Early supplier integration in the US defense industry

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Abstract

Purpose – Each year, the US defense industry outsources nearly \$400 bn of domestic goods and services through competitive bids. These procurement activities are quite often complex and specialized in nature because of a highly regulated federal acquisition contracting environment. Ongoing calls to improve supplier management and drive innovation in the defense industry offers an opportunity to adopt Early Supplier Integration (ESI) initiatives that have proven successful in the private sector. This paper identifies critical ESI activities and acquisition practices that the defense industry should adopt to ensure enhanced effectiveness in new product development.

Design/methodology/approach – Leveraging a conceptual ESI model derived from the research, an in-depth case study of 12 product development projects from a major defense contractor was performed. In the context of project performance, critical ESI activities and moderating effects were assessed.

Findings – Three key ESI activities have the greatest impact on aggregate project performance: system design involvement, design adjustment opportunities and design for manufacturability/assembly/testability involvement. Use of formal supplier agreements also significantly impacts project performance during the development phase. In addition, project complexity and product team maturity were identified as environment moderators; higher complexity projects tended to negatively moderate the impact of ESI upon performance, and higher team maturity levels tended to positively moderate the impact of ESI upon performance.

Originality/value – The results provide a sound framework for empirical validation through future quantitative studies and defense industry analyses. In addition, insights and recommendations for interpretation and adaptation of federal acquisition regulations to allow increased utilization of ESI within the defense industry are substantiated.

Keywords Procurement, New product development, Sourcing, Defense industry, Early supplier integration, Federal acquisition

Paper type Case study

Introduction

The US Department of Defense (DoD) develops and buys weapon systems in accordance with an acquisition process governed by specific directives and regulated by Federal

Acquisition Regulation (FAR) policies (Schwartz, 2014). From a DoD agency perspective, acquisition activities center on procuring goods and services through direct contracts with prime contractors. In turn, as shown in Figure 1, prime contractors use contracts to procure goods and services from suppliers within their supply chain. Figure 1 provides a representative relationship between the defense agency, prime contractor and tiered suppliers. In more complex projects that occur in the defense industry, the supply chain may extend below the second tier.

This study focuses on procurement activities between prime contractors and suppliers within their supply chain. Each year, this US defense industrial base competitively procures over \$400 bn of domestically contracted goods and services (Gansler and Lucyshyn, 2013). Although this is a very sizeable and attractive market, business practices within this industry can be quite complex and specialized because of the federal acquisition environment. Given requirements that are flowed down to contractors from the FAR governance policies (FAR, 2005), defense industry procurement activities can be highly regulated, if not restrictive, relative to commercial practices. Such restrictions, observed across the broader federal regulatory environment, have led to calls to “improve efficiency, reduce red-tape, and provide greater benefit for taxpayer dollars” (Rung, 2014). No less than eight major acquisition reform initiatives have been undertaken since the 1980s, with the most recent directed by the Obama Administration in 2009 (Gansler and Lucyshyn, 2013). While these initiatives have focused broadly on contracting activities, defense industry procurement practices represent a specific recurring opportunity for cost improvements and performance benefits [Government Accountability Office (GAO), 2006, Forum].

Prior studies within the private sector have found that accelerated supplier involvement in product development initiatives can reduce the development cost of new systems and drive innovative outcomes (Petersen *et al.*, 2005; Jayaram, 2008; Johnsen, 2009). However, within the unique defense industrial environment, adoption of early supplier integration (ESI) activities practiced in the private sector can be comparatively rare. Adoption of commonly known principles of ESI have the potential to lead to significantly improved outcomes in traditional defense industry supplier management practices. For instance, within private sector settings, the application of ESI has resulted in 15-20 per cent improvements in purchased material cost, quality, development time and cost and manufacturability (Handfield *et al.*, 1999). But are these improvements possible in the defense industrial complex? Do mandatory FAR flowdown requirements to defense

Figure 1.
Procuring
organizational
relationships

contractors prevent early integration from occurring? Moreover, what are the potential benefits that are *not* being realized in the defense industry because of these regulations?

In the remainder of the paper, we begin by developing a conceptual model grounded in prior ESI research. We then extend this model to identify those ESI activities that may be applied to the defense industry supply chain. Case study methodology is used to explore this model, based on the relatively nascent state of research in this area (Gansler and Lucyshyn, 2013). We describe the case study sample, spanning 12 development projects performed by a major defense firm, and assess which ESI activities produced the most significant impact on project performance. These insights were further validated through interviews with both government acquisition officers, as well as suppliers involved in these projects within the defense industry. Finally, based on our case results, we offer conclusions and recommendations that could potentially have a significant positive impact on future defense industry procurements.

Literature review

The defense acquisition model in new product development

Product development in DoD acquisition tends to follow a sequential acquisition life cycle approach based on phases, milestones and decision-points. Standard designs begin at the concept level and are refined at the subsystem/component level. The concept level design phase is typically summarized in a system concept document. This phase is followed by system-level development, resulting in system performance requirements and description documents. The subsystem/component level phase yields product performance requirements and design documents. The resulting product baseline is then implemented, validated and verified through a series of integration and test activities, beginning at the subsystem/component level and ending at system-level verification. At that point, production and system operations commence [Defense Systems Management College (DSMC), 2001].

Within the context of this larger development environment, US defense firms often follow a traditional sourcing approach, as shown in Figure 2. This process typically begins during the component or detailed-level design phase, after product specifications and engineering drawings have been released. At that point, the system and component designs

Figure 2.
Standard defense
industry supplier
management

are typically well established. Research suggests that up to 80 per cent of the product life cycle cost is “locked in” by the procurement organization during this early engineering concept and design (Handfield *et al.*, 1999). Therefore, an important implication of the traditional US defense industry approach, is that the ability of subcontracted suppliers to significantly influence the product design (and improve manufacturability and cost) can be limited.

