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The Knowledge Application and Utilization Framework Applied to Defense COTS: A Research Synthesis for Outsourced Innovation

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The Knowledge Application and Utilization Framework Applied to Defense COTS: A Research Synthesis for Outsourced Innovation

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Abstract

Purpose -- Militaries of developing nations face increasing budget pressures, high operations tempo, a blitzing pace of technology, and adversaries that often meet or beat government capabilities using commercial off-the-shelf (COTS) technologies. The adoption of COTS products into defense acquisitions has been offered to help meet these challenges by essentially outsourcing new product development and innovation. This research summarizes extant research to develop a framework for managing the innovative and knowledge flows.

Design/Methodology/Approach – A literature review of 62 sources was conducted with the objectives of identifying antecedents (barriers and facilitators) and consequences of COTS adoption.

Findings – The DoD COTS literature predominantly consists of industry case studies, and there's a strong need for further academically rigorous study. Extant rigorous research implicates the importance of the role of knowledge management to government innovative thinking that relies heavily on commercial suppliers.

Research Limitations/Implications – Extant academically rigorous studies tend to depend on measures derived from work in information systems research, relying on user satisfaction as the outcome. Our findings indicate that user satisfaction has no relationship to COTS success; technically complex governmental purchases may be too distant from users or may have socio-economic goals that supersede user satisfaction. The knowledge acquisition and utilization framework worked well to explain the innovative process in COTS.

Practical Implications – Where past research in the commercial context found technological knowledge to outweigh market knowledge in terms of importance, our research found the opposite. Managers either in government or marketing to government should be aware of the importance of market knowledge for defense COTS innovation, especially for commercial companies that work as system integrators.

Originality/Value – From the literature emerged a framework of COTS product usage and a scale to measure COTS product appropriateness that should help to guide COTS product adoption decisions and to help manage COTS product implementations ex post.

Introduction

To maintain its position as the global leader in national defense, power projection, and the defense of its allies, the U.S. military has developed many innovations on the leading edge of technology. The proposed defense budget for 2019 is $675 billion, with $95 billion allocated R&D, the highest amount adjusted for inflation in Pentagon history (Gould, 2018). Three forces threaten the innovative capability of the U.S. military. First is the fiscal reality of exploding national debts not just for the U.S. but across nearly all developed nations. In the U.S. the cumulative national debt is $21.3 trillion, or $65,003 per citizen (US Debt Clock.org, 2018), with public debt loads in most EU countries ranging from $40,000 to $60,000 per capita (Gray, 2017). Second is the shift in market dominance away from the military; increasingly, commercial markets set the pace of innovation much faster than the military's 8.25 years average to field a system from program initiation to initial operating capability (Riposo et al., 2014). Adversaries such as ISIS and Hezbollah have developed unprecedented capabilities by relying on commercial technologies (Hambling, 2017; Turner, 2017). Thirdly, technology is advancing at a breakneck pace. New developments in autonomous units, light-bending hyper stealth, electromagnetic rail guns, hypersonic missiles, 3D printing, artificial intelligence, big data, lasers, and social media occur increasingly rapidly, generating large costs to maintain a diminishing advantage over the competition.

Commercial off-the-shelf (COTS) has been defined as: "products sold, leased or licensed to the public, [for which a] supplier is a commercial entity in the business of making a profit,

integrators use the product without modification, [the] supplier retains intellectual property rights, [the] supplier provides product support and evolution, [and the] commercial market drives product evolution" (Grant, 2000, p. 5). Advantages include faster development time, reduced cost, and higher quality compared to custom development (Torchiano et al., 2002). Spending on commercial items and services has constituted between 16 and 22 percent of all of DOD's contract spending (GAO, 2017). Yet COTS usage is no panacea (Carney and Oberndorf, 1997). Based on a review of approximately 40 programs, defense acquisitions continue to be plagued by immature architectures, COTS integration, interoperability, and obsolescence, with the DoD consistently struggling to insert commercial technology (Erwin, 2016; Baldwin, 2007).

Military innovation is a harbinger of greater shifts. One shift is the increasing dominance of government spending in the economies of developed nations. The Index of Economic Freedom published by the Heritage Foundation and the *Wall Street Journal* estimated local, state, and federal government expenditures in the U.S. to equal 38.1% of GDP in 2017, and even greater for most developed nations such as Germany (44.2%), France (57%), Austria (51.8%), and the United Kingdom (43%). Governments comprise the greatest market for innovation among all industries for most nations, and exert strong influences over pricing and dominant designs in many markets like healthcare, infrastructure, and space. Furthermore, militaries and governments traditionally were innovation-makers, contracting to design and build many technologies like semiconductors because there existed limited commercial markets. Another more general economic shift results from the rise of modularity and globalization, and likely will continue with the advent of future technologies such as 3D printing, drone deliveries, and blockchain that make it easier to quickly and reliably mix and match inputs from diverse expert sources. As a result, militaries and governments have become innovation-takers, contracting to

design and integrate. Even systems such as fighter planes that have no commercial market are developed by companies that integrate many commercial components.

One important example of overlap for COTS use by both the military and commercial world is in IT. The world spent about $3.5 trillion on IT in 2017, and amount projected to grow 6.2% in 2018[1]. The U.S. software publishing market alone constitutes $217.6 billion (IBISWorld, 2017). US DOD systems rely heavily on a backbone of IT and software, especially cloud computing and big data, and has recently significantly increased its spending on command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) applications to $39 billion with projections of 1.4 percent annual increases through 2020 (Keller, 2015). Yet the DOD faces structural problems in the management of weapon system software (Baldwin, 2007). The story is similar for business process IT, with $89 billion spent on IT in fiscal year 2017, despite frequent criticisms of failed projects, cost overruns, and schedule slippages—especially egregious problems for systems described as "…contributing little to the mission-related outcome" (GAO, 2016, p. 2).

Although the importance of buying commercial items goes as far back as five decades, the use of COTS products has been widely researched mostly since the mid-1990s with the Perry Memorandum and the Federal Acquisition Streamlining Act of 1994. The DOD's struggles to harness COTS attests that it is not completely understood. The literature includes some DOD-specific case studies of COTS product usage and numerous non-DOD studies concentrated in the COTS software realm. It has been 17 years since the last comprehensive synthesis of COTS implementations by the Air Force Scientific Advisory Board (Grant, 2000). Most government COTS research focuses on policy rather than managerial implementation.

