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Improving Defense Acquisition Management and Policy Through a Life-Cycle Affordability Framework

4 February 2014

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Abstract

This research, under the direction of the principal investigators from the University of North Texas and with support from the Naval Postgraduate School, achieved its overarching goal of developing life-cycle affordability models that enhance defense acquisition management and policies. We develop models that provide acquisition decision-makers with an affordability trade-off space that considers design and life-cycle cost. Not only do these models consider life-cycle cost to provide acquisition decision-makers with an affordability trade-off space, but they also embrace both the performance and the risk that are associated with public–private partnership contract strategies. Our studies were conducted using a mixed methodological approach. We used qualitative research methods (interviews, surveys, grounded theory, and case studies) to uncover key characteristics and metrics defining affordability. In addition, we incorporated these key characteristics and metrics and developed analytical models to make informed business decisions on defense acquisition management and policy, using econometric, mathematical and statistical, and operations research model techniques.

Keywords: performance-based logistics (PBL), life-cycle affordability framework (LCA), business theory, research methods, supply chain management

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Improving Defense Acquisition Management and Policy Through a Life-Cycle Affordability Framework

Introduction[1]

Successful acquisition programs are affordable programs. Affordability has emerged as an important research area for both academics and practitioners (Gansler, 2012; Greene & Snider, 2012; McFarland, 2012). Affordability is both a systems engineering challenge and a supply chain challenge. Affordability is a program characteristic that strategically balances cost, performance, schedule, and risk throughout the acquisition life cycle. Although the Department of Defense (DoD) is a leader in affordability-oriented, performance-based acquisition strategies, it is faced with continued fiscal pressure and a challenge to further improve affordability of its defense acquisitions. In this research, we develop a life-cycle affordability framework (LCAF) to improve defense acquisition management and policy with the goal of alleviating some of the ongoing, governmental fiscal pressures. The LCAF is an extension of our previous research supported by the Naval Postgraduate School (NPS) Acquisition Research Program (ARP) under Grant No. N00244-10-1-0074 and No. N00244-10-1-0046. We focus on performance-based logistics (PBL) as the context in which we developed our LCAF. PBL is a relevant context due to its proliferation in the defense sector and its potential to positively impact affordability.

We extended our previous research (Randall, Nowicki, & Hawkins, 2011) by conducting interviews and administrating surveys to continue to uncover key characteristics and metrics defining life-cycle affordability. We also conducted archival and literature reviews to identify non-defense markets including the rail industry, fence-to-fence highway construction, social services, maintenance repair and overhaul (MRO), and manufacturing operations. We concentrate on PBL strategies for relevance to life-cycle affordability, both in theory and in practice.

As part of our previous research (NPS ARP Grant No. N00244-10-1-0074 and No. N00244-10-1-0046), we determined that affordability is a key economic indicator for successful PBL strategies. In our quest to develop a life-cycle affordability framework to improve defense acquisition management and policy, we extended this research to determine the key drivers of affordability and their influence on PBL strategies. We provided more depth to this inference by uncovering the key

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components of costs, the important performance metrics, and the elements of risk that define affordability. We developed novel supply chain resiliency models, based on affordability, that augment our previously developed multi-objective optimization models (Nowicki, Randall, & Ramirez-Marquez, 2010, 2012a). These models produce response surfaces showing an affordability trade-off space between cost, performance, and risk. It is important to note that the value of our research study for decision-makers to make more informed decisions lies in the creation of a trade-off space that shows the inherent affordability trade-offs between life-cycle cost, performance, and risk.

This research, under the direction of the principal investigators and with support from the Naval Postgraduate School and University of North Texas, achieved its overarching goal of using a mixed methodological approach to improve defense acquisition management and policy through a LCAF by

- identifying key inter-firm, team-level psychological factors that may help to explain successful PBLs by deriving an inter-firm, team-level model composed of 11 constructs related through six testable propositions (Randall et al., 2012b);

- developing the theoretical foundation for PBL by using a focused group of applicable business theories to improve a leader's ability to explain the business, economic, production, engineering, and supply chain science behind a successful PBL strategy (Randall, in press);

- describing the underlying theoretical fabric of PBL (Randall, 2013);

- showing how service dominant logic (SDL) and neuroeconomics provide theoretical foundations for decisions as a knowledge conversion production process. This process converts knowledge as raw material into applied knowledge and subsequently into value (Randall, Nowicki, Deshpande, & Lusch, 2013a); and

- defining and developing a supply chain resiliency model (Nowicki et al., 2013a).

