solution. As the program evolves, managers consider tradeoffs through a process of Cost Informed Trades Assessment (CITA). Despite these rigorous and iterative processes, underperformance remains prevalent in joint DoD MDAPs. We suspect that analyses might fail to account for inherent complexity risks, which often diminish or outweigh the economic and operational benefits of commonality in joint programs, but this is not the basis for our research. In the course of multi-stakeholder compromise to seek a joint service solution, we have observed eventual divergence into multiple products to satisfy the unmet requirements of the compromise solution. The incremental costs of these products eventually comprise the less obvious expense, across a broader portfolio, of having pursued commonality. We define this consequence as the greater “cost of commonality.” In order to reveal and assist in capturing 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. Our complete technical report can be found at http://www.acquisitionresearch.net/files/FY2016/NPS-AM-16-002.pdf.

In a specific area of defense materiel, specifically mobile combat platforms, we observe that inherent tensions exist 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. As such, the breadth of user requirements can be arrayed on a continuous agility-powered spectrum, in which the attainment of functionality on one end often necessitates tradeoffs 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 due to conflicts, design trades, affordability concerns, and so forth. Such contractions expose capability gaps in the force as peripheral requirements which are left unmet by the common system. This generates negative externalities in the broader capabilities portfolio, which eventually manifest as portfolio costs to address unmet requirements with other systems. As a case in point, our analysis reveals significant scope contraction in the Joint Light Tactical Vehicle (JLTV) program over the course of development. We observed that 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.

Our proposed cost-effectiveness model, which we term the Joint Value Model, seeks to capture these costs by evaluating the program in a portfolio context. We reason that 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 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 un-monetized costs of commonality to facilitate more comprehensive analysis in joint programs for evaluating alternative courses of action throughout the development process.

While the scope of this project includes only one expository case study, we conclude from our analysis that the Joint Value Model may have applicability in the assessment of other large joint and intra-service programs. Incorporation of the Joint Value Model requires something of a paradigm shift with respect to how programs are presently assessed and funded. It allows managers to compare meaningful differences among program alternatives and assess value within capability portfolios. We also conclude that the model is scalable in nature. It offers a means to compare value assessments among different portfolios, informing funding decisions at the highest levels.

A. 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 relatively small quantities (49,550 vehicles from 2015 to 2035 with four variants). In comparison, the Ford Motor Company (2014), which continues to decrease its overall number of global platforms, reported global sales volumes of 5.6 million to 6.3 million vehicles from 2012 to 2014.

The automotive industry relies on a competitive market that allows consumers to choose among several automakers. Consumer selectiveness is tempered, however, 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 of the U.S. auto market “Big Three,” during the 2008–2010 auto crisis, it no longer becomes beneficial or profitable to 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, economies of scale rely on production quantities, and hence, overall purchase quantities must still be a consideration for military procurement. Even with a planned buy of over 3,000 Joint Strike Fighter aircraft, the RAND Corporation determined that, once developed, manufacture by more than one producer would not yield cost efficiencies (Birkler et al., 2001).

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, fuel, batteries, 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. Here, DoD organizations 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 with a zero-based approach 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 or may not be feasible to reuse during development, the utilization of existing compatible test equipment and maintenance facilities become significant cost savers.

B. Costs of Commonality

The costs of commonality manifest in numerous ways but derive principally from the innate complexities that pursuit of large-scale programs demand. The DoD is often pursuing joint solutions without full regard of the associated risks of these complexities. The defining nature of program jointness is the resulting interdependencies among stakeholders, funding, and other programs for enablement or interoperability, for example (Brown, 2011). This paradigm is not unique to defense acquisitions. Where possible, managers seem to attain most success when they limit project scope and partition objectives into projects of manageable scale (Flyvbjerg, Buzelius, & Rothengater, 2003).

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 decreases. 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 compromise or 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.