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[1] Gartner Market Databook, 4Q17

It is important to note that COTS is not a phenomenon unique to the military. It is a specific manifestation of the outsourcing of new product development (NPD) activities. Specifically, this research extends the focus on knowledge's role in innovating via outsourcing to a new context (Rundquist and Halila, 2010). Supply chain management has a strong history of innovation via outsourcing, especially in the procurement area. Theoretically, this research builds on the conceptualization of "appropriate knowledge" of market and technology as determinants of successful inter-organizational innovation (c.f., Veugelers and Cassiman, 1999; Grant, 1996; Rundquist, 2008), and relies on findings that technology knowledge is the most important factor for choosing an outsourcing partner (Rundquist and Halila, 2010).

The purpose of this research is to review the literature surrounding the use of COTS technology to better understand theoretical explanations for COTS product implementation performance, especially with regard to innovation. Evidence shows the potential for COTS to result in faster system deployment, lower development costs, and better performance (Boudreau, 2006; Grant, 2000; Gansler and Lucyshyn, 2008), yet no assessment of extant research's findings regarding the COTS implementation process exists. U.S. DOD COTS was selected because of its size and historical influence, as well as current world events that are driving militaries across the world to leverage COTS to innovate in response to changing world social and political pressures.

This research synthesizes disparate streams of research from DOD system acquisition, software engineering, supply chain management, marketing (new product development), and knowledge management. The following research questions will be explored:

1. What are the antecedents—both barriers and facilitators—to COTS implementations?

2. What are consequences of COTS adoptions, both in terms of successful adoptions and performance outcomes?

The remainder of this paper is organized in the following manner. First, a literature review is presented describing the underlying theoretical foundations. Next, the study presents the review methodology. Following the synthesis of the literature, results are then presented. Lastly, discussion, implications, and conclusions are offered. The overall literature review should provide a sense of required future research.

Theoretical Foundations

A complex phenomenon that exists at multiple economic and social layers requires synthesizing aspects of multiple theories such as those found in knowledge management, information systems, program and project management, systems acquisition, systems engineering, innovation and new product development, supply chain management, and buyer-supplier relationships domains. Because of the great important of market knowledge processes to innovation (e.g., Hakimi, et al., 2014), knowledge management presents a logical integrator for a COTS theoretical framework. Since an information system design project is a multi-phase process of knowledge creation and reuse (Tran, 2012), and software engineering has been studied through the lens of knowledge management (Hauge et al., 2010), the great and increasing importance of software and IT in DOD and government further support for a knowledge-based approach.

Knowledge Management

One oft-cited definition calls knowledge management as "[a] conscious strategy of getting the right knowledge to the right people at the right time and helping people share and put information into action in ways that strive to improve organisational performance" (O'Dell et al., 1998, p. 6). Companies that effectively managed their knowledge achieved a 5 percent increase

to return on sales, return on assets, operating income to assets, and operating income to sales (Holsapple & Wu, 2011). Benefits of effective knowledge management include superior knowledge acquisition, superior storage and retrieval, superior sharing and dissemination, and superior decision making (Holsapple & Wu, 2011).

Beesley and Cooper's (2008) knowledge acquisition and utilization framework (KAUF) synthesized insights from across several theoretical domains to explain the transformation of information into knowledge. The input is the knowledge created or received by a sender that is disseminated through a communication process to a receiver as information (see Figure 1). At this point, the information enters the centerpiece of the framework: depth of processing. A process for transferring useful knowledge into the depth of processing stage acts as both prognosticator and filter for potentially useful knowledge. Useful knowledge undergoes an adoption process, abetted by generative learning to develop new knowledge if required to facilitate the creation of an innovation. The innovation occurs at the implementation stage and can be thought of as an adaptation that results in increased competitiveness.

Research from the new product development stream of marketing literature corroborates that higher levels of innovativeness are associated with cultures that emphasize learning and development (Hogan and Coote, 2014; Hurley and Hult, 1998). It also finds that knowledge is not simply received but begins as information that undergoes stages of input-processing-implementation. A major challenge in knowledge management is to manage the flow of knowledge between individuals to facilitate the input-processing-implementation process (Bjornson and Dingsoyr, 2008).

The key to knowledge flow management is managing activity (Nissen, 2006). The more knowledge a firm applies through action and performance, the more likely the organization will

gain a competitive advantage. An oft-cited study further identifies these actions as interactions: "Organizational knowledge is formed through unique patterns of interactions between technologies, techniques, and people…" (Bhatt, 2001). Knowledge manifests in these interactions both explicitly and tacitly. Explicit knowledge articulates as a trade secret, patent, copyright, process, written instructions, or documents; tacit knowledge is gained through experience and is specific to an organization (Nissen, 2006).

Explicit knowledge resides in documents and electronic archives, making it easily shared. Tacit knowledge often proves more potent (e.g., reading a book about flying an airplane is not the same as experiencing flying), yet presents challenges: it does not flow freely; it is difficult to transfer; it is not easily understood by others; and it is often taken for granted until it is gone (Nissen, 2006). Tacit knowledge mostly resides in the minds and experiences of seasoned professionals who leave an organization's service due to retirement, quitting, transfer, or otherwise. Since tacit knowledge resides within an individual, or even in an IT system, it flows slowly and only when there is some sort of activity such as training, mentoring, research, trial and error, and discussion.

The knowledge acquisition and utilization framework (KAUF) (Beesley and Cooper, 2008) provides an empirically supported framework that accomplishes the knowledge management goal of relating micro-level decision-making to macro-level outcomes (Ragab and Arisha, 2013; Desouza et al., 2003). The KAUF provides a perspective on how to maximize the quantity and quality of flows and interactions, one of the most important goals of successful knowledge management (Bjornson and Dingsoyr, 2008; Bhatt, 2001) that has been found to support learning and development, which in turn predict greater innovativeness and performance

(Hogan and Coote, 2014; Hurley and Hult, 1998). One concern with the KAUF is that it does not explicitly describe organizational limits to the ability to process knowledge into innovations.