This technical report includes our work, supported by NPS, that has either resulted in a published manuscript or is part of a working paper. Our approach for funded research is to ensure that each research question and deliverable (or some combination of those questions and deliverables) are explored using an academic publication framework. That means that our findings emerge by

1. identifying research questions, summarizing the state of the literature, and then describing the specific gap, and methological approach;

2. describing the extant literature that supports the investigation;

3. determining and applying the appropriate methodology;

4. describing the analysis; and

5. tying the findings associated with those research questions into a discussion that addresses practical, and theoretical, implications.

We use this academic publication framework to validate our work through the rigorous double-blind review of refereed academic publications. Some of our research questions identified in this report have already been accepted for print, others are still in the review process, and others are part of a working paper. For the work that is accepted into print, every effort has been made to cite that work specifically. Other material is part of working papers that are in the review cycle; these also have been cited. Lastly, some of our work is part of working papers that have yet to be submitted for publication. The references provide a listing of our published work and work in progress that is the source for NPS-supported research. These references are also listed in the Accomplishments section of this technical report.

This technical report is organized as follows. First, we discuss affordability and its impact on defense acquisition management and policy. We proceed with our vision of a life-cycle affordability framework and also discuss the importance of affordability of PBL strategies to defense acquisition management and policy research. We then discuss PBL successes that span across industry sectors, from government (e.g., defense) to for-profit (e.g., rail, airline, housing, and utilities). Next, we present additional research. Finally, we list our project accomplishments.

Discussion of Affordability

Overview

Affordability has always and will always be paramount to successful defense acquisition management and policy. This sentiment was clearly present at the Ninth Annual Acquisition Research Symposium held in Monterey, CA, on May 16–17, 2012. Greene and Snider (2012, p. 5) strongly encouraged research on affordability, stating, "It [affordability] is a central tenet of the DoD's Better Buying Power initiatives, and budget projections indicate it will continue to be important as the nation works its way out of the recession. This suggests that research with a focus on affordability will be of great interest to the DoD leadership in the year to come." On October 7, 2011, Frank Kendall, acting under secretary of defense for acquisition, technology, and logistics (USD[AT&L]), stated that Achieving Affordable Programs is one of the top priorities of the USD(AT&L) (Spruill, 2012). Gansler

(2012) envisioned that affordability will drive the DoD's procurement of goods and services in the next decade, unlike the post-9/11 decade.

The current economic environment may largely account for this renewed focus on affordability. The acquisition community is now faced with declining defense appropriations, rising costs, and rapid changes in technologies, geopolitics, economics, and globalization security (Gansler, 2012). For existing DoD programs, in 2008, there was about a 25% budget overrun relative to baseline averages. This percentage is trending upward, with an estimate of over 40% by 2016. Only 33% of DoD programs are on time, 38% are between one and 24 months late, 15% are between 24 and 48 months late, and 14% are over 48 months late (McFarland, 2012). It is in this environment of budget overruns, schedule delays, and a declining economy that affordability remains as critical as ever to defense acquisition management and policy research. The budget reductions and force restructuring will create substantial "pain" for defense customers, organic support, and their industrial partners. The changes will shift patterns for acquisition, operations, and sustainment. These shifts mandate more efficient use of materiel, personnel, and intellectual capability. Therefore, a need exists for proactive analysis of how these changes will impact systems from design through retirement. New approaches must be sought to extend the "bathtub" curve and ensure a platform of life-cycle affordability.