Early on, 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 low-cost components. There are multiple contributing factors. Commonality breaks down as user needs evolve and refine, standards change, development teams fail to adequately coordinate and synchronize, and new technologies become integrated 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 have been advised to 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 throughout the life cycle of the product family. And finally, so that commonality is not pursued as an end in itself by considering the associated tradeoffs 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 in design and manufacturing accrue. However, such designs can hinder the ability to extract price premiums though product differentiation. This can manifest as a real or perceived value disparity. Thus, substantial coordination among design, manufacturing, and marketing departments is critical to evaluating the profitability of common configurations and informing sound business decisions (Desai, Kekre, Radhakrishnan, & Srinivasan, 2001). While revenues and profitability are not the objectives of defense acquisition programs, the commonality–differentiation tradeoff is a transferable principle. Product utility, or value, with respect to the warfighter diminishes when common solutions fail to address diverse needs adequately. As sometimes occurs, the more functions that a common, “one size fits all” system can perform to some degree, the less effective it turns out to be at a distinct function. This induces suitability concerns in the operational environment if development efforts do not adequately incorporate the user community and maintain discrete priorities. The balancing act in the design “trade space” becomes a challenge indeed.

The Tactical Fighter, Experimental (TFX) stands out as a classic example of joint commonality pursuit, then compromise, then withdrawal of support, and an eventual result of an inadequately capable F-111A Aardvark (Art, 1968). When the commonality of parts falls below a specified threshold, the systems are no longer common and may be compromised of needed capability. The program is then de-scoped and partitioned into multiple programs. (We see this evolving divergence across several joint or mega-system acquisitions—see our full technical report for elaboration.) The earlier in the life cycle this decision to partition can be made, the greater the costs savings to the program and the broader mission area portfolio. It is incumbent upon program leadership to present this information to decision-makers early enough in the life cycle to facilitate these savings.

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II. Measuring Cost-Effectiveness in DoD Acquisitions

A. Current Theory and Practice

Due to unprecedented government spending in response to the global financial crisis, nation-states have been forced to exert extreme discretion when allocating scarce resources (Melese, Richter, & Solomon, 2015). Military expenditures, as the single largest discretionary item in many national budgets, are perpetually at risk of underfunding or defunding ("Military Expenditure," 2015). Thus, it is incumbent upon acquisition professionals to provide adequate rationale for decisions with respect to resource allocation. The military cost–benefit analysis (CBA) has become an indispensable tool for acquisition leaders to meet this requirement. 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 towards the heads of executive departments within the executive branch. Current theories and practices for the military CBA from government and academia are outlined in the following section.

An effective CBA depends on accurate cost estimations and affordability analyses. The intent of cost estimation is to provide an informed, approximate judgment. Within the Department, there are multiple cost organizations at varying levels, including the Office of the Secretary of Defense (OSD) and service field level components. However, there are a number of limitations in the current military CBA process. Some of these are clearly identified but not readily susceptible to change. Such limitations include the availability of funds and the predictability of appropriations. *Defense News* identifies Lockheed Martin, Boeing, and BAE Systems as the top three U.S. defense contractors in 2014 ("Top 100 for 2015," 2015). A review of 2014 annual reports for all three firms reveals that the number one risk identified for all corporations was the unpredictability of congressional appropriations (BAE Systems, 2014; Boeing Corporation, 2014; Lockheed Martin Corporation, 2014). This external factor is among those that are least susceptible to lower level programmatic influence. Yet it is still incumbent upon military leadership and program managers to consider the consequences of erratic funding, which can change the overall cost-to-benefit ratio of a program. Leaders must manage this risk through contingency analysis of alternatives with respect to program scope. Ultimately, current CBAs 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 when benefits cannot be easily monetized. An instructive case study of this approach was conducted for unmanned aerial systems in 2015 (Everly, Limmer, & MacKenzie, 2015). The cost-effectiveness of several aerial platforms was analyzed by determining unique measures of effectiveness for different platforms, communication payloads, and mission scenarios. Specifically, they compared the life cycle costs of 17 platforms and nine communication payloads with their capabilities in three scenarios: tactical, long-range, and disaster relief. This analysis provided additional framework to decision-makers for the selection of aerial platforms by capturing many of the previously un-monetized benefits of various alternatives.