*** insert Figure 1 here ***

Absorptive Capacity

Absorptive capacity complements the KAUF framework by offering distinct and important nuances and addressing an organization's ability to acquire and use new knowledge rather than just the process of managing knowledge. Popular in the supply chain management literature (Cao and Zhang, 2011; Malhotra, et al., 2005), absorptive capacity holds that an organization's ability to innovate depends on the ability of the organization to exploit external knowledge via four key abilities: identify, assimilate, transform, and apply (Cohen and Levinthal, 1990). Absorptive capacity describes a conceptual limit to the rate or quantity of relevant innovative information that a firm can absorb and convert into improved performance. Zahra and George (2002) developed a four-dimensional construct of absorptive capacity that requires that new knowledge absorbed be combined with knowledge already possessed within the organization via four stages evocative of the KAUF: acquisition, assimilation, transformation, and exploitation. Importantly in the context of COTS, collaborative ability between firms depends heavily on absorptive capacity to empower transferring and sharing of knowledge, with the outcome of increased learning and innovation (Cao and Zhang, 2011). Successful COTS implementation requires incorporating knowledge of the marketplace gained via monitoring into a learning process that determines how to exploit the knowledge for operational needs.

Methodology

A literature review process collects information and data that fulfills several purposes: identify what needs to be done distinct from what has previously been done, unveil relevant variables and constructs, synthesize information, identify relationships between variables and constructs, frame the context of a topic or problem, reveal the significance of a problem, decipher any peculiar vocabulary, understand the subject's structure, relate theory to practice, identify the common research methodologies with respect to the subject, and establish the research into a its historical chronology (Hart, 1998). Although reliant on secondary sources, literature reviews synthesize insights across the published domain in order to develop new theory and reveal under-researched areas (Webster and Watson, 2002).

The systematic literature review process consists of three stages: planning the review, conducting the review, and reporting and dissemination (Tranfield et al., 2003). The planning stage identifies the need for the review and develops a review protocol. Stage two searches, identifies, and selects the relevant literature, and extracts and synthesizes particular data. The final stage drafts a report that includes recommendations and disseminates the report.

Table 1 lists the search terms and keywords used to find the relevant literature; terms were added and evolved as the literature is reviewed (Creswell, 2003; Tranfield et al., 2003). The framework was developed through an aggregative rather than interpretive approach. The unit of analysis was any published study of COTS product implementation.

*** *insert Table 1 here* ***

Table 2 lists the source types searched. A Google search of "commercial off-the-shelf" yielded 512,000 hits, necessitating inclusion and exclusion criteria (Table 3). Academic databases searched included ProQuest ABI/Inform Global, LexisNexis Academic, JSTOR, and

EBSCOHost. Government reports were retrieved from the Acquisition Research Program (ARP) and the Government Accountability Office (GAO) websites. 1,140 military regulations were scanned for COTS applicability[2] and academic courseware was obtained from Defense Acquisition University. Sources were traced backward from reference lists (Leedy and Ormrod, 2005).

*** *insert Table 2 here* ***

*** *insert Table 3 here* ***

The massive amount of sources found was narrowed by inclusion and exclusion criteria (Table 3). Very little rigorous, peer-reviewed academic research examined only DOD acquisitions involving the use of COTS products, so the scope was expanded beyond the DOD context, except for exemplar case studies and the summary of prior recommendations which were constrained to DOD COTS product implementations. The literature search concluded when no new viewpoints emerged (Leedy and Ormrod, 2005).

After compiling the literature, a data extraction form (Appendix A) facilitated development of construct concept matrices (Webster and Watson, 2002) of COTS barriers (Table 4) and facilitators (Table 5). The construct concept matrices used tabulations of the most prevalent antecedents to COTS implementation performance in order to ensure internal validity when identifying patterns and themes across all sources (Webster and Watson, 2002). Four or more sources constituted a pattern which was assessed against relevant theories for consistency. Resultant relationships appear in the COTS Product Usage Framework in Figure 2.

Each article was then classified by its stage in the knowledge acquisition and utilization framework of Beesley and Cooper (2008). Stages include: knowledge creation, dissemination,

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[2] accessed at a repository maintained by the U.S. Navy: https://doni.daps.dla.mil/default.aspx

knowledge transfer, knowledge adoption, and innovation, as explicated previously. In further analysis, theories were classified using Gregor's (2006) typology based on five theoretical objectives: *analyzing, explaining, predicting, explaining and predicting*, and *design and action*. *Analyzing* theories describe what is while making no casual inferences or predictions. This can take the form of classifications or taxonomies. *Explaining* theories explain how, what, why, when, and where without postulating testable hypotheses; examples include conceptual models and theory development, such as case studies. *Predicting* theories say what is and what will be in the future by making predictions that include testable hypotheses, although it does not necessarily explain why the hypotheses should be so. *Explaining and predicting* theories make predictions, offer testable hypotheses, and explain causality. Finally, *design and action* theories are prescriptive in nature and explicate how to do something.

Academic rigor depended on publication in a peer-reviewed source, evidence of validity and reliability, type of data, data source, data collection method with confidence that error is mitigated, and appropriate data analysis method. Reliability refers to consistency, defined as the data analysis procedures must be repeatable. External validity focused on generalizability to the DOD context by prioritizing findings from DOD case studies from diverse contexts: weapon systems platforms, different technologies, different industries, hardware and software COTS components, and cases from all three military departments and DOD civilian agencies. Cases after since 2000 were included as that was deemed long enough after major commercial item legislation from the mid-1990s.

Results

From the literature, 86 concepts were coded as barriers and 89 as enablers to COTS.

Color coding on the concept matrices (see Tables 4 and 5) depicts how common concepts were

combined into themes. "Fit" of COTS products to the situation played a central role, henceforth

termed *COTS appropriateness*. This discussion explains COTS appropriateness and each of its

antecedent factors. COTS appropriateness resembles the widely applied technology acceptance

model (TAM) with its two focal predictors of technology acceptance are *perceived usefulness*

and *perceived ease of use*. (Davis, 1989); many of the antecedents to COTS appropriateness that

emerged exhibited conceptual parallels to these two predictors.

Table 6 enumerates the research methods used, and Table 7 counts research types used

using Gregor's (2006) typology. The constructs were then imposed on Beesley and Cooper's

(2008) knowledge management framework (see Figure 2 for the comprehensive COTS product

usage framework). Articles were assigned to the major stages of the framework (see Table 8).