Much of the sourcing behavior by US defense firms is tied to establishing a “fair and reasonable price” in accordance with the FAR. Although FAR 15.404-1(b) (2) [Federal Acquisition Regulation (FAR), 2005] lists seven price analysis techniques to determine price reasonableness, demonstration of adequate price competition is the most commonly used technique (DAU, 2017). Because most procurement actions attract two or more competitive offerors (DAU, 2017), it is common practice for industry participants to solicit three bids from separate suppliers to demonstrate adequate price competition compliance (Strategic Procurement Solutions, 2010). Therefore, referencing Figure 2, supplier bids are typically requested after product specifications and design documents have been completed. These specifications and design documents are nominally included in the solicitation to suppliers; therefore, the first-time suppliers have an opportunity to review these documents when they generate their bid. Problems can arise because of this practice, which are further described in the following section.

The defense industry sourcing practices

A tendency among defense firms to select their suppliers based primarily on price for each individual procurement, has been criticized for not following commercial industry best practices around strategic sourcing. Specifically, this can lead to an absence of longer-term collaborative relationships between defense contractors and their suppliers (Strategic Procurement Solutions, 2005, 2010). On a broader scale, the Government Accountability Office (GAO) has identified strategic sourcing across multiple tiers of the supply base as a key defense acquisition deficiency [Government Accountability Office (GAO), 2006]. Enhancing supplier relationships also reflects a central theme of the most recent effort to improve federal procurement practices (Rung, 2014). Because of increasing pressure to reduce costs and shrink defense budgets, both government legislators and industry experts are calling for defense firms to re-examine their sourcing practices. One of the clearest opportunities to improve existing practices centers on expanding the limited role of industry suppliers during early phases of product development.

The benefits of early supplier integration

ESI may be defined as a form of collaboration in which purchasing firms involve suppliers at an early stage in the life cycle of a product, generally at the time of product concept or design (Bidault *et al.*, 1998; LaBahn and Krapfel, 2000). This is generally an important opportunity for suppliers to influence the technical elements of the design because of expert knowledge and understanding of process capabilities that may influence project timing, quality, cost or performance (Handfield *et al.*, 1999). For several decades, researchers have identified the need for closer, more integrated relationships between manufacturers and their supply chain partners (Bozarth *et al.*, 2009). More recently, this ESI focus has extended to new product development efforts (Handfield and Lawson, 2007). When applied to a development environment, the goal of ESI is to facilitate product development success and create competitive advantage for the purchasing firm by leveraging the talents, knowledge and innovative spirit of suppliers (Wu and Ragatz, 2010; Lawson *et al.*, 2015).

Multiple studies suggest that ESI can improve new product development in critical areas such as reduced cycle times, enhanced quality, reduced internal complexity and reduced manufacturing costs (McIvor *et al.*, 2006; Tam *et al.*, 2003; Brown and Eisenhardt, 1995; Bensaou, 1992; Ragatz *et al.*, 2002). Although these ESI benefits have been documented across key industries such as automotive, electronics, and semiconductors, the adoption of ESI remains inconsistent across many other industry sectors (Chiu and Kremer, 2014; Zirpoli and Caputo, 2002; McIvor and Humphreys, 2004; Jiao *et al.*, 2008). The defense industry is one of these instances. Prior studies have shown that significant cost reductions are not being exploited because of the prevailing defense industry contractor practices when bidding on these projects (Gansler and Lucyshyn, 2013). Given the fact that up to 80 per cent of total manufacturing costs can be related to third-party outsourcing (Danilovic, 2006), the application of ESI appears to be fertile ground for improving performance of defense industry firms traditionally operating with limited-to-no ESI.

Conceptual model design

Based on prior ESI studies, the research literature consistently emphasizes six primary activities characterizing supplier integration processes during various phases of the product development lifecycle. These ESI activities are summarized in Table I. The literature demonstrates that these activities can provide benefits when applied under different

ESI activity	Description	Literature sources
System design involvement	Supplier involvement during the system design phase to include definition of architecture, interfaces, components, modules and interfaces associated with the new product	Wagner and Hoegl (2006), Clark and Fujimoto (1991), Jaikumar, (1986), Ernst and Kamrad, (2000), Handfield <i>et al.</i> (2000), Dowlatshahi (1999)
Component design involvement	Supplier involvement during the component design phase to include detailed specifications, interfaces and detailed mechanical, electrical and software design for a given component	Wagner and Hoegl (2006), Clark and Fujimoto (1991), Jaikumar, (1986), Ernst and Kamrad, (2000), Handfield <i>et al.</i> (2000), Dowlatshahi (1999)
Design review participation	Supplier involvement in formal design and fabrication reviews during the design and pre-production phases	Wagner and Hoegl (2006), Clark and Fujimoto (1991), Jaikumar, (1986), Ernst and Kamrad, (2000), Handfield <i>et al.</i> (2000), Dowlatshahi (1999)
Design adjustment opportunities	Opportunities to adjust the design based on inputs received from the supplier	Wagner and Hoegl (2006), Clark and Fujimoto (1991), Jaikumar, (1986), Ernst and Kamrad, (2000), Handfield <i>et al.</i> (2000), Dowlatshahi (1999)
Design for X involvement	Supplier involvement in design to cost and design for manufacturability/ assembly/test activities, allowing for adoption of fabrication options enabling reduced cost and improved manufacturability	Wagner and Hoegl (2006), Dowlatshahi (1999), Petersen <i>et al.</i> (2005)
Supplier agreement formalization	Existence of formal supplier agreements, partnerships and intellectual property sharing under non-disclosure agreements between the procuring organization and supplier	Zirpoli and Caputo (2002), Jiao <i>et al.</i> (2008) Primo and Amundson (2002), LaBahn and Krapfel (2000)

Table I.
ESI activities

conditions of complexity, industry conditions, appropriate contractual agreements and other parameters. However, no prior studies exist exploring how ESI is applied in the defense sector. While this is surprising, given the high dollar value of spending across the defense industry, it may be related to the unique supplier-sourcing environment *vis-à-vis* commercial industries, as previously described.

