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# Exploring the implications of transaction cost economics on joint and system-of-systems programs

Angelis, Diana; Dillard, John; Franck, Raymond; Melese, Francois; Brown, Mary Maureen; Flowe, Robert M.

Monterey, California. Naval Postgraduate School

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**Exploring the Implications of Transaction Cost Economics on  
Joint and System-of-Systems Programs**

**23 September 2008**

**Dr. Diana Angelis, Associate Professor,  
John Dillard, Senior Lecturer,  
Brig Gen Raymond Franck (ret.), Senior Lecturer, and  
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Prepared for: Naval Postgraduate School, Monterey, California 93943



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# Abstract

As the Department of Defense (DoD) moves from the single-system, platform-centric paradigm to the capabilities-based paradigm, the scope and complexity of solutions are growing. The increasing emphasis on joint service and system-of-systems (SoS) capabilities has created both opportunities and challenges for materiel acquisition. A key barrier that needs to be overcome for the DoD to achieve the promises of joint service and SoS programs involves the challenge of “transaction costs.” These are the less visible, but nonetheless significant, costs of negotiating, managing and monitoring transactions. In an effort to identify the effect of transaction costs on more complex acquisition programs, this paper examines cost and schedule breaches in a subset of Major Defense Acquisition Programs (MDAP) that includes a sample of 84 programs, divided into “joint service” and “traditional” (single service) acquisition programs, and “single system” and “system-of-systems” (SoS) programs. The results suggest there is a statistically significant higher risk of cost and schedule breaches in SoS programs than in single system acquisition programs. This paper contributes to a broader study that eventually needs to be conducted that will evaluate the benefits and costs of increased reliance on joint service and SoS programs.

**Keywords:** Transaction Costs, Acquisition, Joint Service, System-of-Systems, Cost Breaches, Schedule Breaches, Cost Estimating



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# 1. Introduction

The US Department of Defense (DoD) is in the process of radical transformation—transformation to a national security strategy predicated on joint service purchases and complex system-of-systems (SoS) capabilities.<sup>1</sup> The DoD’s increasing emphasis on joint service and SoS capabilities has created both opportunities and challenges for materiel acquisition. In terms of improving the *effectiveness* of warfighting capabilities, the opportunity exists for joint, interoperable, multi-function, multi-mission systems that leverage information dominance and improve decisions and outcomes by making US and coalition forces not only better informed but also more coordinated, faster and more adaptive. In terms of *efficiencies*, multiple opportunities exist for joint programs to cut “economic production costs”—by reducing duplication, by exploiting learning curves, and by achieving economies of scale and scope in manufacturing and in operations and support activities (e.g., joint training and logistics).

As we move from the single-system, platform-centric paradigm to the capabilities-based paradigm, the scope and complexity of solutions are growing. As we move beyond our experience base (and our empirical data sets) we must ask some profound questions:

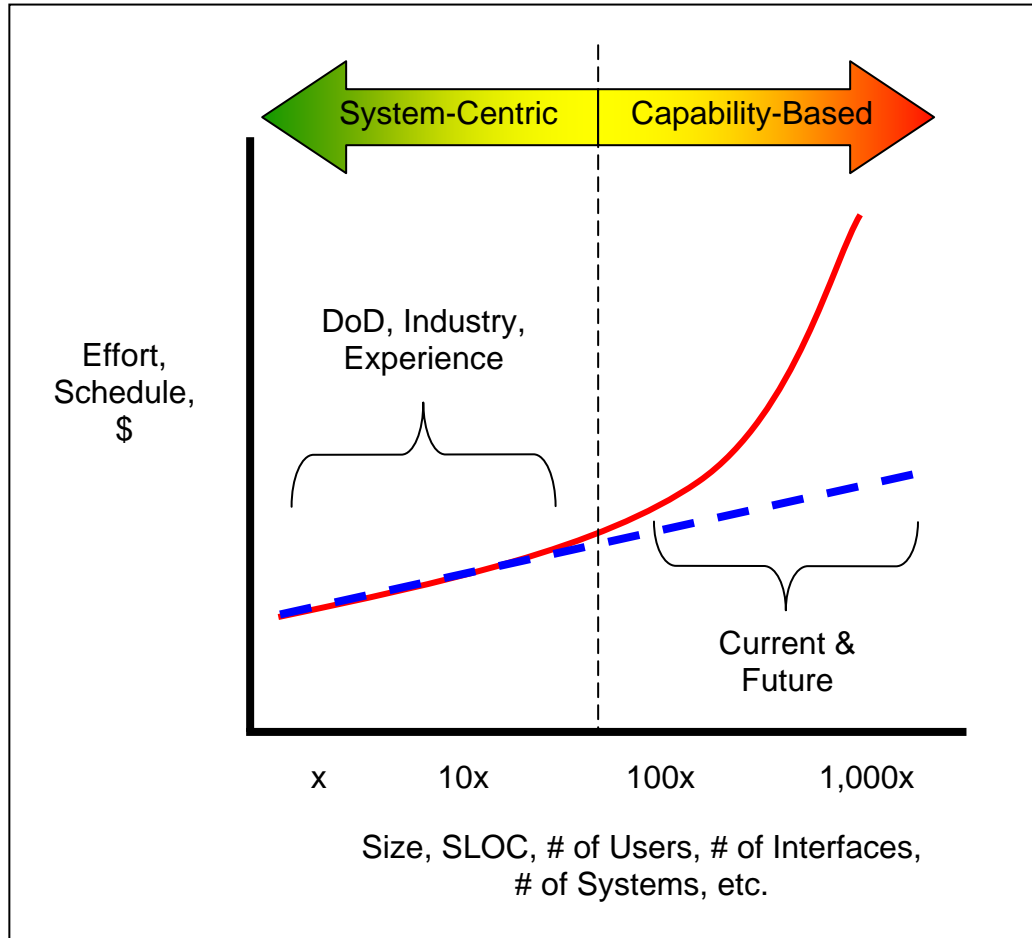
- As the magnitude and complexity of DoD systems increase, how do we develop realistic cost, schedule, & performance baselines?
- Are we measuring the right drivers of cost/schedule?
- Are linear assumptions and models valid?

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<sup>1</sup> As defined in the DoD *Defense Acquisition Guidebook* (2004), an SoS is “a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities.” Joint Program Management is defined as “Any defense acquisition system [...] or technology program that involves formal management or funding by more than one DoD Component during any phase of a system’s life cycle” (DAU, 2004, p.1). *DoD Directive 5000.1, The Defense Acquisition System*, dated 12 May 2003, indicates a policy preference for joint development programs over Component-unique development programs (AT&L).



The answers to these questions lie at the heart of our ability to provide reliable estimates on projected outcomes for major defense investments to senior defense decision-makers as illustrated in Figure 1.



**Figure 1. The New Systems Acquisition Context**

A key barrier needs to be overcome for the DoD to achieve the promises of joint service SoS programs. This involves the challenge of “transaction (coordination and motivation) costs.” These are the less visible, but nonetheless significant, costs of negotiating, managing and monitoring transactions.