Table 9 summarizes the extant research by research type, knowledge management step, data

analysis method, empirical vs. conceptual, and whether theory was used.

*** *insert Figure 2 here* ***

*** *insert Table 6 here* ***

*** *insert Table 7 here* ***

*** *insert Table 8 here* ***

*** *insert Table 9 here* ***

COTS Appropriateness

Placing *COTS appropriateness* as the focal construct finds precedent by practitioners like Grant (2000, p. 31): "not enough emphasis has been placed on understanding and implementing the process to determine the applicability (that is, the appropriateness) of COTS." The DOD's Inspector General (2006) links COTS inappropriateness to performance failures like excess costs. Academic findings confirm practitioner observations. Jilani (2008) mentioned inappropriate selection of COTS components, an issue addressed by Keil and Tiwana (2005) who developed a list of what customers trust and find most appropriate for COTS software. Couts and Gerdes (2010) explored the appropriateness of COTS for certain healthcare software applications. Cechich and Piattini (2007) proffered a procedure for determining suitability of components for COTS.

COTS appropriateness is defined as the extent to which a COTS product adopted for use as-is or integrated into another product or system can meet program objectives with little or no modification without markedly increasing risk to cost, schedule, performance, safety, or security. COTS appropriateness considers the fit between the COTS product functionality and the needs of the DOD user for a particular intended mission effect. In order to assist both academics and practitioners, a COTS appropriateness scale (Appendix B) measures the degree of appropriateness, measured on an interval scale of 1-7, as determined by the presence (or absence) of the following antecedent conditions.

Antecedents to COTS Appropriateness

From the DOD case studies and the at-large literature, the antecedent factors are listed in order of expected strength from least to greatest of the relationship whether a COTS product should be adopted.

- **Fit.** The fit between end user's needed (or desired) outcomes and the capabilities of the COTS product was the most frequently occurring antecedent found in the literature, and is one of DOD's earliest lessons learned: "If the gap is too great, commercial items may not be appropriate" (DOD, 2000, p. 8). Prosnik (2003) and Grant (2000) also identify fit between requirements and COTS products as a success factor. Several studies presented the need to modify a COTS product as a barrier to successful implementation (Grant, 2000; Hauge et al., 2010; Morrow, 2010; DOD, 2009; Baker, 2002), whereas less modification of COTS products increases chances of success (GAO, 2005; Couts and Gerdes, 2010; GlobalPlatform, 2003). In one famous case, an Air Force acquisition bureaucrat engaged in favoritism toward Boeing when she declared aerial refueling tanker aircraft a commercial item despite a lack of fit in order to circumvent requirements for certified cost and pricing data (Branstetter, 2005; Larezos, 2008).

- **Requirements flexibility**. The traditional DOD approach of ex ante specifying needs and then the supplier makes and delivers faces increasing scrutiny, perhaps not least because the outside supplier usually possesses greater expertise at identifying customer needs. Other program objectives such as faster delivery, lower risk, and lower cost increase the attractiveness of trade-offs, especially in an environment of budgetary constraints and rapidly evolving commercial markets. As a result, many sources identify organizational flexibility to meet the capabilities of COTS products as a success factor

(Couts and Gerdes, 2010; Gansler and Lucyshyn, 2008; Grant, 2000; Jilani, 2008; Prosnik, 2003). Yang, et al. (2005, p. 56), went so far as to warn: "Committing to requirements before performing design and glueware integration analysis will likely create architectural mismatch problems, often causing factor-of-four schedule overruns and factor-of-five budget overruns." The Defense Science Board (DOD, 2009) advised that "good enough" is also militarily useful. In one case, the Army opted to reinvent the wheel when it came to intelligence software rather than consider Palantir's commercially available software; a judge determined that the Army was obligated to use the lower-cost and already-proven commercial product rather than incur the cost and risk of developing new software at taxpayer expense (Brill, 2017). Correspondingly, some sources identified requirement inflexibility as a barrier (Rosa et al., 2013). At the extreme, Baker (2002) argued that over-specifying requirements may have contributed to several Air Force T-3 Firefly aircraft fatalities.

- **<u>Post-adoption COTS product change preparedness</u>**. This antecedent is prevalent in the software realm. According to Kristin Baldwin (2007), the Deputy Director, Software Engineering and System Assurance, Office of the Under Secretary of Defense-Acquisition Technology & Logistics, "software life cycle planning and management by acquirers and suppliers is ineffective" (p. 8). Managing configuration control can serve as barrier (Grant, 2002) or critical enabler (Gansler and Lucyshyn, 2008). Many sources cite the number and frequency of supplier updates as an issue requiring complex integration management (Gansler and Lucyshyn, 2008; Grant, 2000). Relatedly, tracking components and their interrelationships presents a challenge (Jilani, 2008), and Yang et al. (2005) and Reifer et al. (2003) assessed the intricacies of planning for and

managing COTS product changes. Remedies include defining a priori the refresh

process for component-based software, synchronizing the COTS package updates with

each other and with the organization's release and business cycle, and analyzing the

impact of software version updates up front (Reifer, et al., 2003). Yang et al. (2005)

attributed changes to the COTS product suppliers' continuous striving for competitive

differentiation and offered six strategies to prepare for COTS changes.

- **<u>A priori and post hoc testing</u>**. Testing presents a double-edged sword. A product

  developed and sold for existing commercial markets is already tested (Ganslyer and

  Lucyshyn, 2008), leading some studies to identify testing as a barrier to COTS

  implementation (Boudreau, 2006). Other studies found testing to be a success enabler,

  such as the at-sea testing of the submarine Acoustic RCIP program (Boudreau, 2006)

  Horowitz and Lambert (2006) cite the inability to conduct design analysis and the

  important of assessing integration problems such as security as justification for testing.

  For software, the Defense Acquisition University's software acquisition management

  course recommends conducting repeated testing with each new COTS product release

  (Prosnik, 2003). Based on their experience with government ERP projects, Thomas and

  Jajodia (2004) recommended extensive testing because the cost of correcting errors

  increases ten-fold in an operational system. Mariani and Pezze (2003) offered their

  behavior, capture, test method to test COTS software components without requiring

  access to the source code. Despite its potential importance, one source determined,

  "software verification techniques are costly and ineffective for dealing with the scale of

  complexity of modern systems" (Baldwin, 2007, p. 8). Realistic testing of non-software

  COTS products can be just at least as problematic as exhibited by the T-3 aircraft that

was tested by expert test pilots in Texas, yet engine stalls contributed to six deaths when used by Air Force instructor pilots and students at higher altitudes of Colorado (Baker, 2002).