The Analysis of Alternatives (AoA) is another form of cost effectiveness analysis and a fundamental step in the DoD process of system development. The AoA examines current capabilities with respect to Doctrinal, Organizational, Training, Materiel, Leader Development, Personnel, Facilities, and Policy (DOTMLPF-P) solutions to determine the most logical alternatives for meeting capability gaps. Yet, these approaches, while useful, fail to incorporate the inherent costs of commonality, with regard to the partitioning of needs and proliferation of products that occur. The relative subjectivity of benefits and often-ambiguous nature of cost dynamics make value determinations difficult.

Consequently, reliable metrics for comprehensive programmatic cost-effectiveness are unavailable to acquisition decision-makers.

B. 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 tradeoffs with respect to resources or designs 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. The derivation of requirements 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 inter-service requirements to be feasible within a common system or family of systems.

In commercial industries, a broad array of tradeoff dynamics can influence system development. Attributes such as the level of reliability, the extent of interoperability, or the amount of production 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. The principle 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 this spectrum. Within the portfolios of each brigade combat team (BCT), the Army seeks to balance capabilities to maximize combat effectiveness.

When a portfolio of systems becomes unbalanced in such a spectrum of capabilities, the result is reduced combat effectiveness overall. 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 (2012) cites this concern as the most critical capability gap for the formation. Conversely, LTG H. R. McMaster, current commander of the Army Capabilities Integration Center, believes that recent trends in maneuver portfolios have driven capabilities too far to the agility end of the spectrum in many cases. He advocates for renewed emphasis on combat power in ground combat systems (Freedberg, 2015). Thus, even within a single service customer community, there can be disagreement over the most fundamental of requirements.

1. The Joint Value Model

To assess the effectiveness with which programs address a broad spectrum of user needs, we propose a quantitative evaluation model. Each user need is examined individually to determine how many total systems in the fleet require that specification. The summation of these needs across users is a measure of requirement density, further quantified in numbers of systems. If, for example, we array these results on the agility–power spectrum relative to one another, the result is a graphical distribution of requirement densities. On this spectrum, capabilities specified at the center reflect the most common use-cases 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 (e.g., Ground Combat Vehicle) will typically depict a bell-shaped curve resembling a normal distribution (see Figure 1). 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.

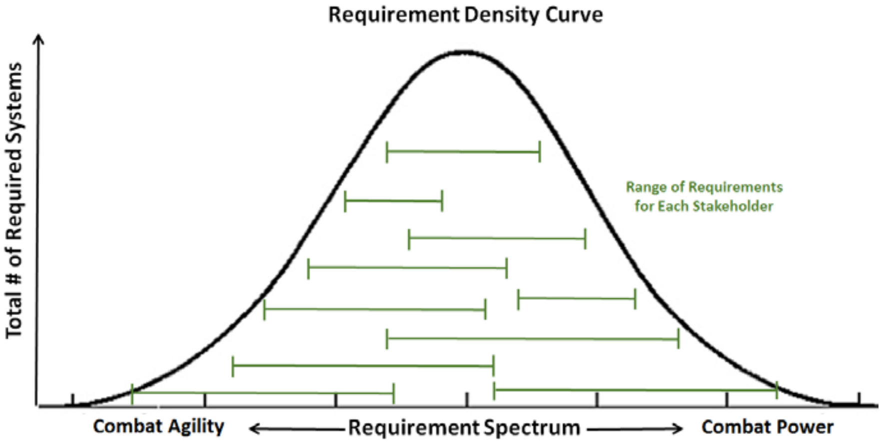

Figure 1. Portfolio Requirements Density Curve

However, we observe that physical, programmatic, and economic realities invariably seem to limit the scope of joint programs to a narrower 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 2). If a program fails to meet the intended range of requirements, these capability gaps constitute negative externalities within 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 may increase development costs. If the scope is narrow, the inverse will result, and negative externalities will increase. Suitability issues may arise also with more system special accommodation in the portfolio that attempts to generally address all needs.