Table I describes several ESI activities that are explored in our research. First, supplier involvement during system design can provide important foundational technologies and interfaces between different elements of the design that may occur prior to the award of the contract. Component design involvement provides a more granular level of design around mechanical, electrical and software elements. Design reviews and adjustment opportunities occur once the product is introduced, and provide important development project improvements that facilitate technical improvement opportunities. Finally, design for manufacturability/assembly/testability involvement drives important manufacturability and cost outcomes, whereas supplier agreement formalization can ensure the free flow of information during the design process.

Moderating effects

Prior research suggests two important potential moderating effects that may impact ESI outcomes: product development team maturity and project complexity. Product team maturity reflects the level of experience among the product team and their ability to apply existing designs to the new development (Mishra *et al.*, 2016). Several studies note that strong product team maturity and risk management practices can allow firms to overcome development hurdles, leading to higher levels of project success (Rabechini and Monteiro de Carvalho, 2013; Albrecht and Spang, 2014). Familiarity of the buyer-supplier team members tends to breed greater trust, which may lead to greater flows of information sharing, improved team productivity and better development project outcomes (Wagner *et al.*, 2006; Wu and Ragatz, 2010).

Project complexity reflects the level of technical challenges that exist, and the need for new and innovative approaches required to overcome these challenges within the product design cycle [Defense Systems Management College (DSMC), 2001]. Research also suggests that project complexity may influence the choice of development lifecycle phase in which a supplier may be engaged. Typically, higher levels of component complexity may require earlier supplier integration (Handfield and Lawson, 2007; Zhao *et al.*, 2014). Greater project complexity also often requires a higher level of collaboration, requiring that partners be assigned greater levels of project responsibility (Handfield and Lawson, 2007). In addition to greater trust, supplier competence and degree of mutual support are key supplier characteristics necessary for driving successful outcomes when encountering complex products (Wagner and Hoegl, 2006).

Performance

In this research, we identified three variables that capture product development performance outcomes in defense projects. Development performance can be measured by comparing the planned versus actual cost/schedule associated with taking a new product from concept development to initial production (Mishra *et al.*, 2016; Bhuiyan, 2011; Ragatz *et al.*, 1997). Production performance can be measured by comparing the planned versus actual cost of materials and labor necessary to manufacture the finished goods in sufficient delivery quantities (Mishra *et al.*, 2016; Johnsen, 2009). Product quality represents the extent to which the product meets design specifications and standards, measured by defect rates and reliability standards (Jayaram, 2008; Zsidisin and Smith, 2005; Johnsen, 2009;

Ragatz *et al.*, 1997). All three of these metrics reflect the degree to which the prior set of ESI activities were successfully carried out, based on the assumption that all three activities are important. In this paper, we explore which ESI activities may have a greater impact on performance, given high or low levels of product complexity and high or low product team maturity.

The conceptual model (Figure 3) captures the essential components of ESI in the form of indicators, moderators and performance categories. As shown in the table, the level of design involvement, design review participation, design for manufacturability as well as the degree to which the supplier's role in the design effort is formalized through written agreements, all have an effect on performance outcomes. These outcomes include better on-time project delivery, production performance and quality. However, these relationships have been shown to be moderated by the degree of project complexity, (including the relative novelty of the technology), as well as the maturity of the relationship. A good example illustrating this relationship is the case of the Boeing 787 (Seattle Times). This project required a completely new battery system that had never been used before with the new electronics integrated into the plane, using an entirely new set of suppliers. An industry expert noted that:

The company's early delegation of control on 787 outsourcing to multiple tiers of suppliers is now coming back to bite the jet program, though it made belated efforts to tighten up oversight of suppliers.

Research questions

Although the potential benefits of ESI are well established within the literature, less clarity exists when identifying which specific ESI activities yield the greatest performance benefit, particularly for industries where ESI is limited (Handfield *et al.*, 2000). Even among mature industries, variance in ESI practices exists. For example, in their analysis of the automotive industry, McIvor and Humphreys (2004), conclude that 77.5 per cent of buyers collaborate with suppliers during the design process. Across four major design phases—concept, development, engineering and manufacturing—they note that 60 per cent of those suppliers enter new product development at the concept stage, 37.5 per cent at the development stage and 2.5 per cent at the manufacturing stage.

Thus, our study seeks to explore the following two research questions:

- RQ1. Which of the identified ESI activities yield the best performance outcomes when applied to projects being performed by defense contractors and their suppliers?
- RQ2. What are the moderating impacts of project complexity and team maturity upon project performance among defense contractors and their suppliers?

Figure 3.
Conceptual early
supplier integration
model

Because these questions are relatively unexplored within the current new product development and sourcing literature, we use the case method to empirically identify issues that may be of interest.

Case methodology

Although significant work has been done on the application of ESI strategies in “black box” industries (automobiles and electronics), significant gaps exist in documenting successful strategies in the context of defense industry firms seeking to operate in a more regulated acquisition environment. In such cases, theory-building is best suited to case study research (Handfield and Ghosh, 1994; Eisenhardt, 1989). In this stage of theory-building, we seek to identify the most important ESI elements that managers can use to successfully guide ESI adoption in the defense industry.

We have applied a single-case study, appropriate in the context of assessing this unique application where we were provided the opportunity to observe and analyze previously inaccessible company data (Zsidisin and Smith, 2005; Yin, 1994). We assessed 12 new product development projects, conducted between 2014 and 2015, using information gathered from a major US defense contractor aka the “prime contractor”, which represents approximately \$6 bn of annual sales to the US government. The projects were selected from procurement team recommendations, based on the existence of a variety of ESI actions taken during their respective development phases. For each of these projects, the prime contractor engaged with multiple suppliers to provide manufactured components and assemblies that were then integrated by the prime contractor.

In each of the 12 product development projects assessed in this study, the role between prime contractor and supplier(s) was assessed.

Using a unique identifier for each project, a summary of projects evaluated in this paper is provided in Table II.