- **<u>Organizational resistance to change</u> (-)**. Organizational resistance to change can result from organizational culture (Gansler and Lucyshyn, 2008) or inertia when it comes to changing business processes, which partially explains the failure of the Air Force's ERP program (Charette, 2013). Baron (2004) also cited organizational inertia in her study of Air Force satellite ground station programs. Fear of job loss and changing roles and responsibilities can also provoke resistance to change (Grant, 2000). The GAO (2015) investigation of the Defense Logistics Agency's (DLA) Business Systems Modernization (BSM) program mentioned parochialism. In the DOD context, the dominant procurement paradigm of *design and build* versus *buy and integrate* leads to sub-optimal COTS implementation (Baron, 2004; Grant, 2000). The Army's refusal to seriously consider Palantir's commercial-based intelligence synthesizing software resulted from the *iron triangle*, an insular ecosystem of defense contractors, the Pentagon, and Congress (Brill, 2017). The Army had a similar failure in the acquisition process for the Distributed Common Ground System-Army (DCGS-A) system designed to meet the same need. Change management as a key success factor to combat resistance to change (Boudreau, 2006; Gansler and Lucyshyn, 2008; Prosnik, 2003).

- **<u>Open systems architecture (OSA)</u>**. Open system architecture has been identified as a success factor (Grant, 2000; Prosnik, 2003) because it: (1) uses modular design and design disclosure, (2) uses reusable software, (3) facilitates interoperable joint platforms, (4) reduces lifecycle costs, and (5) promotes competition via alternative

sources. A simulation modeled the positive effects on performance of the incorporation of OSA in the Navy's Acoustic Rapid COTS Insertion program (RCIP) (Ford and Dillard, 2009). The Defense Science Board noted that OSA had positive effects on costs in the Navy's P-8 Poseidon aircraft program (DOD, 2009). In the context of the Navy E-2 Hawkeye aircraft, Gansler and Lucyshyn (2008) concluded: "the Open Architecture framework of the software now allows for uninhibited expansion and future growth of both the software and hardware components" (p. 20).

- **<u>Robust COTS component evaluation and selection process.</u>** The paradigm shift from design and build to assemblers means that the buyer becomes an integrator that acquires the market knowledge of available COTS products, and then evaluates them to find the best technical fit at the optimal cost. Studies reveal that evaluation of prospective COTS suppliers ex ante and the continuing evaluation of supplier performance become more important. In the context of software components, Ulkuniemi & Seppanen (2004), concluded that some primary challenges were scanning, evaluating, and selecting COTS components; analyzing component cost and value; and managing the overall component acquisition process. Clark et al. (2004) offered a new method of searching for software components because extant methods suffered: (1) too narrow or too many prospective components, (2) errors in the component descriptions, (3) incompatibility, and (4) the system design. Hauge et al.'s (2010) extensive literature review of open source software usage found that learning and understanding new components generated major costs, and the most important factors in choosing components were knowledge and ability to meet requirements. Julian et al. (2011) proposed the value hierarchy model that assessed COTS criteria for the manufacturer, the product, and the technology in seven categories:

(1) manufacturer capability, (2) manufacturer experience, (3) quality, (4) technical specifications, (5) logistics and support, (6) total costs of ownership, and (7) technology evaluation. Rendon (2007) identified supplier performance evaluation as essential to the development of modular open systems architecture (MOSA) as a COTS alternative. Thomas and Jajodia (2004) cited the evaluation of references to assess supplier performance over time in the context of select ERP software. One key to success for component evaluation and selection might be program manager evaluating products and suppliers (Prosnik, 2003).

- **<u>Marketplace knowledge</u>**. The shift from product developer to integrator has increased buyers' need to understand the COTS product market (Grant, 2000; Prosnik, 2003; Yang, et al., 2005; Couts and Gerdes, 2010). Buyer ignorance of what they are buying forms a barrier to successful COTS implementation (Grant, 2000). The Palantir case once again provides an example—insufficient commercial market research reinforced the Army's resistance to adopt commercial intelligence synthesis software (Brill, 2017). Participation in user and industry groups can provide required market knowledge about available COTS products (Prosnik, 2003). Buyers also need insight into the technology roadmap of COTS product suppliers (Grant, 2000). Ulkuniemi & Seppanen (2004) described four types of COTS product markets that each follow a different acquisition process that buyers need to understand.

- **<u>Leadership</u>**. Leadership provides (or impairs) impetus to change, and in COTS scenarios, leadership needs to see that COTS addresses a threat to national security (GAO, 2013). The threat to national security provoked leadership attention to invest in the US Navy's Acoustic RCIP that restored the ability to detect enemy submarines

(Grant, 2000). Insufficient autonomy at the program level to implement change contributed to the US Air Force ignoring less costly, superior commercial solutions to satellite ground control stations (GAO, 2013). Inadequate governance structure contributed to the cancellation of the US Air Force's ERP project, along with leadership turnover totaling six program managers, five program executive officers, and 10 organizational designs (Charette, 2013). Strong leadership contributed to the success of programs such as the DLA's BSM program (Gansler and Lucyshyn, 2008) and the Navy's Acoustic RCIP submarine program (Boudreau, 2006). Leadership reduces structural barriers and secures resources to make the paradigm shift from design and build to integration.

- **COTS Experience**. Based on the study of 34 COTS implementations, the Air Force Scientific Advisory Board concluded that the contractor's experience with COTS product implementations contributed to program success (Grant, 2000). Prosnik (2003) also suggested that buyers consult the expertise of COTS product suppliers and consultants. Information technology staff experience has an important impact on successful integration of software components (Horowitz and Lambert, 2006). Retaining the buying team through program implementation and sustainment bolsters program success because of the experience that the buying team accrues during a COTS acquisition (Thomas and Jajodia, 2004). The Defense Science Board (DOD, 2009) found that a lack of COTS experience was a barrier to implementation, and recommended program managers have commercial leadership experience and should ensure that program teams have leadership experience and domain expertise. A lack of software engineering expertise relative to the complexity and scope required by modern

systems is troublesome (Baldwin, 2007). The Air Force's ERP project (called ECSS) reinforces the importance of experience citing program manager turnover for the COTS implementation failure (Charette, 2013).