This paper investigates cost and schedule breaches in a subset of Major Defense Acquisition Programs (MDAP) that includes a sample of 84 programs, divided into “joint service” and “traditional” (single service) acquisition programs, and



“single system” and “system-of-systems” (SoS) programs. The results suggest there is a statistically significant higher risk of cost and schedule breaches in SoS programs than in “single system” acquisition programs. This paper contributes to a broader study that eventually needs to be conducted that will evaluate the benefits and costs of increased reliance on joint service and SoS programs.





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## 2. Joint Service and System-of-Systems Programs

In 2003, the Joint Capabilities Integration and Development System (JCIDS) replaced the “Requirements Generation System” that had identified warfighter needs for nearly 30 years (recently updated in CJCS, 2007, May 1). Providing a new, substantive role for Combatant Commanders, the JCIDS process reflects a significant shift in the focus of defense programming toward joint system capabilities.

Greater emphasis on joint operations in the DoD has led to the requirement for interoperability not only between new systems and legacy systems but also between systems developed by different agencies or services. This requires cooperative management of development and acquisition programs. Crossing management domains creates or intensifies issues related to decentralized management and independent authority of service agencies and can result in asymmetrical incentives for SoS versus “single system” and/or “single service” weapon systems.

In several recent cases, the size and complexity of undertaking SoS programs has overwhelmed the DoD’s ability to effectively manage them. According to a recent Congressional Research Service report, “management and oversight of acquisition programs increases as the value of the program increases” (Chadwick, 2007, p. 12). The larger the program, “the more difficult it is to sustain communications among staff members. In general, if there are ‘n’ people in a program, the potential number of pair-wise channels is  $n(n-1)/2$  [...] larger teams [...] have a greater chance of communications breakdown” (DAU, 2004, p. 16). *Ceteris paribus*—the bigger the program, the larger the transaction (coordination) costs.

There are a variety of categories of joint service programs. These range from relatively simple, “single system”, “single service” programs to which other services sign on to use the end product, to fully integrated, multi-service SoS programs. Examples of the latter include the Joint Strike Fighter (JSF) and the Joint



Surveillance Target Attack Radar System (JSTARS). Clearly, the latter (joint service SoS) acquisitions are considerably more challenging than the former. The reason can be traced to greater interdependence, manifested in greater complexity and uncertainty.

Most weapon system programs are interdependent in one way or another. They often exchange resources and information, which imposes additional costs and constraints on the efficient execution of the program. The effects of interdependence and complexity can be largely hidden however, since the majority of weapon systems are still managed in a single service environment. In essence, the DoD defines capabilities at the joint level but manages the majority of acquisitions at the service level. As a result, the costs of interdependence and complexity are not routinely captured or included in cost and budget estimates.

Joint service SoS acquisitions involve more stakeholders, multiple users and funding sources, divergent and competing requirements, and conflicting objectives that lead to difficult and contentious trade-offs, diffused authority, negotiated budget arrangements, complex project management structures, etc. This increased interdependence is generally reflected in greater transaction costs: higher “coordination costs” from increased complexity and uncertainty, and higher “motivation costs” from greater asset specificity and limited market contestability.



### 3. Transaction Costs = Motivation Costs + Coordination Costs

In business, two costs are typically factored into strategic acquisition decisions: production costs and the costs of managing the transaction—or “transaction costs” (Coase, 1937). Conventional strategies tend to focus on economic production costs (input costs, learning curves, economies of scale and scope, etc.). TCE emphasizes another set of costs—coordination and motivation costs. Economic production (opportunity) cost advantages tend to guide companies to specialize in “core” activities in which they have a comparative advantage and to “transact” with outside suppliers to acquire other goods and services. A key contribution of TCE is to formally introduce and fully reveal the nontrivial costs of managing those transactions.

Transaction costs include coordination and motivation costs, such as search and information costs; decision, contracting and incentive costs; and measurement, monitoring and enforcement costs. TCE predicts these costs will vary across weapon system acquisition programs to the extent there are differences in certain key characteristics of the transaction—complexity, uncertainty, frequency, and asset specificity—as well as market contestability, and the choice of governance (contracting, etc.) mechanisms. A central point from TCE is that the choice of contract, organization, and incentives, along with key characteristics of the transaction (complexity, uncertainty, frequency, and asset specificity) and market contestability, must be considered in order to obtain reliable cost estimates of joint programs (Melese, Franck, Angelis & Dillard, 2007).

One of the key insights of TCE is that capital (and human capital investments) that are specific to a transaction (e.g., made to support a joint program acquisition) can generate cost savings but also carry the risk of increasing transaction costs from opportunistic behavior. The role of relation-specific investments (“asset specificity”)



is an important consideration that needs to be anticipated and factored into any analysis of “joint service” and SoS programs.<sup>2</sup>

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<sup>2</sup> Williamson (1996) identifies six types of asset specificity: 1) site, 2) physical asset, 3) human asset, 4) dedicated asset, 5) brand-name capital, and 6) temporal. These are specialized investments that generate high returns within a specific relationship but offer little value outside it. Site specificity refers to the co-location of facilities to minimize inventory or production costs. Physical asset specificity refers to the use of customized assets such as specialized dies and equipment. Human asset specificity refers to firm-specific knowledge and skills (e.g., “specific” as opposed to “general” training). Dedicated asset specificity refers to additional investments in plant and equipment made to sell the extra output to a specific customer. Brand-name capital specificity refers to investments in reputation. Temporal asset specificity refers to investments that facilitate timing and coordination of projects (e.g., investments in critical-path activities).



## 4. Motivation Costs: The Role of Asset Specificity

Having made a specialized investment in location, physical, human, or other specific assets, a supplier often becomes the most efficient provider, which is good from a production-cost perspective, but provides incentives for the supplier to look for opportunities to extract more from the transaction (perhaps by demanding steep prices for any modifications to the contract). After investments in specific assets are made, the relationship is transformed from a customer having the choice of a number of competing suppliers to a bilateral monopolistic relationship between a buyer and seller.

Similar to “sunk costs,” investments in relationship-specific assets (“asset specificity”) are potentially valuable but can increase risks to both parties in a transaction (Klein, Crawford, & Alchian, 1978). Close-in bilateral bargaining (a principal-agent type game) replaces the competitive marketplace. This entails a transformation of the supplier from competitive bidder (prior to source selection) to monopoly supplier (after source selection), especially if there are no close substitutes. Accordingly, the customer (government) is now vulnerable to “opportunistic behavior” from the supplier.

Unforeseen contingencies, combined with newly inelastic demand, may prompt the supplier to extract more of the surplus created in the relationship.<sup>3</sup> In this case, suppliers can exploit their power in the relationship by renegotiating a basic agreement to their advantage, otherwise threatening to dissolve the agreement. The TCE literature refers to this as a “hold-up”<sup>4</sup> (Klein, Crawford, & Alchian 1978).

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<sup>3</sup> Williamson (1975), Besanko, Dranove, Shanley & Schaefer (2000), and others have labeled the transition from one prospective buyer and many sellers to one buyer and one seller or from competitive market to bilateral monopoly, as the “fundamental transformation.” To some extent, this transformation occurs after the completion of every military source-selection process.

<sup>4</sup> According to Besanko et al. (2000), a holdup problem arises when a party in a contractual arrangement exploits the other party’s vulnerability due to relationship-specific assets.