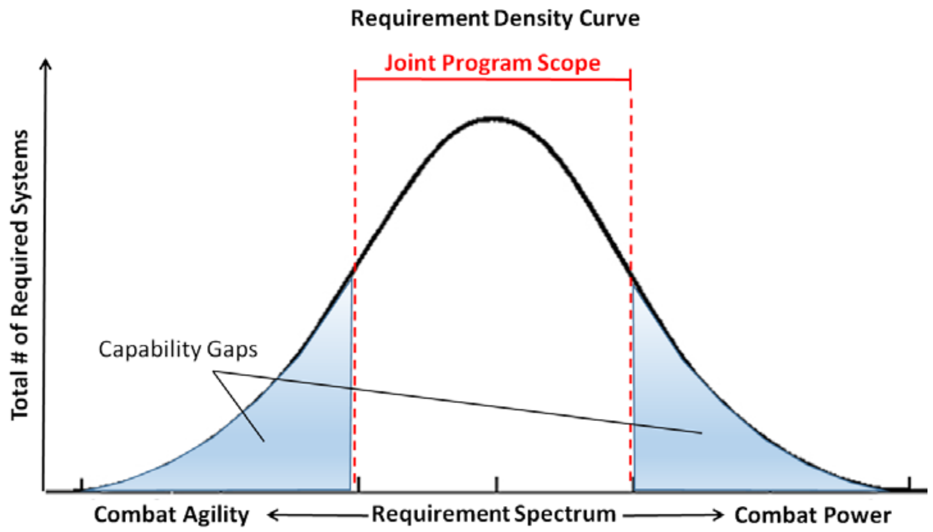

Figure 2. Portfolio Requirements Density Curve: Joint Program Scope

The agility–power spectrum may not fully encapsulate the diversity of 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 the greatest performance distinguishing characteristics dictating program scope. Thus, for the purposes of this study, we project the distribution of requirements on a single-dimensional scale, the agility–power spectrum. We suggest that effectiveness is a volumetric measurement of requirement density. For our two-dimensional model depicted in Figure 2, 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.

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

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 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 should be 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, our model calculates cost (shown in Equation 2) with estimates of Program Average Unit Cost (PAUC) for each system developed across the requirement spectrum. (The Program Acquisition Unit Cost [PAUC] divides the total acquisition expense, including research and development [R&D], procurement, and military construction funds, by the total number of planned test and operational end items.) The model weights each PAUC based on the total number of systems to be produced, or the Acquisition Objective (AO) of each system. Therefore, 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*.

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

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 and well into operational employment. 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, thereby 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.

2. Assumptions and Limitations

The principal assumption of this model is that all specified requirements are valid user needs, necessitating materiel solutions to mitigate critical capability gaps. In addition, the model is a data intensive construct. We assume that the costs of collecting and synthesizing necessary data are negligible in relation to the cost savings potential. The value of model results is limited by the accuracy and availability of 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. This increases risk visibility for decision-makers.

The model injects a paradigm shift with respect to program analysis in that it requires a broader analytical aperture, with implications for sponsors and portfolio managers. Here again, we assume that the costs of any inefficiencies associated with this shift are minor, and ultimately negligible, in relation to potential cost savings. 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. However, 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.

Finally, the model does not discount monetary costs with respect to time. While the principle of time-value of money is applicable, we reason that any delay in projected outlays directly corresponds with a delay in system fielding. Thus, budgetary cost savings associated with discounted estimates are directly proportional to the operational cost of delaying required capabilities to the warfighter. In this way, time is counterbalanced in the model and therefore excluded as a decision parameter.