- **<u>Complexity</u>** (-). As in other areas of supply chain management, complexity presents a barrier to COTS product usage (Grant, 2000; Gansler and Lucyshyn, 2008). In the context of service oriented architecture, complexity reduces software usefulness over time (Cameron, et al., 2015). Supply chain complexity was identified as a limiting factor for the P-8 Navy aircraft (Naegle and Petros, 2010) and safety systems engineering (O'Halloran et al., 2017). Problems arise when a component has to be modeled by Integrating parts of functionality from different components or even from other suppliers creates problems in the context of component-based software (Jilani, 2008). Most studies recommend reducing complexity to improve outcomes.

- **<u>COTS product lifecycles</u>** (-). Diminishing manufacturing supply sources and obsolescence of parts as well as short product life cycles constitute barriers to successful COTS management (Grant, 2000). Suppliers upgrade COTS products approximately every 10 months, and cease technical support after an average of three releases (Yang et al., 2005). One approach includes technology refresh and insertion costs as one criterion to be evaluated in models of COTS component selection (Julian et al., 2011). The ability to manage obsolete parts is an important success factor (Grant, 2000).

- **<u>Intellectual property constraints</u>** (-). Heterogeneous software intellectual property licenses create barriers (Scacchi and Alspaugh, 2016). Since user interface code can be considered a competitive advantage, the maze of licenses and patents constitute a barrier

when it comes to selecting and modifying software components (Hauge, et al., 2010). Limited DOD buyer knowledge of existing COTS enterprise licenses exacerbates the situation (GAO, 2015). Success factors include using flexible COTS-based systems (CBS) software licensing practices (Reifer et al., 2003) and seeking enterprise licenses and negotiating licenses for volume discounts and transferable rights to the government (Prosnik, 2003).

- **COTS product training**. A lack of COTS product training forms a barrier to COTS product implementation. The lack of sufficiently trained instructor pilots and students for the T-3 Firefly aircraft was implicated as a barrier to COTS product screening success (Baker, 2002). The GAO (2005) also cited a lack of training in COTS products as a barrier in the successful implementation of an ERP project. The Air Force Scientific Advisory Board study (Grant, 2000) recommended education to understand COTS product usage, advocating for COTS competency at all levels of the workforce, with case studies and lessons learned be adopted in Defense Acquisition University training. COTS suppliers understand the value of product usage training, such as GlobalPlatform (2003) recommending user training on the use of new common access "smart" identification cards. Product usage training has also been recommended by Defense Acquisition University (Prosnik, 2003).

- **Evaluating lifecycle TCO**. The DOD Deputy Director, Software Engineering and System Assurance, stated: "Inadequate attention is given to total life cycle issues for COTS/NDI impacts on life cycle cost and risk (Baldwin, 2007, p. 8)." The Air Force Scientific Advisory Board emphasized the importance of evaluating total cost of ownership (TCO) during source selection, suggesting that failure to consider cost trade-

offs deters COTS usage (Grant, 2000). Prosnik (2003) concurred and additionally recommended that TCO models be developed to assist program teams. On the other hand, a study of 16 COTS systems integrations found that the cost to maintain COTS-based systems is the same as or greater than that of developing custom software, in part because of factors such as maintenance workload and *glue code* used to adapt code components to be compatible with each other typically costing three times that of custom code (Reifer, et al., 2003).

- **"Black box" design** (-). Proprietary, black-box designs and inaccessibility render source code abstruse for engineers (Grant, 2000; Prosnik, 2003; O'Halloran, et al., 2017). Buying instead of designing code creates the inability to perform design analysis, and as a consequence limit the ability to predict before testing: 1) system integration problems; 2) system capacity; 3) system performance; 4) system failure modes and responses; 5) system security shortfalls" (Horowitz and Lambert, 2006, p. 288). Use of a COTS component supplier also incurs a risk of going out of business, underscoring the importance of gaining knowledge of the product's underlying coding language and technology (Couts and Gerdes, 2010).

- **Stakeholder buy-in**. Involving users and stakeholders early bolsters success (Prosnik, 2003), a fact included in the training for the DOD common access card program (GlobalPlatform, 2003). At the extreme, a lack of buy-in among the numerous logistics organizations contributed to the cancellation of the Air Force's ERP project (Charette, 2013). Stakeholder buy-in also strongly affects delivery lead time (Boudreau, 2006).

- **Contractual financial incentives**. A study of Air Force satellite ground control stations found that a misaligned reward system impedes COTS product adoption (Baron, 2004).

Informants reported no incentive to adopt COTS products, and even incentives not to.

Instilling negative financial incentives effectively motivates control of sustainment costs

(Grant, 2000). DAU training teaches that long-term-focused incentives are a key to

success (Prosnik, 2003). Incentive fees, award fees, and award-term contract incentives

have been found to generate success in an assessment of DOD's modular open systems

architecture data (Rendon, 2007).

- **<u>Communication</u>**. The Defense Science Board identified poor buying team

  communication as a barrier to COTS product implementation (DOD, 2009). A study of

  34 COTS product cases found that co-located and integrated product teams led to

  success (Grant, 2000). The success of the Acoustic Rapid COTS Insertion program for

  the US Navy's submarine sonar systems resulted from abating organizational

  boundaries and extensive communication between users, material developers, and

  contractors (Boudreau, 2006).

Decision to Adopt COTS Products

The antecedents to COTS appropriateness drive the estimation of COTS appropriateness

(Appendix B), culminating in a specific decision to adopt COTS products.

COTS Search and Selection

After the decision to adopt COTS products, buyers engage the process to identify,

evaluate, and select a product while also evaluating and selecting the supplier. The acquisition

strategy and magnitude of the program influence whether this process occurs in-house or by a

systems integrator.

COTS Usage

Once selected, the COTS products enter usage either as stand-alone products or components in a larger system.