Conversely, a supplier (defense contractor) that makes specific investments in assets that are only valuable in the context of the relationship with a specific customer (government), can find itself vulnerable to any changes in demand from that customer (i.e., the supplier suffers from “demand uncertainty”). Given the government is the only buyer (or one of only a few) of joint SoS weapon systems, and given its limited ability to commit as a result of the annual nature of most budgetary processes, defense industry sellers often face a monopsony—a buyer that cannot make credible multi-year commitments. This leads to sellers facing substantial demand uncertainty and the real risk of strategic renegotiation.

Whereas relation-specific investments can increase the total gains to both parties, the risk exists of opportunistic behavior; either party can hold up the other, for instance, by threatening to change the terms of the contract (e.g., the government’s sovereign right to terminate a contract for convenience as well as default). The danger is that if neither party feels it can recover the full costs of its investment in the relationship/transaction (say through a continuation or renewal of the contract—“frequency”),<sup>5</sup> then efficiency-generating, specific investments will not be made, resulting in higher costs.<sup>6</sup>

It is important to note at this point that whereas TCE has traditionally examined the customer-supplier relationship in the context of a contractual

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<sup>5</sup> In terms of “frequency,” past experience with similar programs appears to have a significant impact on a supplier’s costs and capabilities. So, if source selection and strategic partnership decisions recognize this and clearly favor past performance, the acquisition process will be converted from a one-shot game into a repeated game, allowing suppliers to earn a return on their investment in reputation. In this way, increasing frequency through strategic partnerships and recurrent transactions can mitigate opportunistic behavior and build trust in the contracting relationship. By identifying key characteristics of transactions such as frequency and fully understanding their implications, decision-makers could mitigate cost, schedule and performance breaches.

<sup>6</sup> Scope for opportunistic behavior may lead to adverse selection, choice of an (ex-ante) inferior option (or technology), or moral hazard. Such scope increases risks that if a relationship-specific investment is made, the other party will exploit the terms of the contract to “hold them up.” For example, changes in specifications are frequently used by contractors as a reason to raise prices and profits under government contracts—especially when those investments by the contractor create barriers to the entry of competitors.



arrangement, the domain of joint capabilities acquisition is distinctive (though not exclusively so) in the establishment of partnerships among government entities (such as between DoD services or agencies), as well as teaming arrangements among private-sector enterprises within the defense industrial base (e.g., product development contractors and their first- and second-tier suppliers). These internal relationships also incur transaction costs related to coordination and motivation costs; search and information costs; decision, contracting and incentive costs, etc. This notion is explored further below.

Whereas defense acquisition has traditionally focused on economic production costs, joint programs expose the DoD to the potentially greater costs of managing the relationship, and more importantly, to the risks of opportunistic behavior on the part of contracting partners—a critical “transaction cost.” Given the multiple competing stakeholders in a joint SoS acquisition, the principle of self-interest suggests all sides have incentives to behave opportunistically and may not necessarily have the motivation to cooperate to make cost-saving investments—particularly when specific assets are involved and information is imperfect (incomplete or uncertain) and asymmetric.<sup>7</sup> Clarification of the risks of “opportunism” (i.e., motivation costs) is one of the key advantages of TCE.

If it turns out that joint service SoS programs require a significantly greater ratio of specific assets to total investments, then this increases the risk of bilateral dependency and “hold-up.” Moreover, given the difficulty of writing complete contracts for joint SoS programs that will cover every contingency, with incomplete contracts the hold-up problem poses additional risks for the government, such as

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<sup>7</sup> In order to combat this tendency, and in the spirit of resolving the principal-agent problem, an interesting incentive clause is included by the US Air Force in its “National Polar-Orbiting Operational Environmental Satellite System.” When establishing top executives’ salaries and bonuses, the contract requires TRW’s corporate board to consider contract performance. By tying senior executive pay directly to contract performance, decision-makers can help align incentives, increase accountability and reduce cost overruns (Graham, 2003).





contractors charging excessively high prices for change orders and strategic renegotiations.



## 5. Governance Issues

TCE suggests the degree of completeness of a contract is an optimizing decision by the parties involved, one that reflects tradeoffs between ex-ante investments in contract design and the risk of ex-post costs of opportunistic renegotiation. In reality, contracting offers an imperfect solution to opportunism. What may be required are additional governance mechanisms (i.e., rules and regulations, reputation mechanisms, termination agreements, government-furnished equipment, Government Owned Contractor Operated (GOCO) facilities, warranties, etc.) to shift risks to safeguard and protect transaction-specific investments, settle disputes, and adapt to new conditions. Ex-ante efforts may also be necessary to screen for reliability and reputation (e.g., pre-award contract surveys of potential vendors). These structures can include anything from agreements to share and verify cost and performance information through incentive contracts, to the careful crafting of dispute-settlement mechanisms (e.g., alternate dispute resolution, proactive management councils, etc.). Among government entities in joint acquisition programs, memoranda of understanding or agreement (MOUs or MOAs)<sup>8</sup> reflect a “quasi contractual” relationship among ostensibly sovereign entities. The enforceability of these is always questionable, but they nevertheless serve to make the particulars of agreements among the parties explicit and provide both implicit and explicit dispute-resolution mechanisms to reduce the risk of hold-up.

In general, the less complex and uncertain a transaction, and the lower the requirement for specific assets, the easier it is to write an explicit contract that covers all contingencies. Also, the lower the administrative and enforcement costs of

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<sup>8</sup> The Air Force F-35 Joint Strike Fighter (JSF) program featured elaborate memoranda of agreement among domestic and international partners to reduce the risk of hold-up. Despite these structures, the sovereignty of partner governments limited the enforceability of these instruments, and hold-ups did occur—notably when the legislatures of the partner governments imposed changes to the agreements articulated in the MOAs, upon which program plans were based. The consequential impact of program cost, schedule, and performance outcomes have not been fully characterized but would be a worthwhile subject of future TCE research.



that contract, the lower the risk of hold-up. These favorable characteristics are more likely to exist in established, traditional (“single service”), “single system” acquisition programs, and contribute to lower costs (or cost overruns), and better performance and schedules.<sup>9</sup>

Evidence uncovered by Bajari and Tadelis (2001) in construction contracts reveals that in cases in which a transaction is easy to define and measure (i.e., there is little complexity) and only a few minor changes are expected (i.e., there is little uncertainty), fixed-price type contracts tend to dominate. However, the more complex the transaction—the more difficult/costly it is to define and measure performance; the more uncertain the transaction—the more likely it is that a change in the contract will be required and the more severe the adversarial relationships experienced ex-post when fixed-price contracts are chosen. In the latter case, fixed-price type construction contracts often end in costly renegotiations—in which any surplus generated was dissipated in the course of those negotiations through unproductive bargaining and influence activities. Thus, *complexity* and *uncertainty* can force parties to turn away from fixed-price type contracts and towards cost-reimbursement type contracts (e.g., costs plus a award/incentive fee) and to rely heavily on reputation and other enforcement mechanisms to avoid ex-post

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<sup>9</sup> If a transaction requires little in the way of specific assets (no hold-up problem), and involves a product or service that is: a) well-defined and homogeneous, b) easy to measure (limited complexity and mild information asymmetry), c) routinely used (recurring/frequent purchases), d) not subject to change (limited demand uncertainty), and e) is offered by competing suppliers, then there is little room for negotiation (price and performance are market-driven), and the marginal benefit of unproductive bargaining is near zero. With little room for bargaining over such routine and uncomplicated transactions, substantial production and transaction cost stability can be expected in the acquisition. Moreover, since administrative, incentive, and enforcement costs tend to be low for acquisitions in more contestable (competitive) markets, the marginal cost of engaging in the transaction is relatively smaller for the military, and there exists an incentive for the supplier to invest in the transaction that generates opportunities for cost savings. International competition for standard (off-the-shelf) commercial components of weapon systems might be an example. By unbundling large, complex weapons systems into sub-systems, decision-makers might reveal opportunities to enjoy the benefits of lower transaction costs and greater competition, leading to lower production costs. These favorable characteristics generally lend themselves to more accurate cost estimating and may result in fewer cost breaches.



opportunistic behavior that threatens to dissipate the gains generated by a transaction.