Our Vision of a Life-Cycle Affordability Framework

We view affordability as understanding and quantifying the inherent trade-offs between cost, performance, and risk over a system or program life. This view is consistent with Gansler's (2012) definition of *affordability*, which was adapted from Redman's (2012) definition, stated as follows:

> that characteristic of a product or service that enables military users to:
> (1) acquire it for a reasonable <u>life-cycle cost</u>, that falls within their budget; and in the <u>quantity required</u>, (2) use it to meet their <u>performance requirements</u>, at a level of <u>quality</u> that they demand, and (3) use it <u>whenever they need it</u>, over the <u>expected life span</u> of the product or service. (p.6; emphasis added)

Gansler (2012) stated that affordability is an engineering challenge and not an accounting or auditing problem. We certainly agree with this statement, but we believe it is incomplete. We suggest that affordability is both an engineering challenge and a supply chain challenge. More eloquently, we believe that affordability involves the continuous searching for ways to meet current demands for spares, repairs, and overhaul while also searching for new technologies, materials, and processes that allow demand to be designed out of the system. Engineering challenges exist when determining how to meet technical performance

characteristics such as sustained loading, time-to-altitude, logistics footprint, weight, and target accuracy. However, engineering decisions that arise to meet these challenges largely determine the out year operational and support costs that are supply chain challenges. Engineering decisions determine the reliability, maintainability, and supportability characteristics of the system design. The "nonreliability" of the system determines the frequency of demand for support resources (e.g., labor, spares, test equipment, transportation, and facilities). The maintainability and supportability characteristics of the systems design determine the duration of use and wait time for these support resources. Determining the quantity, location, dependencies, and polices of these support resources are supply chain challenges. Our vision of a LCAF addresses both engineering challenges and supply chain challenges but does so using dynamism and innovation. In short, to the current system design criteria of reliability, maintainability, and supportability, we add the idea of innovatability. Innovatability is that inherent design objective that anticipates and economically enhances the introduction of new materials, processes, and technologies.

Since performance-based acquisition strategies need to understand the intricate relationships between engineering systems design challenges and the design's supply chain challenges, we propose to continue our focus on performance-based acquisition strategies, such as PBL, as we evolve a LCAF.

Discussion and Breadth of Performance-Based Acquisition Strategies

Performance-based acquisition strategies continue to receive increased attention in systems engineering, operations management, economic, supply chain, and logistics research (Kim, Cohen, & Netessine, 2007; Kim, Cohen, Netessine, & Veeraraghavan, 2010; Kratz & Diaz, 2012; Ng, Maull, & Yip, 2009; Nowicki, Kumar, Steudel, & Verma, 2008; Nowicki, Randall, & Ramirez-Marquez, 2012b; Randall, 2012, in press; Randall, Brady, & Nowicki, 2012a; Randall et al., 2011; Randall et al., 2012b; Randall, Pohlen, & Hanna, 2010; Randall, Wittman, Nowicki, & Pohlen, 2013b; Sols, Nowicki, & Verma, 2007; Ssengooba, McPake, & Palmer, 2012). Under our previous research supported by the NPS ARP, we compared performance-based acquisition strategies and how they differ from the more traditional, transactional-based strategies (Nowicki, Sauser, & Randall, 2013b; Randall et al., 2012a).

PBL's success in defense has led to strategies that are now being employed in other industry sectors, such as aerospace, transportation, telecommunications, power generation, health care, child and family services, and manufacturing support (Flint, 2007; Kim et al., 2007; Perry, 1994). The use of performance-based contracting spans a rather diverse array of public- and private-industry sectors,

including roads and bridges (Ozbek & de la Garza, 2011), high-speed rail (Siemens, 2011), transportation (National Research Council, 2009), child welfare (Collins-Camargo, McBeath, & Ensign, 2011), and public health care (Ssengooba et al., 2012; Administration for Children & Families, 2011; The World Bank, 2008). In fact, many of these performance-based contracts are private-public partnerships.

In the next section, we examine economic and business theories in support of PBL, with particular attention to their relevance to success.

PBL as a Science of Discovery With Supporting Business and Economic Theories

The content in this section is largely extracted from Randall (2013). Our PBL research to date has essentially been a science of discovery (Randall, 2012), looking at what works and what doesn't work to answer key questions, and establish tenets. In general, this research has led to the common consensus that PBL works, if done correctly. PBL is not a magic bullet but a strategy, one that needs to be correctly applied. We have uncovered insights into how to execute a PBL. Those insights suggest that execution depends on the system, the level of repair, and a strategy of subsystem- or system-level PBL. From a relationship perspective, we also show how the length of a PBL contract affects outcomes. Shorter term contracts appear to generate quick wins in classic logistics (i.e., warehousing, transportation, and inventory), medium-length contracts can improve purchasing and item management, but real, reliability-driven affordability requires a longer term contract. The Primary System Integrator (PSI) debate has been largely exposed as an argument in semantics. On one side, the government is the PSI when it comes to integrating warfighter requirements, determining and funding budgets, and defining operational and strategic objectives. When it comes to integrating the supply chain, the PSI of choice is the original equipment manufacturer (OEM). However, practice also shows that there are times when a government-industry PSI team might work, or even an industry non-OEM PSI.