Data collection began via an e-mail introduction from the researchers inviting a target sample of 75 key individuals to participate in a research investigation, with the stated objective focused on improving prime contractor performance and affording the opportunity

Project identifier	Description
Amsterdam	Antenna radome redesign for a cellular-based ground platform
Canada	Radio Frequency (RF) amplitude and delay controller for an avionics platform
Gibraltar	Ground station antenna and equipment for air-to-ground communications with commercial aircraft
Kimberley	RF limiter components for a ground-based proprietary program
Liverpool	Open virtual path cross connects computer bus chassis for a ground-based proprietary program
Madagascar	Electromagnetic interference shelter and filters for a satellite communications ground terminal
Montreal	High-speed virtual path cross connect circuit cards/connectors for space applications (R&D only; no production phase)
Ontario	Custom-printed wire boards for a proprietary ground application
Rivoli	Custom housings and printed wiring boards for space-based hosted payload application
Santiago	RF components for a space-based antenna reflector program
Sudbury	RF filter for a space-based antenna program
Tokyo	RF printed wiring boards for a space-based antenna program

Table II.
Project summary

for higher levels of ESI in future development. The targeted individuals consisted of knowledgeable product and engineering managers, design engineers and procurement specialists from the prime contractor, along with cognizant representatives from the supplier firms.

Forty-two individuals elected to participate in the research and, during the third calendar quarter of 2015, the first researcher conducted interviews using the questions provided in [Appendix 1](#). Moreover, the first researcher independently assessed project documentation, for example, design review documentation and engineering changes to compile all available data related to ESI engagement. A summary was generated for each development project and is presented in our results.

Results

Referencing our conceptual model, [Tables III-V](#) summarize the assessed ESI activity for each project along with the project's assessed level of complexity and team maturity, accompanied by each project's performance level compared to its plan. Consistent with the literature review and [Appendix A](#), complexity was identified by areas such as design requirements, interfaces, artifacts, stability and test requirements. Maturity was identified by team experience, documentation, metrics, manufacturing technologies and technology readiness.

Projects are segmented by high, medium and low performance, respectively ([Tables III-V](#)).

[Table VI](#) contains amplifying narrative containing key comments and observations gathered during the interviews and data analysis.

To address our first research question, we summarized the primary differences between different coded responses to assess the relative impact of supplier involvement activities upon performance across the three dimensions of performance, as shown in [Figures 4-6](#). We also supplemented these quantified results with supplemental discussion items derived from the case study interviews, to provide additional insights.

Development performance represents the development cost/schedule relative to plan. When considering development cost/schedule relative to plan, Liverpool, Madagascar, Sudbury and Rivoli demonstrated better than expected performance.

[Figure 4](#) shows the most important factors that drive development performance. In the case of the four projects (Liverpool, Madagascar, Sudbury and Rivoli) having better than expected performance, the four ESI variables that tended to have the most significant performance impact include:

- *System Design Involvement* – Supplier involvement during the system design phase to include definition of architecture, interfaces, components, modules and interfaces associated with the new product.
- *Supplier Agreement Formalization* – Existence of formal supplier agreements, partnerships and intellectual property sharing under non-disclosure agreements between the procuring organization and supplier.
- *Design Adjustment Opportunities* – Opportunities to adjust the design based on inputs received from the supplier.
- *Design For X Involvement* – Supplier involvement in design to cost and design for manufacturability/assembly/test activities, allowing for adoption of fabrication options enabling reduced cost and improved manufacturability.

Project	System design	Early supplier integration (described in Table I)					Environment		Performance
		Component design	Design reviews	Design adjustments	Design for X	Supplier agreements	Project complexity	Team maturity	
Liverpool	5	5	5	5	5	5	3	5	5
Madagascar	5	5	3	5	5	3	3	5	5
Sudbury	5	5	5	3	3	3	3	5	5
Rivoli	5	5	1	5	5	5	3	5	5
Amsterdam	3	5	1	5	5	3	3	5	3
Canada	3	3	3	3	5	1	3	5	3
Gibraltar	1	3	1	1	1	1	3	3	3
Montreal	1	5	5	5	3	1	5	3	3
Santiago	3	3	3	3	3	3	3	5	3
Kimberley	1	3	1	1	1	1	5	3	1
Ontario	1	5	5	5	1	1	3	5	1
Tokyo	3	5	5	3	5	3	5	5	1
Note: 5 High 3 Medium 1 Low									

Table III.
Supplier involvement
levels, environment
and development
results

Project	System design	Early supplier integration (described in Table I)			Supplier agreements	Environment		Performance
		Component design	Design reviews	Design adjustments		Design for X	Project complexity	
Amsterdam	3	5	1	5	3	3	5	5
Canada	3	3	3	3	1	3	5	5
Madagascar	5	5	3	5	3	3	5	5
Rivoli	5	5	1	5	5	3	5	5
Sudbury	5	5	5	3	3	3	5	5
Liverpool	5	5	5	5	5	3	5	3
Santiago	3	3	3	3	3	3	5	1
Tokyo	3	5	5	3	3	5	5	1

Notes: 5 High3 Medium 1 Low; at the time of the study, Gibraltar and Ontario were still in development; Kimberley was cancelled before production and Montreal was R&D only

Project	Early supplier integration (described in Table I)							Environment		Performance	
	System design	Component design	Design reviews	Design adjustments	Design for X	Supplier agreements	Project complexity	Team maturity	Quality		
Liverpool	5	5	5	5	5	5	3	5	5		
Madagascar	5	5	3	5	5	3	3	5	5		
Amsterdam	3	5	1	5	5	3	3	5	3		
Canada	3	3	3	3	5	1	3	5	3		
Rivoli	5	5	1	5	5	5	3	5	3		
Sudbury	5	5	5	3	3	3	3	5	3		
Santiago	3	3	3	3	3	3	3	5	1		
Tokyo	3	5	5	3	5	3	5	5	1		

Notes: 5 High 3 Medium 1 Low; At the time of the study, Gibraltar and Ontario were still in development; Kimberley was cancelled before production and Montreal was R&D only

Table V.
Supplier involvement
levels, environment
and quality results

Table VI.
Summary of key ESI
actions and
observations' impact
of supplier activities
on performance