In reality, joint service acquisition programs often involve highly interdependent, complex system-of-systems (SoS) that usually end in a bilateral monopoly contractual setting.<sup>10</sup> In this case, assuming no specific assets are required, the outcome depends on the degree of contractual ambiguity governing the transaction, as well as on any administrative and enforcement costs involved. However, as complexity, uncertainty, and opportunism due to specific investments increase, so does the risk of hold-up and so do the coordination and motivation (transaction) costs required to measure, monitor, and govern both the internal relationships among the Components and the external relationship with the contractor. These less-favorable characteristics of joint SoS programs can discourage productive efforts and investments in both internal Component relationships and external contractor relationships, thus contributing to more serious cost overruns, schedule breaches, and performance shortfalls.

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<sup>10</sup> Many factors conspire to create this bi-lateral monopoly. On the buyer side, monopsony power partly derives from the fact the military value of most systems depends solely on their performance relative to the systems of adversaries. This is specific to a country and the defense environment it faces at a particular point in time, effectively making it the sole buyer of a highly differentiated product. The appearance of a superior alternative results in what might be termed military obsolescence. Response to new threats can require redesign during development, and modifications during the system's operational life. This cause-and-effect relationship conspires to reduce the number of buyers of a particular weapon system, since these weapon systems are often evolving products (spiral acquisition). Thus, in addition to technical uncertainty, there is a significant degree of demand uncertainty.



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## 6. Coordination Costs: Interdependency yields Complexity and Uncertainty

Interdependency is typically defined as the degree to which the performance of one activity (or system) relies on an external activity (or system) for its success (Thompson, 1967). Under conditions in which organizations are allowed to seek the most efficient path to task accomplishment, interdependent relationships will be established as long as the benefits exceed the costs. Private entities typically make technology investments and seek interdependencies to achieve the benefits of synergy and economies of scale based on measurable effects on the “bottom line.” In contrast, government agencies are often guided and constrained by legislative requirements for cross-organizational integration to establish interdependent relationships. Consider, for example, the increased emphasis on “jointness” since the *Goldwater Nichols Department of Defense Reorganization Act of 1986*. The intent of this legislation was clearly to increase interoperability, and hence interdependency, in the DoD. Combined with recent reforms that reinforce joint solutions to defense capability needs (such as JCIDS), simultaneously encouraging SoS, the result is increased interdependency reflected in increased complexity and uncertainty, and correspondingly higher coordination costs.<sup>11</sup>

For most systems, interoperability is pursued as a means to leverage the collective assets of various organizations located at different points along the value

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<sup>11</sup> Interdependent activities are not new to the DoD or to government in general. However, what is new is the scale in which interdependent actions are applied. Prior to the information technology revolution of the 1990s, spatial and temporal distances tended to impede communication and the sharing of information among partners. Hence, tightly coupled activities were generally restricted to small groups of geographically co-located groups where coordination costs could be minimized. The advent of advanced information and communication technologies eroded many of the spatial and temporal barriers that once thwarted collaboration. The potential benefits of information-sharing enabled by interoperability were then quickly realized and became a major thrust for many organizations, the DoD included. Network externalities were increasingly recognized—the value of the network to individual participants increased with the number of participants connected to the network.



chain. For example, in the command and control (C2) process, military operations benefit when commanders can seek, synthesize, and disseminate several types of information derived from different organizations. Experts in a variety of areas must collaborate during the C2 process to effectively create and execute battle plans. These experts may come from different disciplines (or specialties), different branches of the military, or even different countries. In short, interoperable systems promote interdependent actions. In turn, increased interdependency is reflected in increased complexity and uncertainty and higher coordination costs.

*Complexity* is a key component of transaction costs. When advanced (immature) technologies are combined with systems integration challenges across diverse organizations in the scale of joint service SoS programs, the resulting complexity leads to higher coordination costs. Marshall and Meckling (1962) were among the first to discover that variability in the size of cost-estimating errors in defense contracts could at least partly be attributed to technological complexity, with larger errors associated with greater technological advances sought in different systems.<sup>12</sup>

*Uncertainty* is another key component of transaction costs. The reconciliation of competing requirements of different players in joint programs can lead to design changes and implementation challenges (demand uncertainty). Similarly, the “free rider problem” (in which none of the players want to sacrifice individual budgets to cover costs that might benefit others), combined with changes in Congressional priorities (political uncertainty), can lead to funding instability (budget uncertainty).

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<sup>12</sup> Adler (1995) examines the complex and interdependent relationship between product design and manufacturing, describing four possible governance mechanisms to improve coordination (e.g., standards, schedules, mutual adaptation and teams). McNaugher (1989) provides evidence that costs rise rapidly with system complexity, as does the variance of costs around expected costs (p. 128). Consider the increase in complexity in the US Navy’s new Littoral Combat Ship (LCS) class, which has experienced a 128% cost growth and which was designed to avoid costs through smaller crews (substituting capital for labor). It is unclear whether the substantial increase in transaction costs and scope for opportunism introduced with the increased complexity (capital investment in complex onboard systems) justifies the anticipated labor-cost savings.



Besides demand, political, and budget uncertainty, joint programs face measurement uncertainty, technological uncertainty, supplier performance uncertainty, etc.<sup>13</sup>

An interesting avenue for future research would be to investigate if increased emphasis on “jointness” since the *Goldwater Nichols Department of Defense Reorganization Act of 1986* or the advent of the JCIDS in 2003 has increased the complexity and uncertainty of joint programs relative to others and, consequently, raised coordination and motivation costs. The possibility exists that other characteristics inherent in many joint programs might offset these higher transaction costs.

On the one hand, a joint program manager that manages a program that is technologically mature, that does not require strict military specifications, in which funding and requirements are relatively stable, and in which a contestable market exists for the product or service, may in fact experience lower transaction costs. On the other hand, if the program is facing immature technologies, rigid specifications, funding and requirements instability, and monopolistic suppliers, joint program managers and other key decision-makers should recognize the potential for high transaction costs and opportunistic behavior.