The discoveries in the how, when, and why of PBL have been legion. These discoveries now provide us with the necessary empirical data to propose a theoretical foundation for PBL. This is a key contribution, one that has potential to rationally close the PBL debate for all of those interested in rationality. Ultimately, the goal of science is to explain and predict phenomena. Therefore, the next step is to understand PBL at an elemental level, so that we can explain, predict, and extend PBL success.

Theory allows us the ability to explain and predict, and that gives us untold efficiency. Theory gives us the power to predict a future, explain why that future will occur, and then take action to improve that future. The current state of PBL

research and practice provides the opportunity for us to synthesize business theory to describe a theory foundation for PBL that will improve our ability to explain and predict PBL success and overcome perceptual barriers to implementation and execution of PBL. Foundational business and economic theories for PBL include

- Coase's theory of the firm,

- transaction cost economics (TCE),

- make versus buy,

- core competency, and

- SDL.

As part of our research, we first discuss Coase's Nobel Prize–winning work (Coase, 1937) with regard to how the theory of the firm is used as a foundation to understand the role of a PSI as a network entrepreneur who links actions with outcomes, and improves the efficiency of transactions. TCE is used to affirm the role of integration but adds to how PBL addresses human behavioral characteristics of bounded rationality and opportunism. Using bounded rationality helps defend the logic behind PBLs' use of networks of firms to deal with complex transactions that cannot be effectively managed in a single organization. The TCE concept of opportunism explains the underlying logic of the multiyear contracts, metrics, and investment in cost avoidance governance structures of PBL. Make or buy decisions, another extension of TCE, explain how effective PBL governance structures determine when value should be created inside the firm or purchased from a supply chain. Make or buy is also extended to the idea of PBL incentive shift of the efficient frontier of repair to redesign. Together, make or buy and repair or redesign provide a theory foundation to explain and predict who should repair and redesign and when the efficient frontier shifts from repair to redesign. The discussion of efficient frontiers also reaffirms the predictive implication of contract length.

When it comes to who should be doing what, when and why, Prahalad and Hamel's (1990) core competency theories provide an ability to predict PBL success by understanding, utilizing, and reinvesting in the core competency of the collaborative supply chain. Our empirical research demonstrates how PBL concepts of integration and integrated supply chains consistent with the "buzz" associated with the rise of supply chain management are put into a PBL (Koh, Saad, & Arunachalam, 2006; Randall et al., 2011). Somewhat dramatically, PBL is shown to be a practical implementation of SDL, which is considered to be an evolutionary economic theory framework. This means that the massive expansion into SDL research provides a ready-made framework to explain and predict the role of knowledge, relationships, a focus on value and metrics. PBL and SDL are not about parts but about what matters most to customers—value.

Thus, PBL establishes a governance mechanism that seeks to optimize supply chain management cost while being cognizant of the link between supply chain management cost and the cost-effective introduction of material, process, and technology that improves the reliability of a system to reduce cost across the program life cycle. The applicable theories clarify the underlying econometric model of a PBL strategy. This understanding should influence development of new sustainable and affordable design strategies. These strategies rest upon systems design and and governance structures that accelerate the insertion of new materials, processes, and technologies that reduce life cycle cost. For new programs the PBL strategy should focus on ideas such as modularity and redundancy that reduce the cost of sustainment engineering innovation. For fielded systems, the PBL strategy should focus on development of materials, processes, and technologies that accelerate the shift from repair to redesign, or reduce supply chain costs. In both cases, these approaches are built against the backdrop of a theoretically sound PBL strategy.