Project identifier	Key activities and observations
Amsterdam	<p>The Buying contractor reached out to the Supplier early in the process to provide fabrication recommendations. Supplier developed a prototype for RF performance evaluation and manufacturability assessment performed by producer. Some issues with manufacturability were worked out by Supplier before solidifying the final design.</p> <p>From the Supplier perspective, material options were provided prior to start of project and not heeded; options would have had a major impact on quality. More time should have been spent on the front end of the project working to understand the quality goals. The job ended up being reworked because of lack of understanding of the materials. Note that perspectives differed between Procuring contractor and Supplier contractor</p> <p>The Buying contractor obtained preliminary quotes and feedback from Suppliers on tolerances and recommendations to improve manufacturability and lower cost. The Buying contractor actively used design to cost targets. The Buyer's engineering team engaged in follow-up with Suppliers after receiving feedback. There were technical interchange meetings organized with technical experts from Suppliers to review drawing feedback jointly and brainstorm ways to achieve the tolerances that could not be relaxed. This also helped Suppliers understand why some tolerances were tighter</p>
Canada	
Gibraltar	<p>The Buying contractor discussed general fabrication options with the Supplier. The Supplier met in person with the Gibraltar team to discuss more detailed options to reduce cost, ensure producibility in the antenna dip braze process, reduce part count (which reduces touch labor) and reduce fabrication time. However, technical baseline inconsistencies existed. From the project engineer's perspective, there were no design to cost goals set up within the program and the entire brazed antenna design should not have been the baseline; it was eventually abandoned for an alternate solution</p> <p>The Buying contractor issued fixed price order to the Supplier for components. Based on changes not executed through purchasing, the Supplier overran by 200 per cent over 12 months and stopped work, pending payment for work performed. In an effort to move forward, the Buying contractor approved payment of charges. However, the Buyer then changed revision of the applicable component drawing and the Supplier proposed an additional charge and extended lead-time to support the revision change. The Buyer then identified an alternative contractor, provided part and directed purchasing to terminate the order. Buying contractor disconnects were observed between the program engineering and purchasing teams relative to Supplier interaction</p> <p>The program had a unique chassis requirement. The Buyer's engineer reached out to various chassis suppliers inquiring if they could meet unique ANS/VITA 46.0 standards. The engineer then contacted those suppliers that could meet the specification to ask for their proprietary Computer Aided Design (CAD) files to form a supplier partnership that would result in a custom chassis. Supplier X agreed to release their proprietary CAD files to the Buyer. The Prime then involved purchasing to request a quote and signed a non-disclosure agreement with Supplier X for their files.</p> <p>The Buyer ordered two prototype units from the Supplier; then worked with them to create the custom chassis design. Purchasing remained involved with emails and conference calls until the prototypes were received. From there, engineering created and released drawings. Over 80 of these specialized units have been delivered with only one quality write-up</p>
Kimberley	
Liverpool	
Madagascar	<p>Engineering and purchasing worked closely with the enclosure and filter suppliers during design and manufacturing. This involved system design, project kickoff and early supplier engagement. Although formal supplier agreements/partnerships were not created, the Procurer discussed quantity pricing options, supplier material purchase requirements and other supplier cost drivers at length during the component design process. For enclosures, requirements were subsequently added that were not reflected in original drawings; requiring modifications. These were Buyer Contractor defects. For the filter, airflow requirements were initially inadequate. Resolution drove some increase in production material costs</p>

(continued)

Project identifier	Key activities and observations
Montreal	Early supplier engagement by engineering (mechanical design and electrical interfaces) and purchasing occurred with both printed wiring board vendors. ESI was viewed as a definite contributor to success. Success factors also included selection and dialog with the correct vendors (2 of 5 were selected)—relevant experience was essential. Qualification testing of the system was successful. Note this was more complicated than what the Procurer usually performs due to the space qualification of the components
Ontario	Working with the design engineer, the purchasing organization obtained design for manufacturability input from Suppliers prior to data release and order placement. Valuable input was obtained, such as incorrect circuit card vertical interconnect access (VIA) hole quantities. VIA hole size tolerance increase and a stack-up was provided for reference/review. Collected data was reviewed and incorporated into the released design, where applicable, with a goal of reducing issues during fabrication. The purchasing organization also suggested and set up a fabrication readiness review at the Supplier's facility after order placement and prior to the job being released on the shop floor. The results were positive with some key takeaways. One standout item involved removing the plated pedestals, as they created a high processing risk well into the fabrication process. The Procurer's team reviewed the design, and removed all pedestals to create a much more producible product with much lower risk. This action was performed without added time to the delivery schedule. Despite the favorable ESI activities, a several month schedule slip on the boards was still encountered, related to process and material selection
Rivoli	For hybrid housings, Supplier X participated in drawing reviews prior to release. For the printed wiring boards, the Buyer had Supplier Y review preliminary drawings to help with rigid-flex-rigid printed wiring board designs. Supplier Y also helped the electrical engineers figure out line widths, hatching, etc. for impedance issues. Suppliers built mechanical samples of the boards at its own expense before the Buyer released drawings or executed orders
Santiago	Examples existed of both positive early involvement and negative Engineering Change Orders (ECOs) driven by Supplier Support Requests (SSRs). The early involvement came at the beginning of the program when the drawing release curve was on schedule. The ECOs because of SSRs were in the later stages of the program as the drawing release curve slipped schedule and the Procurer didn't have time to engage the supply chain. The ECOs driven by design changes or SSRs after drawing release were required, could have been avoided with better supplier engagement. In the end, the Procurer's initial expectation of higher build to print items was incorrect and a higher number (approximately 80) of custom parts were required

(continued)

Table VI.

Table VI.