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<sup>13</sup> A dynamic programming model by Womer & Terasawa (1989) finds that under demand uncertainty, a rational defense contractor must prepare for various contingencies, and will, for example, restrict investments in specific assets, which drives costs higher than they would be if demand were certain. This tends to increase information and contracting costs, and as the authors demonstrate, threatens investments in specific assets. The authors show that the higher the probability the contract will be canceled, the less the contractor will invest in capital equipment (relation-specific investments), which results in relatively more labor-intensive production and raises costs. Thus, demand uncertainty increases contracting costs and also raises issues related to asset specificity. Under demand uncertainty, the rational contractor will restrict investments in specific assets (such as capital tooling or specialized expertise), unless they are reasonably sure to recover these costs via overhead. Allowing “Facilities Capital Cost of Money” to be an expense is a mechanism by which the government reduces the risk to the contractor by allowing recovery of costs associated with specific capital assets (buildings, tooling, etc.) through overhead. Critics argue this encourages defense contractors to over-capitalize, which increases costs DoD-wide.





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## 7. TCE and Cost Estimating

The higher the transaction costs, the greater the economic production cost efficiencies need to offset them. As recently emphasized by Melese et al. (2007), if initial cost estimates focus exclusively on economic production costs and ignore transaction costs, the result can be systematic cost overruns.

According to a recent RAND study of major acquisition programs, the average cost overruns of weapon systems in the development phase ranged from 16% to 26%. Procurement cost growth over initial estimates averaged between 16% and 65%, while total weapon program cost overruns averaged from 20% to 54% (Arena, Leonard, Murray, & Younossi, 2006).

Since the official “acquisition program baseline” (APB) estimates for these programs reflect the best current understanding of the cost, schedule, and performance objectives at the time the baseline is established (typically at Milestone B decisions), Congressional funding of these programs represents an implicit contract with the Executive Branch. When incomplete or unrealistic cost estimates lead to significant cost and schedule overruns relative to expectations established in the APB, administrative sanctions, such as statutory (Nunn-McCurdy<sup>14</sup>) unit cost

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<sup>14</sup> Since the law was enacted in 1982, Title 10 USC Section 2433, a “Nunn-McCurdy” unit cost breach occurs when a major defense acquisition program experiences an increase of at least 15% in program acquisition unit cost or average procurement unit cost above the unit costs in the acquisition program baseline. Through 2006, the DoD had the ability to administratively change the acquisition program baseline for the purposes of unit cost reporting and so was able to reduce the number of apparent Nunn-McCurdy breaches, despite apparent cost growth that would otherwise trigger the Nunn-McCurdy sanctions. In 2006, the Nunn-McCurdy law was amended. The FY 2006 *National Defense Authorization Act (NDAA)* severely restricted the DoD’s ability to change unit cost reporting criteria. As a result, Nunn-McCurdy unit cost breaches are incurred at 15% (“Significant”), and 25% (“Critical”) above the current unit cost threshold. Additionally, a “Significant” Nunn-McCurdy breach is incurred at 30% of the Milestone B unit cost threshold, and a “Critical” Nunn-McCurdy breach is declared at 50% growth above the Milestone B unit cost threshold. Thus, the ability of the DoD to mask unit cost growth through changes to unit cost thresholds is restricted.

The sanctions imposed by Congress on programs breaching Nunn-McCurdy criteria are noteworthy: For “Significant” breaches, the service Secretary must notify Congress within 45 days of the report (normally program deviation report) upon which the determination is based (normally a program



breaches, can be triggered. In turn, these breaches can dramatically impact program execution; they also jeopardize relations between the Legislative and Executive Branches of government.

A study conducted by the DoD in 2007 to develop a business case for improving system cost estimating in the DoD (Brown, Flowe, & Hamel, 2007a) examined the cost growth of all major defense acquisition programs (MDAPs) from 1995 to 2005 to determine the source and relative magnitude of cost growth and schedule breaches. See Figure 2.

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deviation report initiated when the Program Manager becomes aware of the breach). The program must submit a Selected Acquisition Report (SAR) with the required unit cost breach information.

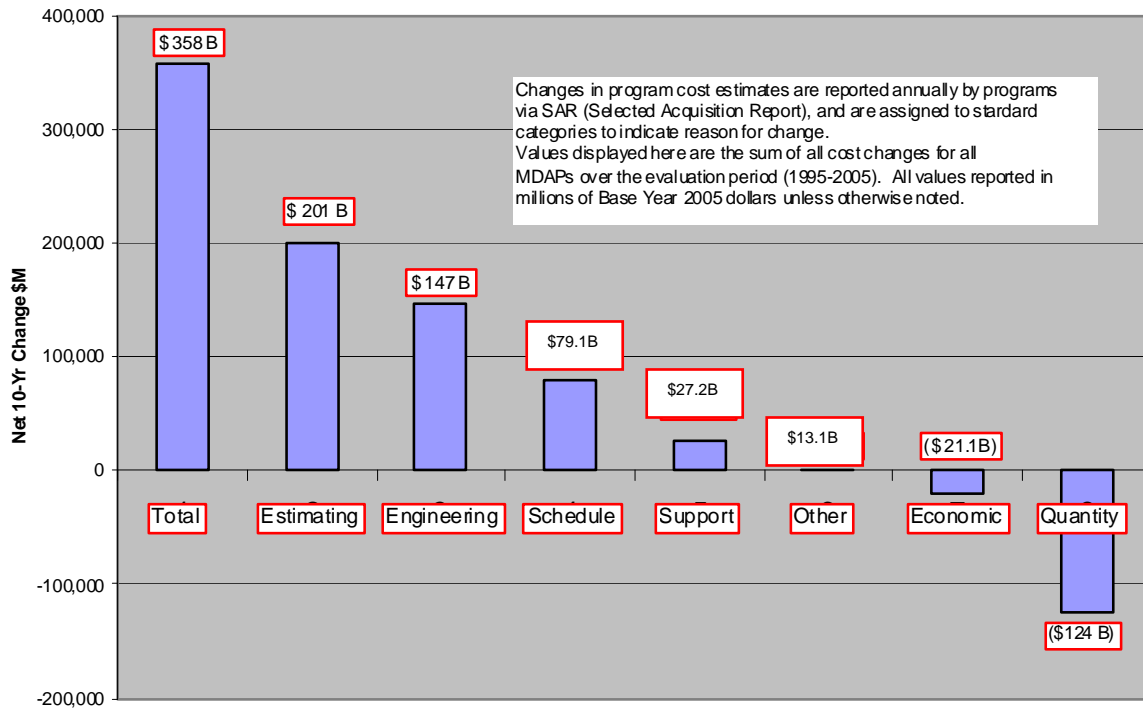
For “Critical” breaches, the Defense Secretary (usually delegated to the Under Secretary of Defense for Acquisition, Technology, and Logistics) must certify to Congress within 60 days of notification that:

- 1) the program is essential to national security,
- 2) there is no alternative which can provide equal capability at less cost,
- 3) the updated estimates of unit cost (calculated independently by the OSD Cost Analysis Improvement Group) are reasonable, and
- 4) the management structure is adequate to control unit cost going forward.

Failure to certify within the 60-day timeframe will result in suspension of obligations for major contracts until 30 days of continuous session of Congress, beginning from the date of receipt of SAR/Certification.