Affordability of Performance-Based Logistics Strategies and Its Importance to the Defense Acquisition Management and Policy Research

The central theme of any PBL strategy is to establish a multiyear governance structure that monetizes cost avoidance to create an incentive for investment in reducing cost and increasing performance (Kim et al., 2007). The operating and sustainment costs of a system often exceed 80% of the total life-cycle cost of the system (Fabrycky & Blanchard, 1991)For example, the cost to sustain the Joint Strike Fighter program exceeds its development and production cost by over $250 billion (Government Accountability Office, 2008). The commercial sector is equally burdened by the cost to sustain such systems. In the U.S., the airline industry spent $45 billion in 2008 on MRO; this is against a calculated $185 billion in revenue (Air Transport Association, 2008; Flint, 2007). These staggering costs provide further evidence for the need to focus on affordability.

In 2001 the United States Department of Defense (DoD) stated that PBL would be their preferred method for procuring maintenance support (Vitasek and Geary, 2008). Currently DoD is engaged in 76 performance-based contracts with another 95 scheduled in the near future (Geary and Vitasek, 2008). PBL has also been successfully employed in a commercial sector including aerospace, transportation, telecommunications and power generation industries (Keating and Huff, 2005). By 2005, 50 countries were exploring or implementing performance based maintenance contracts (Transportation Research Board, 2009). Existing PBL experience has been shown to be effective in terms of cost reductions and increases in system performance (Fowler, 2009; Kratz, 2008).

Suppliers through the traditional, transactional based, post-production service agreements commonly experience steady work. The more systems break the more revenue the suppliers make. However, this facilitates an uneasy economic imbalance between suppliers and customers. Alexander et al. (2002) and Bundschuh and Dezvane (2003)recognize that even though after-sales support is a very profitable business, the supplier's lack the financial incentive to invest into cost-avoidance/design improving strategies (i.e., affordable designs) such as reliability, maintainability and supportability. As a natural consequence of PBL, the supplier is inherently incentivized to invest in design and supply improvements to reduce out year costs, thereby improving the life-cycle affordability of the system. As a result, there is often a mutually beneficial effect where the customer's maintenance reduced, the system's operational availability increased, and the supplier's profit margin increased (Kim et al., 2007).

PBL changes the postproduction business model. While PBL still accomplishes the traditional postproduction support tasks such as inventory management, repair, and overhaul, it does so using a continuous calculus that seeks more efficient demand management aimed at driving out demand through improved reliability (Kim et al., 2007; Kim et al., 2010; Randall et al., 2010). The basis of the PBL calculation involves a long-term collaborative relationship based on a multiyear contract with the supplier network. The decision to invest in reliability improvements is an example of how the life-cycle affordability framework presents a trade-off space between costs, performance, and risk.

Successful PBL strategies use cost-avoidance incentives to focus upstream trading partners on the outcome that matters most to the end user—an operational system at the lowest possible cost; in brief, a target level of operational effectiveness that is most efficient. Figure 1 displays this pictorially. This figure, or some variation of it, has been shown in nearly all PBL research, PBL seminars, PBL education and training, and PBL conferences.
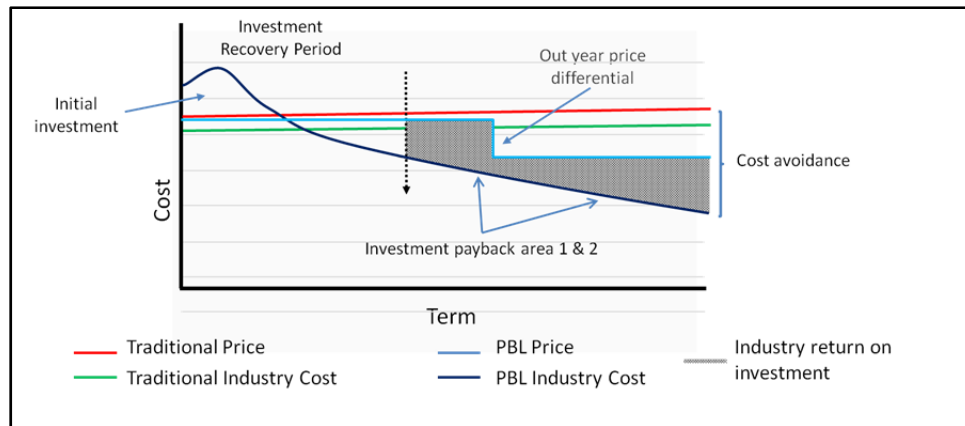
Figure 1.   **Investment vs. Contract Length**
(Randall et al., 2011)

The first use of this chart known to us was by PRTM (a subsidiary of PwC) to the DoD. Versions of the chart have also been presented by Randall (2008, 2009, 2010), originally based on his dissertation research. University of Tennessee Center for Executive Education has also presented versions of the chart.