Project identifier	Key activities and observations
Sudbury	Early technical discussions with Supplier X helped shape a producible design. The project was almost uniformly successful with no ECOs and minor development cost (writing an interface control document). One risky decision made by the Buyer was to leave Particle Impact Noise Detection (PIND) out of the specification, which ultimately resulted in an instance of foreign object damage in a device. The Procurer ultimately had to use PIND in its parts. Otherwise, this was deemed a very successful development
Tokyo	This printed wiring board was a redesign from a prior version but the end use of the product resulted in a design that was low yielding and difficult to manufacture. Long lead material purchase orders were let prior to the final design, which was released a month later. The Buyer purchased through Supplier X first and when they did not meet their delivery, the Procurer placed another order with Supplier Y in hopes that one of the two suppliers would be able to deliver. Supplier Y was never able to produce the design and Supplier X took much longer than they had originally quoted. The development was for high-performance boards with buried VIAs and several other challenging design implementations. Because multiple printed wiring boards of similar types existed, the intent was to procure from two separate vendors because of initial breadboard procurement challenges on earlier variants. A very high level of RF performance and sensitivity to any deviations identified on the drawing posed challenges to both vendors. In retrospect, the team believes a dual-source approach from the beginning would have yielded better results

Figure 4.
Impact on
development
performance

Also, of note, each of the projects were of moderate complexity with high levels of team maturity. These results suggest that lower complexity may have played some role in allowing improved development schedule performance when accompanied by higher design involvement on the part of the supplier. This may be contrasted with the lowest performing projects (Kimberley, Ontario and Tokyo), which had lower levels of ESI engagement but also tended to have higher levels of project complexity. Note that even with mature teams, highly complex projects tended to yield poor performance. This is represented by the negative moderating impact shown in [Figure 4](#).

Overall, these results encourage a behavior of early engagement during the system/component design process, coupled with the need to establish formal supplier agreements, and a focus on manufacturability. When done properly, results can emulate Madagascar, whose project leader commented:

The only reason sufficient schedule was in place for component development is that the system design effort, procurement kickoff, and supplier engagement started very early in the program, which allowed for sufficient time to develop the component with manufacturability, design to cost, and supplier costs in mind.

Figure 5.
Impact on production
performance

However, we also found that the formal “competitive bidding” process tends to limit this level of engagement prior to award. As one prime contractor stated:

When you are asking questions in a competitive procurement, you need to have most of your design sorted out. They [acquisition agency] will publish the questions to all the respective bidders – so you have to be cautious if you want to change the design process. It is a lot easier before the formal agreement begins, to talk to the customer, and understand how design requirements will help them and lower the cost. Once the request for proposal (RFP) is dropped, you are much more constrained.

Production performance represents the production cost/schedule performance relative to plan. In the case of the five projects (Amsterdam, Canada, Madagascar, Sudbury and Rivoli) having better than expected performance, the two ESI variables that positively impacted production outcomes included higher levels of Design Adjustment Opportunities (opportunities to adjust the design based on inputs received from the

Figure 6.
High- and low-quality
performance factors

supplier) and higher levels of Design For X involvement. Successful projects during the production phase also identified the need for lower levels of Design Reviews (supplier involvement in formal design and fabrication reviews during the design and pre-production phases) and lower levels of lower levels of formal supplier agreements. Also, similar to the development phase, design complexity tended to negatively moderate performance results.

These findings suggest that during the production phase, continuous improvement initiatives drive success. Formal supplier agreements and design reviews will largely have been completed during development, and more focus will be on the adoption of different fabrication options, enabling reduced cost and improved manufacturability. Overall, this translates to financial benefit to the firm, as reduced production costs enable realization of higher margins. As stated by a Canada project leader:

All the early engagement with vendors and heavy levels of early prototyping we did is helping us make 35 per cent + earnings before interest and taxes margins on fixed price production lots.

Four projects did not mature to the production phase at the time the data were collected. Gibraltar and Ontario were still completing development, Kimberley was cancelled because of poor performance and Montreal was an R&D project, which was not produced in volume.

Performance quality represents the level of product performance to design specifications and standards, measured by defect rates and reliability standards. In the case of the two projects (Liverpool and Madagascar) that had better than expected quality performance, both projects tended to use ESI extensively across the board. Although dominant ESI contributors are less pronounced in this area, increased system design involvement and increased design adjustment opportunities stand out.

This indicates that higher levels of supplier involvement and improvement initiatives, particularly in the early project stages, resulted in higher quality products. For example, Liverpool reported that their close supplier partnership which included the transfer of proprietary CAD files and adaptation of existing prototype units to create a custom design, yielded an extremely low defect rate. Consistent with these results, one of the federal contractors we spoke with also emphasized that quality problems may often occur when early supplier involvement is overlooked:

One of the obvious potential hidden costs [of low supplier involvement early] is re-work. If a prime does not engage with a supplier and does their own design in a vacuum and then engages the supplier who has a much better solution, the design has to be re-done. This could end up being passed along to the government depending on where in the contracting cycle it was discovered (pre-award or post-award) and contract type (fixed price or cost reimbursable).

Relationships between early supplier integration activities and project performance

In aggregate, as shown in [Figures 4-6](#), system design involvement stands out as a dominant ESI contributor, followed by design adjustment opportunities and design for manufacturability/assembly/test involvement. The relationship between system design involvement and design adjustment opportunities is a natural one, as involvement in the system design process is optimally realized in opportunities to make adjustments prior to solidifying a design baseline. Design for manufacturability/assembly/test involvement, identified by activities such as design-to-cost, cost reduction inputs and recommendations for manufacturability improvements, represents a contribution most recognized in terms of production and quality performance. Supplier agreements significantly impact development performance, but their impact is less pronounced in the production phase and in the quality area.

Moderating impacts upon project performance

Our second research question explores the moderating impacts of project complexity and team maturity upon project performance within the defense acquisition environment. Project complexity is represented by factors such as difficulty of requirements, quantity of interfaces, severity of the test environment and the technology readiness level of available products. [Tables III-V](#) indicate that complexity was most commonly present in projects related to high-performance circuit board requirements and space environment qualified systems. Team maturity is represented by factors such as relevant experience, defined practices and metrics and knowledge of relevant technologies that may be applied to the project.

By assessing [Tables III-V](#) as well as [Figures 4-6](#), it was observed that team maturity led to very small positive moderating effects between ESI variables and performance. In other words, team maturity did not significantly hinder or improve project outcomes. As shown in [Tables III-V](#), although all of the highest performing projects were conducted by highly mature teams, some of the lower performing projects demonstrated less team maturity. For example, in the case of Gibraltar, a project team leader reported that, “due to lack of schedule on the program, very little pre-coordination or options were evaluated. Most decisions were

made last minute”. Similarly, with Kimberley, procurement and engineering teams were not aligned. One procurement team member noted:

There was a perception from the supplier that they could take change direction from engineering without formal change orders, resulting in cost that could have been avoided and damage to our negotiations.