### Ten Year Cost Change by Category



Source SAR Data 1995-2005 All MDAPs

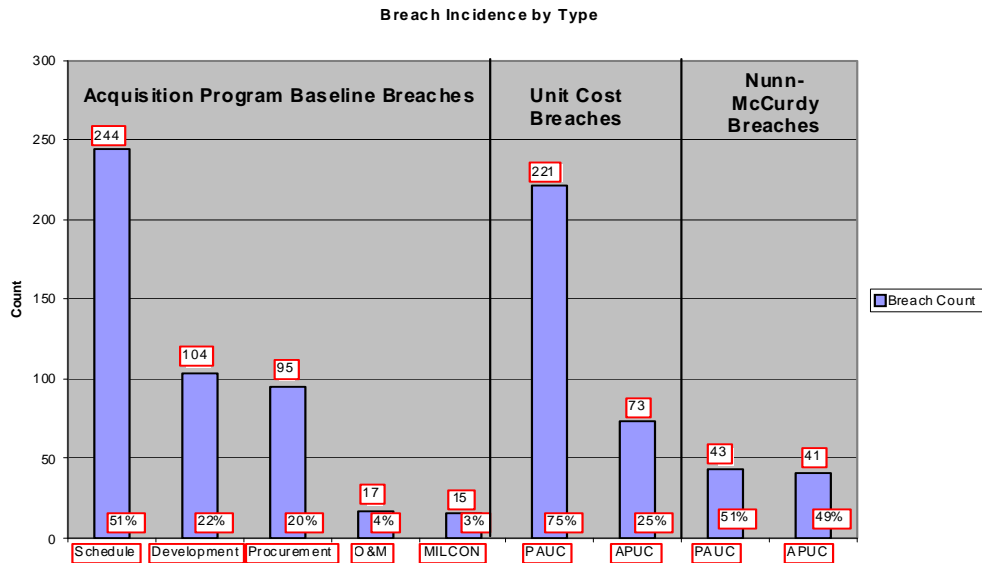
Figure 2. Cost Growth by Category for All MDAPs 1995-2005  
(Brown, Flowe, & Hamel, 2007a)

As shown in Figure 2, the largest source of cost growth as reported in the Selected Acquisition Reports (SAR) is “Estimation.” This indicates that estimates made in establishing MDAP acquisition program baselines were often in error, and thus program costs appeared to grow despite very little change in the objective content of the program. This “Estimation” error accounted for approximately \$201 billion in apparent cost growth over the 10-year period examined across all major programs.

Figure 3 is a related analysis that examines the quantity and sources of breaches for 108 MDAPs over the same 10-year period (1995–2005). With respect to the Acquisition Program Baseline (APB), schedule breaches were the most



common; occurring 244 times over the 10-year period examined, suggesting that multiple schedule breaches is a relatively common occurrence in many programs.



Source SAR Data 1995-2005 All MDAPs

**Figure 3. Breaches Reported by SAR All MDAPs 1995-2005  
(Brown, Flowe, & Hamel, 2007a)**

Development and procurement cost breaches occur with less frequency than schedule breaches but still occur sufficiently frequently that on average, each MDAP can expect to have one of each. Program Acquisition Unit Cost (PAUC) breaches occur nearly as frequently as schedule breaches, indicating that the confluence of development and procurement cost increases conspire to increase unit costs at least 10% above that established by the APB. Nunn-McCurdy breaches are notably less common, suggesting that only about 20% of programs that breach their APB unit costs will grow substantially beyond that. Overall, the raw quantity of breaches indicate that expectations regarding costs and schedules are usually unmet, to the extent that for the 108 MDAPs examined, each breached on average more than twice for schedule and unit cost and at least once for development cost.<sup>15</sup>

<sup>15</sup> This is not to imply that every program was equally troubled. A subset of particularly troubled programs, approximately 30% of the total, breached in some way every year they reported.



## 8. Cost and Schedule Breaches

We investigated cost and schedule breaches in a subset of MDAPs that included a sample of 84 programs, divided into “joint service” and “traditional” (single service) acquisition programs, and “single system” and “system-of-systems” (SoS) programs. The 84 DoD weapon system programs were initially examined by Brown, Flowe, and Hamel (2007b) and were identified as being either “single system” or “system-of-systems.” The “system-of-systems” designator was used as a proxy for complexity.

While it seems reasonable to assume that programs designated as “system-of-systems” will be more complex, it is not necessarily true that such programs will be joint programs involving more than one service. For example, an aircraft carrier is certainly a “system-of-systems” but is managed by a single service, the Navy. Another example would be the F-22, arguably a “system-of-systems” and certainly complex, but still only managed by a single service, in this case the Air Force. On the other hand, there may be “single systems” that are considered joint programs because they are either managed or procured by more than one service.

SoS programs are defined as independent systems that are integrated into a larger system to provide unique capabilities. The identification of a program as SoS can be seen as a proxy for *complexity*. Joint programs are systems that involve more than one service during any phase of the program (i.e., development, production, operations) and can be seen as proxy for *coordination* costs. Using this distinction between “system-of-systems” and “joint,” we assigned a “joint service” designator to the 84 DoD weapon systems originally used by Brown, Flowe, and Hamel (2007b). Table 1 shows the programs divided into “single service” and “joint service” categories.



<b>Single Service (n = 58)</b>	<b>Joint Service (n = 26)</b>
PATRIOT PAC-3	H-1 UPGRADES (4BW/4BN)
CVN 68	NAVSTAR GPS
EELV	AMRAAM
TRIDENT II MISSILE	MH-60R
ARH	F-35 (JSF)
DDG 51	V-22
DDG 1000 (DD(X))	ATIRCM/CMWS
C-17A	GBS
SBIRS HIGH	NPOESS
C-130J	AEHF
CVN 21	MH-60S
T-45TS	JTRS JOINT WAVEFORM
SSDS	MP RTIP
MINUTEMAN III PRP	WGS
ADS (AN/WQR-3)	BLACK HAWK UPGRADE (UH-60M)
GLOBAL HAWK (RQ-4A/B)	JTRS GMR (CLUSTER 1)
GMLRS	BMDS
F-22A	AGM-88E AARGM
E-2C REPRODUCTION	JTRS HMS (CLUSTER 5)
CH-47F	JDAM
JAVELIN	PATRIOT/MEADS CAP
LAND WARRIOR	MIDS
TACTICAL TOMAHAWK	JASSM
FBCB2	JPATS
WIN -T	AIM-9X
C-130 AMP	JSOW
STRYKER	
FCS	
MINUTEMAN III GRP	
C-5 RERP	
AESA	
LHA REPLACEMENT	
SSGN	
MUOS	
SDB I	
E-2D AHE	
COBRA JUDY REPLACEMENT	
EXCALIBUR	
HIMARS	
JLENS	
LCS	
B-2 RMP	
EA-18G	



ASDS	
SM-6	
VH-71 (VXX)	
MPS	
EFV	
SSN 774 (VIRGINIA CLASS)	
NAS	
LPD 17	
F/A-18E/F	
CEC	
T-AKE	
BRADLEY UPGRADE	
MCS	
FMTV	
LONGBOW APACHE	

**Table 1. Single Service and Joint Service Programs**

a. Methodology

A set of 84 DoD weapon system programs first divided into “single service” and “joint service” programs by Brown, Flowe, and Hamel (2007b) were further divided into either “single system” or “system-of-systems” (SoS) programs. (Data available upon request.) Our tests focused on four categories of breaches: Schedule, RDT&E, Program Acquisition Unit Cost (PAUC), and Average Procurement Unit Cost (APUC) defined as follows:

- **Schedule Breach:** When schedule exceeds most recent Acquisition Program Baseline (APB) schedule estimate by 6 months
- **RDT&E Breach:** When the program’s research, development, test and evaluation costs exceed 15% of the baseline threshold.
- **PAUC Breach:** When the program acquisition unit cost exceeds the most recent APB threshold by 15%. This is a Congressionally reportable breach.
- **APUC Breach:** When the average procurement unit cost exceeds the most recent APB threshold by 15%. This is a Congressionally reportable breach.