In a traditional postproduction support business model, the customer pays a transactional fee for each task required to keep the system in service (e.g., sparing, overhaul, and repair). This transactional business model has no avenue for investments focused on reducing cost. At the same time, as systems age, the repairable parts wear out, fatigue accumulates, sources of supply diminish, there is an overall rate of degradation, and the cost of postproduction support increases (MaClean, Richman, Larsson, & Richman, 2005). In Figure 1, is the lines labled "traditional price" and "traditional industry cost" represent the cost increase due to degradation over time The age-based cost increases and performance decreases are what led to the development of the PBL strategy. As costs continue to balloon, operators under the traditional postproduction support business model found themselves accepting significant risk when a lack of coordination across the supply chain resulted in material shortages, diminishing sources of supply, and system down-time due to stock outs (Nowicki et al., 2008; Sols et al., 2007).

Performance-based approaches convert the year-after-year transactional spending of traditional postproduction support (e.g., maintenance, repair, and overhaul) into large pools of cost avoidance (Randall et al., 2010). This potential pool of cost avoidance represents the area under the traditional price (for postproduction support services). The PBL strategy encourages suppliers to make initial investments (as shown at the left side of Figure 1) that reduce total life-cycle costs (as shown at the right side of Figure 1).

The incentive to make these investments is best captured by a multiyear, firm-fixed-price contract (Garnder, 2008). That contract strategy allows the suppliers to harvest the cost avoidance through a return on investment strategy, as shown in Figure 1. The customer gets stable expenses, and after the agreed-to contract period, savings are passed to the customer, as shown by the box labeled "out year price differential" in Figure 1. PBL strategies have proven successful in many industries because they create an affordable solution for the DoD and its suppliers. We developed our life-cycle affordability framework with a focus on PBL because of its proliferation in the defense sector and its potential to positively impact affordability.

Research Studies

Performance-Based Contracting and Inter-Firm Team Processes

This research study establishes a new research path by examining inter-firm, team-level factors, in the context of PBL, that lead to successful supply chain teams. The majority of this section is taken directly from Randall et al. (2012b). This research provides managers with a mechanism for improving team performance and learning by making adjustments to strategic metrics over time.

PBL uses long-term contracts and metrics to align inter-firm teams to create innovations and reduce costs. Because PBL initiatives are implemented using teams, we examined emergent team-level factors and their associations found in successful PBL inter-firm teams composed of both public and private members.

Using grounded theory, we interviewed 17 managers who are part of government-industry teams that use a PBL strategy to determine key team-level psychological factors found in successful PBL teams. This methodology led to identifying the proximal factors and processes leading to PBL team success.