Barriers and Enablers of Effective COTS Usage

The ability of COTS products to achieve the desired level of value and performance depend on the extent of COTS barriers (see Table 4) and COTS enablers (see Table 5). Each barrier and enabler is posited to negatively or positively moderate the relationship between COTS usage and COTS product performance. Barriers are the same as the COTS antecedents designated with a negative relationship above (-) while enablers lack the negative relationship indicator above (-).

*** insert table 4 here ***

COTS Performance

COTS performance manifests in many ways: performance levels, development time, acquisition cost, lifecycle or sustainment costs, product or system availability, product or system reliability, and supply base competition. Boudreau's (2006) case study of The Navy's acoustic rapid COTS insertion program found improved performance from COTS usage including decreased development time, lowered cost, and improved logistics performance. Performance outcomes become incorporated as updated knowledge (See COTS Framework in Figure 2).

Lessons Learned

Comparing expected to actual performance outcomes generates lessons learned, or knowledge about how those results transpired. Lessons learned manifest via the process of generative learning, which is the process of developing new concepts and attitudes, cognitively

recodes existing classifications, and amends standards of judgment, leading to knowledge

adoption (Beesley and Cooper, 2008). Generative learning is a function of the depth of cognitive

processing. In order for learning or knowledge to spread throughout the relevant community, a

process heavily dependent on communication ensures knowledge transfer (Beesley and Cooper,

2008). Knowledge transfer occurs both tacitly and in tangible form as codified by policies,

directives, guidebooks, regulations, training, and education. Lessons learned can be shared with

product managers, system owners, research and development centers, program executive

officers, technical authorities, and users to create new weapon systems and capabilities so that

knowledge can be considered for adoption in order to facilitate new innovation.

Knowledge Dissemination

Newly discovered knowledge and lessons learn disseminate via best practices and

incorporation into policies, laws, regulations, guidebooks, handbooks, online communities, and

training and education content.

Many of the emerged antecedents resemble the COTS issues identified at the COTScon

conference in 2000. That conference prioritized COTS issues: (1) integrating multiple COTS

products, (2) cost versus benefit of upgrading, (3) requirements versus COTS capabilities, (4)

testing in an operational context, (5) vendor relationships, (6) whether standards are good or bad,

(7) cross platform portability, (8) API breakage, (9) acquisition and support strategies, (10)

vendor responsiveness, (11) dormant functionality, (12) the definition of COTS, and (13)

marketplace maturity (Kohl, 2000).

Discussion

The Iraq War proved a watershed moment for how advanced drone capabilities developed by the US military could be matched by extremely low-budget adversaries using COTS technology (Hambling, 2017; Singer, 2009). Adoption of COTS products into defense acquisitions continues to increase. Indeed, a search of the government's Federal Business Opportunities portal yielded 14,411 active solicitations using the keyword "commercial off the shelf" out of 37,962, about 38% of all US federal government solicitations[3].

Interestingly, the traditional DoD procurement process focuses more on technology knowledge than market knowledge. Past research indicates that this is the most effective approach (Rundquist and Halili, 2010), yet few studies apply academic rigor to the processes of innovation and knowledge management. Considering the sizable economic impacts of governmental spending, researchers have opportunities to contribute to social and economic well-being in an arena characterized by transparent processes and publicly available data.

This literature review of 62 sources has provided insights into COTS product implementation performance, including antecedents that comprise barriers and success factors. The emerged framework of COTS product usage and scale to measure COTS product appropriateness provide insights for COTS product adoption decisions and managing product implementations. COTS usage appropriateness depends on a large number of antecedent factors, revealing the complexity of COTS implementation. The limited number of published case studies makes the discovery of more factors highly probable. What follows are research opportunities, managerial implications, study limitations, and future research directions.

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[3] https://www.fbo.gov/ accessed on July 27, 2018

Research Opportunities

Viewing COTS as essentially a knowledge-based innovative response provides a lens uniquely suited for understanding and assessing important innovation phenomena that affect the increasing number of governments and organizations that outsource their production inputs. The knowledge-based literature review revealed several important areas that require further research.

The academic literature relies upon user satisfaction as the key measure of information systems COTS success due to the difficulty of operationalizing economic-based measures (c.f., Kakar, 2013), especially in the IS literature where the technology acceptance model (Davis, 1989) demonstrates a strong empirical relationship on IT system adoption by perceived ease of use and perceived usefulness. However, DOD case studies overwhelmingly fail to find user satisfaction as a key to successful COTS implementation. A research opportunity could explore whether this results from the powerful role of stakeholder or the top-down nature of DOD procurement.

On the other hand, most COTS case studies lack methodological rigor and sufficient explanatory detail regarding findings, data characteristics and collection methods, anlaysis, and how validity and reliability were assured. Very few case studies mentioned the location of interviews or whether they were recorded and transcribed, or whether informants reviewed transcripts for validity. Many cases even lacked basic demographic data for interviewees or triangulated data with other sources to corroborate findings with secondary sources. New insights could emerge from application of basic research discipline such as iteratively reviewing qualitative data until a new theme or pattern emerged and via code matrices (Miles and Huberman, 1994) and using multiple coders and measuring inter-rater reliability and conducting member checking sessions (Yin, 2009) to validate findings and analyses.

The literature since 2000 (c.f., Grant, 2000) suggests that intellectual property (IP) rights is a formidable barrier when adopting COTS product yet hardly any research has addressed the issue. At issue is the need to reconcile the IP rights of multiple pieces of hardware or multiple software components, obligating the tracking of use restrictions, access rights, royalties, warranties, and liabilities unique to each component. ComponentSource provides component information repository from 343 publishers on 1,982 components, 701 applications, and 376 add-ins to systems integrators and developers, and may be a rich source of data for researchers (ComponentSource, 2018).

While COTS software has been researched extensively, COTS hardware receives very little scholarly attention. This could be attributed to the newness and magnitude of software issues. It could also be due to the expectation that the commercial sector will favor commercial hardware integration when it is cost effective.

Managerial Implications

While there appears to be a desire to use COTS products (evidenced by statutory requirements and policy directives), the actual integration of COTS products into systems is easier said than done. It introduces one more risk to programs unlikely to be welcomed by program managers who spend their days anticipating and defending against risks. What has DOD structurally infused to alleviate those perceived risks from program managers?