Our hypothesis is that SoS programs are more complex than single system programs, so they will be more likely to experience cost and schedule breaches. Likewise, Joint programs require more coordination than traditional (single service) programs and are also more likely to experience cost and schedule breaches. Schedule and cost breaches may be evidence of hidden transaction costs.

To investigate the differences between the data groupings described above, we ran an analysis of variance using “jointness” as the grouping variable instead of “system-of-systems.” Because the subdivided samples were not normally distributed, we also ran a Kruskal-Wallis (H) test to determine if there was a significant difference in the mean ranks of the groups, testing single service vs. joint service and single systems vs. system-of-systems (SoS). The H test is particularly robust as it does not make any assumptions about the underlying distribution of the samples. We also considered whether there might be a difference in average number of breaches between development and production programs. We used a Mann-Whitney (U) test (which does not make any assumptions about the underlying distribution of the samples) to test our hypothesis. We looked at the difference in mean ranks for schedule breaches, cost breaches (including RDT&E, procurement, PAUC and APUC) and total breaches.

## b. Results

Table 2 compares the results of the tests based on the two different groupings. While it is clear, as noted by Brown, Flowe, and Hamel (2007b) that there is a significant difference (at the .05 level) in the average number of schedule breaches and RDT&E cost breaches between “single system” and “system-of-systems” programs, there is no significant difference between “single service” and “joint service” for any of the breach categories examined.



Variable	Single System	System of Systems		Single Service	Joint Service	
	Mean (n=39)	Mean (n=45)	p-value	Mean (n=58)	Mean (n=26)	p-value
Schedule breaches	4.49	8.60	0.0229	5.71	8.88	0.1058
RDT&E breaches	1.64	5.87	0.0010	3.48	4.85	0.3404
PAUC breaches	2.36	4.24	0.0693	3.17	3.81	0.5739
APUC breaches	1.10	1.82	0.1678	1.48	1.50	0.9757

**Table 2. Analysis of Variance**

This data suggests that while the “system-of-systems” designator may be a good proxy for complexity, which in turn may lead to schedule and cost breaches, “jointness” does not appear to make a difference when it comes to program breaches. This is an unexpected result, since we reasoned that joint programs are more likely to experience higher transaction costs and therefore might experience more cost breaches if their cost estimation models do not include variables to account for those transaction costs. The data seems to suggest that complexity may be the overriding influence on schedule and cost breaches regardless of whether a program is managed by a single service or multiple (joint) services.

The results of the H test are reported in Table 3. Again we see that complexity (as measured by “system-of-systems”) has a significant influence on the mean ranks for schedule and RDT&E breaches. We also see that there is a significant difference between mean ranks for schedule breaches between “single service” and “joint service” programs but not for cost breaches. As Brown, Flowe, and Hamel (2007b) noted, joint programs have more participants, divergent requirements, diffuse authority and complex management structures all of which might contribute to schedule breaches. It appears, however, that those conditions



do not necessarily lead to cost breaches. Again, we may conclude that complexity is more important to cost breaches than “jointness.”

Variable	Single System	System of Systems		Single Service	Joint Service	
	Mean Rank (n=39)	Mean Rank (n=45)	p-value	Mean Rank (n=58)	Mean Rank (n=26)	p-value
Schedule breaches	34.36	49.56	0.0039	38.56	51.31	0.0246
RDT&E breaches	32.44	51.22	0.0002	39.34	49.56	0.0631
PAUC breaches	39.14	45.41	0.2244	41.70	44.29	0.6418
APUC breaches	39.60	45.01	0.2633	42.09	43.42	0.7977

**Table 3. Kruskal-Wallis (H) Test**

Overall, the results are consistent but somewhat weaker considering the difference in the average number of breaches between development and production programs using the U test as shown in Table 4. The results show a significant difference between the mean rank of schedule, cost and total breaches in development programs based on complexity (as measured by “system-of-systems”). In each case, the mean rank is higher for “system-of-systems” programs than for “single system” programs. We also see a significant difference in mean ranks of cost and total breaches in production programs based on complexity. Again, the mean ranks are higher for “system-of-systems” programs than for “single system” programs. But there is no significant difference in mean ranks of either development or production program breaches between “single service” and “joint service.” This reinforces our earlier observations that complexity (as measured by “system-of-systems”) appears to be a stronger indicator of possible schedule and cost breaches than “jointness.”



Variable	Single System vs. System-of-systems		Single Service vs. Joint Service	
	Development	Production	Development	Production
	n=48	n=36	n=48	n=36
Schedule breaches	0.0104	0.1558	0.0624	0.2126
Cost breaches	0.0414	0.0225	0.2603	0.5703
Total	0.0276	0.0289	0.1632	0.4497

**Table 4. Mann-Whitney (U) test**

These findings should be interpreted with a note of caution. For example, the limited sample, the method for categorizing the degree of interdependence or “jointness” and SoS, and the failure to include and control for other important factors may be significant. Though preliminary, these results offer evidence to support further investigations on the role of “jointness” and SoS in program acquisition.

c. Discussion

The results suggest there is a statistically significant higher risk of cost and schedule breaches in SoS programs than in “single system” acquisition programs. Interestingly, while “joint service” programs in general have a weak statistically significant greater risk of schedule (and RDT&E cost) breaches than “traditional” (single service) programs, there is no significant difference between the two in terms of Program Acquisition Unit Cost (PAUC) breaches or Average Procurement Unit Cost (APUC) breaches.

Based on our sample, SoS programs tend to take relatively longer and cost more than “single system” acquisitions. This preliminary empirical evidence of cost and schedule breaches suggests initial cost (schedule) estimates of SoS programs may not be adequately capturing transaction costs. In fact, since production cost breaches are significantly greater, the transaction costs experienced by SoS programs may be overwhelming any potential economic production cost savings



(Melese et al., 2007). If this is indeed the case, the anticipated warfighting benefits of SoS solutions need to be sufficiently large to compensate for the extra costs and schedule delays experienced by these programs.

Meanwhile, it appears that while “jointness” contributes to schedule overruns, it only weakly contributes to development cost overruns, and by itself, does not explain production cost overruns. While our results suggest joint programs tend to breach their schedules relatively more often than “single service” programs (“every event in a joint program takes longer [...] extra time needs to be included in the program schedule” (DAU, 2004, p. 20)), “joint service” programs in our sample only experienced a few more cost breaches than “single service” programs in the early development (RDT&E) stages. There does not appear to be any statistical difference in production cost breaches (PAUC or APUC) between “joint service” and “single service” programs.