This research explicates the team-level psychological factors associated with PBL success. The study is novel because it captures the impact that inter-firm, team-level factors have on PBL strategy implementation and outcomes. The success of PBL is explained using an inter-firm, team-level model composed of 11 constructs related through six testable propositions. The performance-based strategy inter-firm team model that we developed is shown in Figure 2.
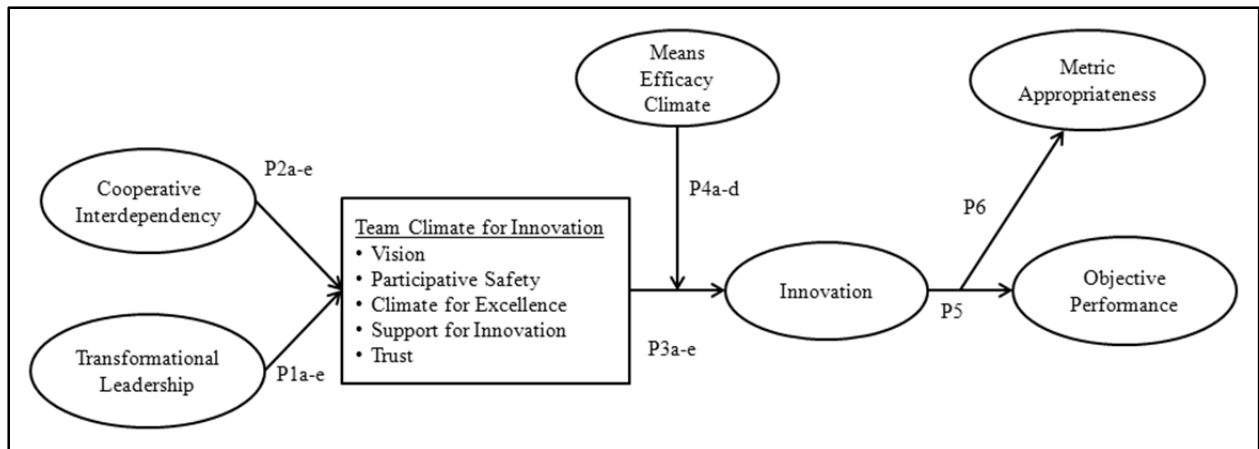
Figure 2. **Performance-Based Strategy Inter-Firm Team Model**
(Randall et al., 2012b)

Based on our research (Randall et al., 2012b), we derived six testable hypotheses with regard to PBL teams:

1. Propositions 1a–1e: Transformational leadership will be positively related to (a) team vision, (b) participative safety, (c) climate for excellence, (d) support for innovation, and (e) trust.

2. Propositions 2a–2e: Cooperative interdependence will be positively related to (a) team vision, (b) participative safety, (c) climate for excellence, (d) support for innovation, and (e) trust.

3. Propositions 3a–3e: (a) Team vision, (b) participative safety, (c) climate for excellence, (d) support for innovation, and (e) trust will be positively related to innovation.

4. Propositions 4a–4e: Means efficacy climate will moderate the positive relationships of (a) team vision, (b) participative safety, (c) climate for excellence, (d) support for innovation, and (e) trust with innovation such that the relationships are stronger when means efficacy climate is high and weaker when it is low.

5. Proposition 5: Team innovation will be positively related to objective performance.

6. Proposition 6: The strength of the positive relationship between team innovation and performance will positively relate with metric appropriateness, such that when the slope is weak, metric appropriateness will be low, and when the slope is strong, metric appropriateness will be high.

The findings outline behaviors and systems of behaviors that both support and are a result of a PBL initiative. This investigation identifies two antecedents of

team climate for innovation (TCI): cooperative interdependence and TFL. Cooperative interdependence indicates the importance of having commonly shared goals in enhancing TCI. Consistent with Deutsch (1973), this climate engenders consideration for all team members to create and value cooperative goals. PBL creates goals that are cooperative and not competitive. Previous research has already established a positive relationship between TFL and support for innovation (Eisenbeiss, van Knippenberg, & Boerner, 2008), and we extend this research by relating TFL to additional components of TCI, including vision, participative safety, a climate for excellence, support for innovation, and trust.

Our findings have significant managerial implications. For example, organizations can benefit from these inter-firm, team-level psychology relationships by understanding the importance of cooperative team goals. Managerial tactics can be used to avoid creating a zero-sum game among team members. Our findings suggest that organizations need to appoint individuals who are transformational to management positions so that they can inspire team members to challenge the status quo and promote an environment conducive for innovation.

Our research in the PBL setting supports recent meta-analytic results indicating a positive relationship between TCI and innovation (Hulsheger et al., 2009). However, a large portion of studies in the meta-analysis examined research and development teams because they provided researchers with an objective means for tracking innovation through patents (Hulsheger, Anderson, & Salgado, 2009). Thus, the main effects of TCI may in fact be limited. Research and development teams may have access to sufficient resources necessary for enhancing the likelihood of innovation. We found that there may be environmental factors present that influence the strength of the positive relationship between a team climate for innovation and actual innovation.