III. JLTV Case Study

A. Program Overview

The genesis of the JLTV program dates back to a 2005 Army and U.S. Marine Corps (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 approved the JLTV program in November 2006 (GAO, 2010). The Army and Marines intended to solicit a request for proposal (RFP) for the Technology Development (TD) phase of the program as early as October 2007. However, Defense Acquisition Executive John Young expressed reservations about the maturity of required technologies, writing that “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). The revised Army and Marine TD plan was executed by 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, 2015a). 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 wheel-base payload Category B variant (Feickert, 2015a). 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 as well. 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 (GAO, 2010). Revised JLTV acquisition quantities call for the procurement of 49,909 JLTVs for the Army from fiscal year (FY) 2015 to FY2040 and 5,500 JLTVs for the USMC from FY2015 to FY2021 (Feickert, 2015b). The current strategy also identifies that there is still 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). 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 JLTV program has experienced significant scope contraction (number of included requirements) 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. Here, we apply the Joint Value Model to the JLTV program in order to analyze this dynamic.

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. Our intent 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 Joint Value Model. To this end, we obtained sufficient data to populate the model and make appropriate calculations for assessment. Much of the collected data represented 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 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 (introduction to Technology Maturation/Risk Reduction phase for prototyping, typically followed by a significant advanced development phase to fully demonstrate system integration and readiness for production) and MS C (low rate initial production). In measuring the requirement density of the portfolio, we determined that while individual KPP threshold and objective values evolved over time, the individual requirement performance values remained relatively consistent throughout advanced development. For example, the most dramatic change in KPP values was with respect to underbody protection, as described in the preceding section. While this change to increase the level of protection had a dramatic impact on the program, it did not change the number of vehicles in the fleet requiring underbody protection. 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. We assess that this has not 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 agility (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 published basis of issue plans. These documents provided sufficient data to identify, with reasonable confidence, how many vehicles within a formation require each specification of configuration. 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 3). Using these values, we calculated LTV portfolio effectiveness to be 211,812 requirement units. 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.