One explanation for this is that the “joint service” programs in the sample encompass a spectrum that includes both “single systems” and SoS, as well as the complexity and uncertainty associated with SoS is so significant as to overwhelm any additional complexity and uncertainty that might be experienced by joint service programs. Another possibility is that built-in checks and balances tend to offset the extra transaction costs of joint service programs.

For instance, “joint programs require special attention to multi-service funding requirements and to acquiring the right mix of joint expertise for the source selection process”; indeed, “full consultation and coordination with the participating components” is required (DAU, 2004, pp. 12, 21). The ultimate outcome may be to help anticipate and mitigate the extra transaction costs and to avoid requirements creep in production stages of the program. Guidance for joint program managers is designed to inhibit any changes in scope, stating that “substantive changes to [...] program documentation, such as the acquisition strategy or the contract [need to be] negotiated with the participating Components prior to making changes” (p. 12).



With weapon system investments expected to capture a significant, and perhaps growing, share of defense budgets, unprecedented attention has been devoted to clarifying the determinants of risk, failure, and success in the joint arena (Pracchia, 2004). The Defense Department's apparent inability to avert or even predict adverse program outcomes such as cost and schedule breaches is not only a source of external criticism (GAO, 2006) and internal attention (Krieg, 2005), it has undermined confidence in the time-honored practices of program management and oversight.

To date, there is significant debate regarding the factors that influence the outcomes of programs. Thus, the search for root causes and potential solutions of program cost growth, schedule delay, and capability shortfall have received increased attention. To help explain potential pitfalls associated with joint programs, this study leverages "Transaction Cost Economics" (TCE), which has recently been applied to generate new insights into defense cost overruns (Melese et al., 2007).



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## 9.

## Conclusion

Transaction Cost Economics (TCE) suggests investigating the specific characteristics of transactions that make up joint service programs (like SoS) could help anticipate (and perhaps mitigate) cost and schedule breaches. Since increases in interoperability/interdependence tend to increase complexity and uncertainty, and complexity and uncertainty increase coordination and motivation costs, it is likely that cost and schedule breaches partly depend on decisions regarding the extent of bundling or unbundling of the many interdependent parts of joint systems,<sup>16</sup> and on the particular phase of development or production of those weapon systems.

Historically, fixed-price contracts are usually prescribed in later stages of product development when complexity and uncertainty have been resolved, and the contract is complete. In contrast, cost-reimbursement contracts are usually prescribed in earlier stages of product development when complexity and uncertainty have not been resolved, and the contract is incomplete.<sup>17</sup> Today, cost-reimbursement contracts are phased out and fixed-price contracts phased in, as complexity and uncertainty issues are resolved. However, complexity and

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<sup>16</sup> For instance, an extremely complex interoperable system is envisioned for the Coast Guard's new "integrated deepwater system program." The system is intended to include cutters and small boats, a new fleet of fixed-wing aircraft, a combination of new and upgraded helicopters, and land- and cutter-based unmanned aerial vehicles (UAVs)—all linked with Command, Control, Communications and Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) systems and supported by integrated logistics. According to a recent Coast Guard press release (2007, June 25), "Deepwater is a 25-year, \$24 billion effort that will produce more than 91 new cutters; 195 new aircraft" and C4ISR equipment. The lead systems integrator is a joint venture between Lockheed Martin and Northrop Grumman that has recently been in the news for major cost overruns, schedule slippages, and quality issues—the latter involving several modified ships that were determined un-seaworthy.

<sup>17</sup> "Complexity" and "technological uncertainty" (as opposed to "demand uncertainty") are usually correlated. Ignorance about what buyers want and what contractors can do result in large up-front search and information or Research and Development (R&D) costs. R&D is similar to a real option in the sense that real options models are learning models (Kogut & Kulatilaka, 2001). The problem that gives rise to high transaction costs in the case of complex weapon systems is that this characteristic of the transaction leads to market failure (missing markets). From a TCE perspective, the classic market failures—natural monopoly, negative externalities, public goods, etc.—have information analogues: missing markets, adverse selection, and moral hazard.





uncertainty must be characterized in the context of TCE for this strategy to succeed. Note that while these prescribed contracts focus on the characteristics of *complexity* and *uncertainty*, often overlooked is the vital role of *asset specificity*—a key component reflected in the motivation cost component of transaction costs.

The main strategy of reducing cost and schedule breaches is employed to identify ways to cut coordination and motivation costs. Specific recommendations include: a) reducing complexity by investing in a more complete contract (e.g., setting realistic baselines—entailing higher search and information costs—or using more mature technologies, recently emergent in acquisition policies; b) reducing uncertainty through multi-year contracts (reducing demand uncertainty) or investing in a more complete contract (reducing relationship uncertainty); c) increasing measurement (CAIG) and monitoring (GAO) of performance and both production and transaction costs to reduce information asymmetries and the associated risks of moral hazard and adverse selection; d) placing credible deterrents to bad behavior in place—such as penalty clauses, warranties and bonding; e) using multi-year contracts to gather information and to reward good reputations (Kelman, 1990); f) mitigating opportunistic behavior introduced by asset specificity through careful use of incentives, proper bundling (or task-partitioning) of joint programs, and strategic investments in government-furnished equipment or government-owned and contractor-operated assets; and finally g) increasing market contestability through investments in real options (e.g., government-controlled standby capacity—credible threat of vertical integration; or second sourcing—credible threat of entry).<sup>18</sup>

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<sup>18</sup> Since full-scale competition can involve duplicating high fixed costs and can require significant investments in specific assets, reliance on multiple sources is often prohibitively costly. Instead, duplicative supply has often been a way to hedge against technical uncertainty. For example, in the crash effort to develop ICBMs, two fully duplicative, concurrent programs were used to cut lead times—the Atlas and Titan projects. In more limited attempts to secure competition, parallel efforts can be applied in early stages of acquisitions (such as in systems development), with production then being allocated to a single source (“fly before you buy”). In practice, however, the greater the degree of asset specificity and fixed costs required in these design competitions, the less effective they are; indeed, knowledge is not easily transferred and close integration is needed between design and production. As witnessed in the Air Force’s F-22 program, GAO (2006) reports 200% cost overruns;



We believe any evaluation of joint service—and particularly SoS—acquisition programs would benefit from an analysis of the characteristics of the corresponding bundles of transactions through the lens of TCE. An inspired effort to collect and analyze data guided by TCE (as described in this paper) could help DoD decision-makers anticipate and mitigate cost and schedule breaches and avoid future performance shortfalls.

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the bulk of costs in most programs occur in the post-design stages. The threat of second sourcing (turning to another supplier) may be one way to inject discipline into the supply process. But if this threat is perceived by the seller to increase the risk of opportunistic behavior by the government buyer, then this added risk will raise the initial bids. Assuming effective competition existed for the initial contract, program managers cannot gain overall efficiency by using such tactics (Anton & Yao, 1987). Another possibility is inter-generational competition or to inject some competition between a new system and its predecessor. The extension of existing systems provides some insurance against delays in the availability of the next-generation systems.



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