The findings from academic and DOD case studies—coupled with the emerged knowledge-based framework—clearly implicate the importance of monitoring the commercial marketplace. An organization must recognize the value of new external information (Grandinetti, 2016), which entails a knowledge sharing and generation process for technical and scientific

details, DOD infrastructure, user needs, and desired effects. This is at odds with research

conducted in the commercial context that found that technological knowledge mattered more

than market knowledge (Rundquist and Halili, 2010); it remains to be seen whether this is an

artifact of the unique government setting or perhaps the government purchasing process already

provides deep technological knowledge that is taken for granted. Market intelligence cells were

recommended in 2014 (Finkenstadt et al., 2014), yet the personnel with the requisite knowledge

are scarce. The DOD will likely continue to rely on systems integrators to conduct the

commercial marketplace monitoring, generating principle-agent implications. Application of

agency theory may explain the few but costly and increasingly common incidents of bid protests,

where losing bidders often cite lack of government knowledge as a factor leading to improper

requests for proposals (e.g., Hawkins, et al., 2016).

DOD managers—and companies selling to them—should consider shortening the

traditionally slow government acquisition process. Commercial firms rapidly update their

products to keep pace to pursue differentiation and competitive advantage, leading to short

product lifecycles and short time-to-market, and shortened acquisition cycles. For example, the

DOD established the Commercial Solutions Opening (CSO) pilot program in section 879 of the

2017 National Defense Authorization Act (Public Law 114-328). A CSO uses a merit-based

source selection process called Other Transaction Agreements (OTA) rather than traditional

government contracts. The Defense Innovation Unit Experimental (DIUx) program

(https://diux.mil/) has awarded 30 OTAs valued at $84M (DIUx, 2018). This program is drawing

private investment from venture capitalists and participation from firms that normally do not

transact with the DOD. Project technologies are cutting edge: autonomy, personal aerial

vehicle, tactical autonomous indoor drone expansion, human cooling, digitally aided close air

support platform, hardened network defense, knowledge management, multifactor authentication for network access, and advanced analytics from synthetic aperture radar imagery.

The DOD struggles to use COTS products to create a military advantage (Erwin, 2016), even when they have strong user support. Soldiers lauded the Palantir commercial analytics software as life critical yet the Army leadership refused to consider it (U.S. COFC, 2016). COTS antecedent factors beyond functional capability require further attention by management.

Security of COTS-based systems has long been and will continue to be a serious issue (DODIG, 2016a; Baldwin, 2007; Grant, 2000). A new regulation (DFARS clause 252.204.7012) requires protection of defense information and cyber incident reporting applies to systems that integrate COTS, yet excludes purely purchased commercial items (Cassidy and Stanton, 2017). Relatedly, counterfeiting poses a clear risk to system security and performance yet has generated very little research. And, the DFARS requirements for counterfeit electronic part detection and avoidance (DFARS 252.246-7007) that flows down to suppliers might repel viable COTS product sources.

The global sprawl of modern supply chains complicate security efforts especially with respect to IT which may include insertion of counterfeits, unauthorized production, tampering, theft, insertion of malicious software and hardware, and poor manufacturing and development practices (Gump et al., 2015). Avoiding grey market products – those distributed beyond the manufacturer's intended channel – has become difficult. The Aerospace Industry Association has expressed concern over DOD regulatory changes attempting to gain more control over free market supply chains (Rentsch, 2014).

Some have called for a new defense acquisition process tailored to COTS product usage. Our literature review fails to find that the DOD's 5000 series of regulations cannot effectively

integrate COTS products, although some changes could provide guidance and consistency for COTS product adoption. Horowitz and Lambert's (2006, p. 286) "learn as you go" framework offers some insight: "An assembly sequence (components to be assembled, corresponding dates and costs) has several risks including: 1) technical risk: successful (or not) function of assembled components by planned schedule milestones; 2) operational risk: achieving (or not) the desired business value by using the new system of assembled components; and 3) programmatic (schedule and cost) risks: accomplishing the assembly within time and budget constraints." Principles from this framework could inform changes or special cases under DOD regulations.

Study Limitations

These findings may exhibit the shortcomings inherent to literature reviews, such as selective inclusion and subjective weighting of studies while interpreting the findings, misleading interpretations of study findings, failing to relate study characteristics to disparate or consistent inter-study results, and failing to examine moderating variables (Wolfe, 1986).

The findings herein are limited to cases that have been made publicly available. Many COTS product implementations are leading-edge classified programs, excluding them from the sample set. The small number of published DOD case studies , and the even smaller number that were academically rigorous, may have excluded or influenced observations of antecedents to COTS appropriateness, barriers to successful implementation, and COTS implementation enablers because they (1) may not be captured in the study, and (2) may not rise to their true level of impact on dependent variables. The criteria of four mentions across different sources for inclusion of an antecedent factor is admittedly arbitrary; a different threshold could change results. The inclusion of non-DOD academic studies of COTS product usage may have

ameliorated the limitation posed by a limited number of rigorous DOD cases, yet could have

skewed results.

Conclusion

From the literature emerged a framework of COTS product usage that elucidates COTS

product adoption decisions and informs COTS product implementations. We explored: (1) the

antecedents (barriers and facilitators) and (2) outcomes of COTS adoption. The number of

commercial off the shelf research articles (see Figure 3) and patents (Google, 2017; see Figure 4)

have decreased since 2009. Rather than indicating a decline in COTS usage, it may have become

standard (Maras et al., 2012). As COTS becomes ubiquitous, it becomes unnecessary to mention.

Many COTS implementation and management recommendations have been made; future

research should measure the prevalence of these recommendations. The proposed scale COTS

appropriateness scale requires further empirical validation, as well as an assessment of the

minimum level of appropriateness needed (on the scale of 1-7) before adopting COTS, and

whether various contingencies affect this level.

*** *insert Figure 3 here* ***

*** *insert Figure 4 here* ***

The DOD faces pressure to sustain its competitive advantages in national security.

Enduring budget pressures, a record-long high operations tempo, the blitzing pace of technology,

and adversaries that are leveraging commercial technology compound the challenge. COTS

products offer potential cycle time savings, performance improvements, and lifecycle cost

reductions for defense acquisition. Further research will reduce program risks of poor

performance, failure, cost growth, and schedule slippage. In an increasingly uncertain world, the

DOD acquisition community will increasingly depend on COTS products to achieve mission

mandates and retain a competitive advantage against existing and potential foes.

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