Both of these indicate a lack of team maturity and appear to contribute to the lower performing projects.

Unlike maturity, project complexity appears to demonstrate a stronger negative moderating effect between ESI variables and performance. That is, all of the highest performing projects with strong ESI contribution, also tended to have lower complexity in nature. This is shown by a negative gap in [Figures 4-6](#) when assessing differences between high- and low-performing teams. Conversely, independent of ESI, high project complexity tended to always accompany the lower performing projects such as Kimberley and Tokyo. For example, Kimberley’s procurement team reported that “additional cost incurred was a direct result of undefined requirements and ongoing changes driven by revisions to higher-level design at the prime contractor level”. Kimberley was eventually cancelled. Similarly, Tokyo’s team reported that the failure to recognize the complexity of the high-performance printed wiring board led to multiple supplier challenges to meet design requirements and/or project schedule.

What are the barriers to early supplier integration in the defense industry?

One of the important motivating factors behind this research was to understand how ESI was used by prime contractors and their suppliers in the defense industry, and the role of applicable FAR flowdown requirements, in either supporting or preventing ESI from occurring. In exploring this question, we learned that the FAR does neither; rather, it is the managerial responses to perceived price reasonableness requirements that often preclude effective supplier involvement. This behavior can limit the ability of ESI activities to drive down the cost and performance of new defense development projects. As part of this research, we also sought to derive insights on the specific characteristics of FAR flowdown requirements, and how these flowdown requirements were interpreted by defense contractors relative to our results.

In reviewing the insights from this research, we identified a number of important observations shared by executives that helped us to understand how traditional behaviors may play a role in shaping these outcomes. First, we spoke with a government agency contracting officer, who emphasized again that the FAR was often misperceived by contractors as a vehicle that prevents ESI from occurring:

We do not see the requirement for certified cost or pricing data (FAR 15.403) inhibiting contractors from formalizing supplier relationships in advance of product design completion. In many cases, the prime contractor would need the supplier’s information in order to complete the product design. If this is a commercial transaction, (where the prime provides the government a Commercial Item Determination), it is even easier to see supplier involvement up front. In many cases, early supplier involvement leads to a more informed competitive proposal as well.

This individual also suggested that early supplier engagement should be encouraged during the sourcing process, as it often could lead to improved cost management over the life of the project.

Although it was surprising to hear that the FAR in no way prevents ESI from occurring, we recognize there are many myths associated with the FAR that do encourage unnecessary

behavior. The Office of Management and Budget (OMB, 2011) prepared a document specifically discussing eight misconceptions and facts regarding the FAR, one of which specifically states:

Misconception - The program manager already talked to industry to develop the technical requirements, so the contracting officer doesn't need to do anything else before issuing the RFP.

Fact - The technical requirements are only part of the acquisition; getting feedback on terms and conditions, pricing structure, performance metrics, evaluation criteria, and contract administration matters will improve the award and implementation process.

One of the government agency contracting officers also suggested alternative wording in the FAR that might drive improved early supplier involvement in discussion of the performance requirements prior to issuance of the RFP:

We're not aware of anything in the FAR that precludes early supplier engagement. I've experienced a few cases of prime contractor reticence to get suppliers involved because it would involve sharing of data. In some cases, a prime is wary of a sub becoming a potential competitor. There may be instances in a cost reimbursable contract situation where the prime could not get reimbursed for expenses incurred by paying the subcontractor in advance of a contract award (allowability of the cost). Perhaps the FAR could be changed to specifically allow this in certain instances.

One of the Prime suppliers we interviewed agreed that the competitive bidding process often leads to reticence in sharing cost and quality improvement ideas upfront:

If you are working with a supplier, and you get a good idea, one that could yield a cost benefit to the Prime; one that might even lead to the relaxation of a specification, you are often hesitant to put that in front of the government. Why? You would be showing your hand in front of your competitors. You can identify it as an alternative proposal during the bid, but this doesn't happen very often. Why? Because the government won't accept an alternative proposal, as they are worried about other suppliers filing a protest that they were not allowed to submit an alternative as well.

They also pointed out that in a sourcing situation, time is often constrained, which leads to a lack of preparation prior to issuing a bid.

In an ideal world, there would be extensive efforts to engage with suppliers before a final RFP is issued. This time would be spent in establishing a supply base, determine who is qualified based on their prior experience, process, procedures, quality, etc. You could share specifications with them, and asked them for feedback to update the government specification. In such cases, suppliers will respond, knowing their feedback will affect the end specification for a subsystem or component specification. They may also advise us to back off on a performance parameter, so they could use an existing product that would cost less. When there is enough time, one can work through all these matters ahead of time. Then when the RFP is issued in a competitive environment, the right specification will allow cost savings to be realized as these elements have been worked through. When there is a mature specification (e.g. lower complexity), the technical evaluation process has already been done, and the project may be more successful.

Conclusions and implications

Returning to our objective, we sought insights into how ESI could be used in the defense industry, where federal acquisition requirements may impede (either perceptually or actually) the effectiveness of prime contractors and suppliers; thereby negatively impacting project performance. We developed a case study research design of 12 different projects to

identify the most important ESI elements from the research literature, and sought to explore the application of ESI practices within the unique US defense acquisition environment. The insights developed provide some important outcomes and also suggest other areas for future research.

First, we identified that many of the ESI approaches used in private industry exist in the context of product development sourcing within the defense industry, despite the perceived existence of limitations that exist within the highly regulated federal acquisition environment. We identified the need to improve supplier engagement practices, which also revealed that many of the perceived limitations around price reasonableness requirements could be overcome through effective sourcing practices.