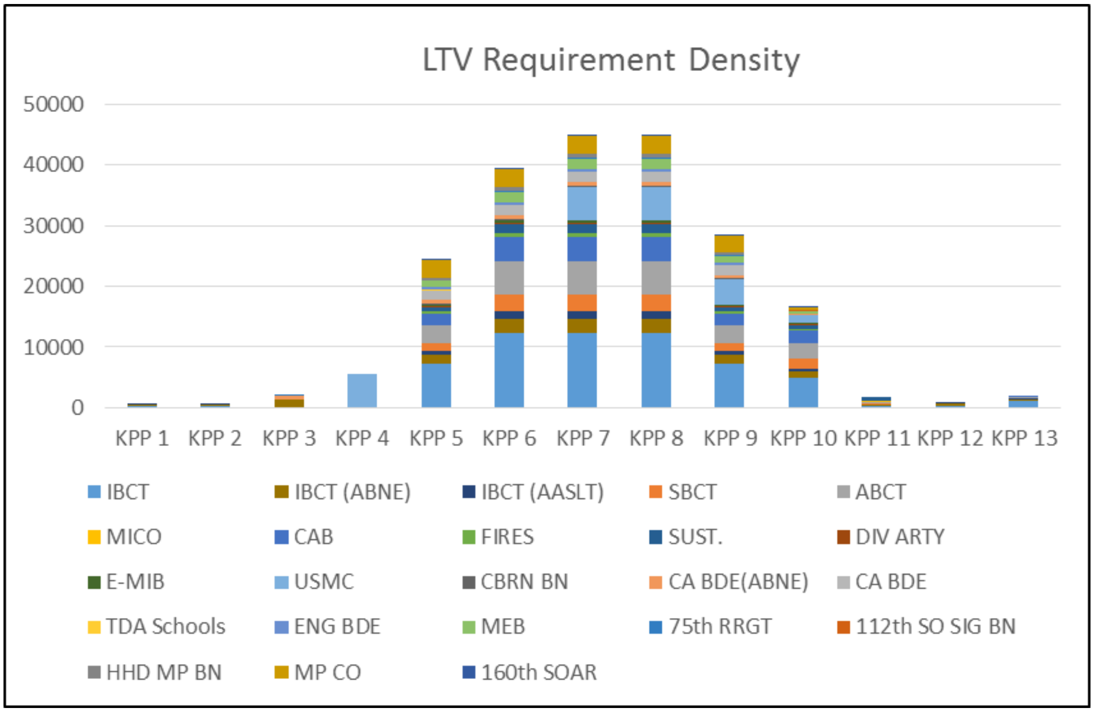

Figure 3. LTV Requirement Density

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 is also currently 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 squadrons' reconnaissance mission. Similarly, KPP 13 dictates requirements for a battlefield ambulance with equivalent force protection, mobility, and transportability attributes 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 4.

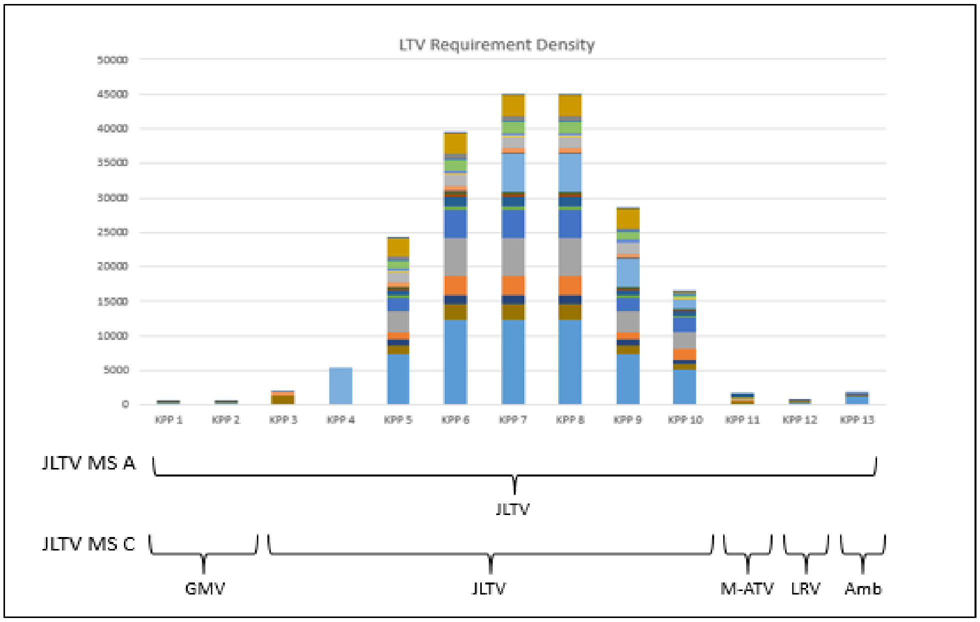

Figure 4. LTV Portfolio Structure at JLTV MS A and MS C

To calculate portfolio cost, we used current estimates of program average unit cost (PAUC) for each relevant program within it. PAUC is defined as total program cost (including non-recurring R&D, etc.) 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 their respective 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 officially 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 and uncertainty 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 Joint Value Model at JLTV's MS A (one vehicle planned) and MS C (five different vehicles planned) 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 C. 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 MS 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 thus far, JLTV is an ideal case study for analysis. In the course of development, program leadership made necessary and appropriate decisions to divest of 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 payload Category B configuration variant that supported LRV and ambulance platforms generated capability gaps and unfunded requirements in the portfolio. If the Joint Value Model were 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 life cycle cost estimates 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 wheel base variant more attractive from a portfolio perspective.

The model effectively captures the consequence 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 un-monetized in program estimates. Suitability concerns are relevant as well if suboptimal solutions result from USMC-unique requirements being accommodated. 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 most optimal course of action.

IV. Conclusions 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 sub-optimal 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 programmatic assessment. By capturing the cost of commonality and broadening the aperture of analysis, the 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 the current service-centric strategies to include the current Army Tactical Wheeled Vehicle Strategy. However, the 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 suggests the usefulness of the Joint Value Model beyond the examined program, follow-on research should be conducted to determine the breadth of valid applicability.

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