Second, based on the extant literature, we developed a conceptual model designed to characterize ESI activities and map those activities to project performance. This model consisted of ESI activities, moderators and performance categories, and identified some important trends. Through case studies of 12 development projects in the defense acquisition environment, the research suggests that the most important three ESI practices that contributed to positive project performance within our sample consisted of: systems design involvement, design adjustment opportunities and design for manufacturability/assembly/test involvement. Although formalizing supplier non-disclosure and intellectual property agreements were valuable during the development phase, they did not tend to affect production and quality as highly as the other three factors. The research suggests that each of these elements play an important role, but their adoption is often hindered by perceived barriers within the acquisition community based upon price reasonableness.

Third, our study also identified the likely importance of project complexity and team maturity as moderating factors relative to the ESI and performance indicators. Higher complexity projects tended to negatively moderate the impact of ESI upon performance, whereas higher team maturity levels tended to positively moderate the impact of ESI upon performance. Although higher levels of confirmatory evidence are required, these factors appear to be strong candidates for moderator variables in future analyses.

Finally, our research provides some important insights that may impact the nature of the applicable FAR requirements. Perceptions exist among defense contractors that the criteria for “price reasonableness” are not easy to achieve, and a major area of concern is that federal auditors will come in after a project has started and identify discrepancies around this factor. This appears to be the contract compliance-driven force behind “three bids”. One industry executive noted:

Industry practices need to change. There is a government audit arm that will sometimes interpret things the way they want to. It would be helpful to establish practices and guidelines that they might follow to establish what price reasonableness means when an audit occurs, and whether it precludes ESI or not. There may be a lot of nail biting within the compliance world relative to being able to meet the auditing requirements.

I think the focus should be on the Defense Contract Management Agency, as the auditing arm can be so threatening that it drives industry to “overdo” the price reasonableness benchmark and create unnecessary work.

This “extra work” appears particularly pronounced during the production phase, when each “production lot contract” requires the same level of price reasonableness scrutiny, even when the supply chain is well defined. This scrutiny extends even to the smallest part-level. As one industry executive stated:

There could be a dollar threshold (say \$100,000 or more) that is the requirement for competitive bidding, or an agreement to use a previously agreed-upon price. When we get three quotes, it is wasteful and causes programs problems. If we are forced to change suppliers because of this rule, the agency may experience quality or delivery issues when a new bidder tries to figure out the contract requirements for the first time.

In summary, although the preponderance of academic literature dedicated to ESI in new product development is focused on commercial industries, our results suggest the ESI activities, moderators and performance categories adopted from this literature do convey to the defense industry.

Opportunities for future research

This study provides exploratory analysis into the application of ESI within the unique defense acquisition environment. As such, our model requires further validation using a formal quantitative study. We propose converting the conceptual model into normative factors, which can be validated using scales applied to a broader defense industry survey. Factor analysis should also be applied to the selected ESI indicator variables to refine the validity of the model. This may then be extended into other companies and industries that are just beginning to develop their supplier engagement activities.

Further, a consistent theme found in the exiting literature emphasizes the importance of top management commitment to ESI to drive success in its implementation (Cadden and Downes, 2013; Danilovic, 2006; Ragatz *et al.*, 1997). Accordingly, we suggest including management commitment to ESI as a moderating factor in any subsequent research.

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Appendix 1. Interview protocol/questions*ESI activities*

- (1) To what degree and how did Procuring contractor actively involve key supplier(s) in the system design phase?
- (2) To what degree and how did the Procuring contractor actively involve key supplier(s) in the component design phase?
- (3) To what degree did the Procuring contractor regularly share preliminary versions of the component design with key supplier(s) prior to design completion?
- (4) To what degree and how did the Procuring contractor actively solicit supplier(s) feedback prior to finalizing the component design?
- (5) Were formal component design reviews conducted with key supplier(s) prior to design completion? If so, what types?
- (6) Based on inputs from key supplier(s), to what degree did the Procuring contractor adjust elements of the component design prior to finalization?
- (7) How much did the Procuring contractor actively engage key supplier(s) in Design to Cost/Design for Manufacturability activities?
- (8) Did the Procuring contractor use supplier agreements and/or partnerships with key supplier(s) in the development process? If so, what types of agreements?
- (9) To what degree did the key supplier(s) provide the Procuring contractor with fabrication options that helped reduce cost?
- (10) To what degree did key supplier(s) provide the Procuring contractor with fabrication options that helped improve manufacturability?
- (11) Did the Procuring contractor regularly engage in fabrication/manufacturing readiness reviews with key supplier(s) prior to beginning production? If so, which reviews?

Project complexity

- (1) How well were component requirements defined (minimal TBDs/TBRs) entering the design phase?
- (2) What was the degree component performance requirements difficulty relative to similar developments?
- (3) What was the degree of component interfaces complexity relative to similar developments?
- (4) How did the number of interfaces compare to similar developments?
- (5) How did the number of design artifacts compare to other developments of this nature?
- (6) How did the technology readiness level of components compare to similar developments?
- (7) How stable were component requirements entering the design phase?
- (8) How difficult were test requirements compared to similar projects?
- (9) Was the staffing level sufficient for component development?

- (10) Was the schedule sufficient for component development?
- (11) How much component design re-use was used in this project?

Project team maturity

- (1) How much experience did the Procuring contractor's development team have when compared to similar efforts?
- (2) How much experience did the supplier's development team have when compared to similar efforts?
- (3) How well defined/documented were the design practices used by the Procuring contractor's development team?
- (4) How well defined/documented were the process metrics used by the Procuring contractor during the development phase?
- (5) How well defined/documented were the process metrics used by the supplier team during the development phase?
- (6) How mature were the manufacturing technologies used to produce each component?
- (7) What percentage of component features and functions involved technologies that were new to the supplier?

Project performance (project engineers only)

- (1) Relative to the standard/expected ECO count, what percentage was realized on the assessed component(s)?
- (2) Relative to the planned development cost what actual percentage was realized on the assessed component(s)?
- (3) Relative to the planned development schedule, what actual percentage was realized on the assessed component(s)?
- (4) Relative to the planned production cost, what actual percentage was realized on the assessed component(s)?
- (5) Relative to standard/projected supplier defects, what actual percentage was realized on the assessed component(s)?

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