We believe that another contribution of this research involves identifying how means efficacy climate acts as a moderator of the positive relationship between TCI and team innovation. The managerial implication is that if organizations properly fund and assist in the success of PBL initiatives, they should experience more innovation when teams have both the financial and policy support necessary for success. Thus, organizations that under-invest in PBL programs may not experience the same levels of innovation despite their focus on cooperative interdependency and transformational leadership to increase the positive effect of team climate for innovation.

Of considerable importance is our finding that metric appropriateness is a reaction to the relationship growth between team innovation and performance. When the relationship is weak, metric appropriateness is judged to be low. Conversely, when the relationship is strong, metric appropriateness is judged to be high. From a

managerial perspective, it is important to take this information and incorporate it into future contracts. Therefore, PBL should not simply be thought of as a static process but instead as continual improvement needed for long-term success. Teams that witness low metric appropriateness need to ensure that this new knowledge is not lost and reevaluate the metrics to overcome the poor project performance. The reality of business suggests that there is not a single set of metrics that works with all projects so team members need to take action when these metric appropriateness evaluations are low. Metric appropriateness is therefore a factor to consider when designing a PBL strategy. This insight may help teams realize that adjustments should be made to the metric to improve metric appropriateness.

PBL drives learning and innovations. Based on the knowledge gained, future adjustments to the metrics can be made. While team learning is not modeled directly in this research, the insight with regard to team learning and the effect of metric approapriateness is an important contribution to the supply chain literature.

Collectively, our findings establish a new research path by examining inter-firm, team-level factors for judging success in PBL teams. We found that PBL is effective because there is a process of team learning and adjustments to the strategic metrics over time that leads to team success. Thus, the strategy itself requires a flexible mentality so that it never becomes static and remains always appropriate for the external context.

Converting Knowledge Into Value: Gaining Insights From Service Dominant Logic and Neuroeconomics

[The research in this section is documented in Randall et al. (2013a)]

The fabric of supply chain management coupled with SDL provides a rich tapestry to describe the conversion of knowledge into value. Vargo and Lusch (2004) posited that the fundamental unit of exchange is applied knowledge. Conceptualizing the market as shifting from conversion of material to conversion of knowledge represents the move globally to nations competing based on their knowledge versus competing based on their material goods production. These research findings suggest a confluence between SDL's focus on knowledge as the fundamental unit of exchange and supply chain management as a discipline focused on sourcing raw materials and converting those materials, through the mechanism of production, into products (Lambert & García-Dastugue, 2006; Vargo & Lusch, 2011).

There exists a confluence of practice and thought that seems to suggest an emerging character of the global knowledge economy. The first element of this confluence finds practitioners, in general, creating competitive advantage by embracing research ideas like: Exchange is about the conversion of intangible knowledge, skill, and ability into value and products merely assist in the transfer of

this value (Vargo & Lusch, 2011). The second element of this confluence is suggested by the rise of a supply chain view where firms create value by integrating complementary core competencies from a global supply chain (Jüttner, Christopher, & Godsell, 2010; Rice & Hoppe, 2001). The third element is the increasing success of an emerging supply chain strategy called performance-based logistics (PBL).

Neurological processes behind the actions of the decision-makers influence the production process. Evidently, decision-makers in the PBL-SDL environment use knowledge and weigh the risks and rewards of their actions in order to make a decision (Randall et al., 2010). Risk is an important component in decision-making. In a knowledge-based economy, having an optimum level of risk behavior in a decision-making environment may provide a means of optimizing production efficiency (Emonds, Declerck, Boone, Vandervliet, & Parizel, 2011; Xue, Lu, Levin, & Bechara, 2011).

Neuroeconomic researchers have shown that there are distinct and individual brain patterns that can be used to predict purchasing decisions (Knutson, Rick, Wimmer, Prelec, & Loewenstein, 2007). Neuroscientific methods and tools such as the functional magnetic resonance imaging (fMRI) provide the ability to map the structures of the brain involved in various functions (Bandettini, Wong, Hinks, Tikofsky, & Hyde, 1992; Ogawa et al., 1992). Our research in this area led to the development of a method to design a a risk propensity scale, as displayed in Table 1.

Table 1.   Risk Propensity Scale Development
(Randall et al., 2013a)

Step	Task	Objective
One	Define desired behavior.	Determine the optimal risk-reward behavior. This may be based on the supply chain position (buyer-supplier) or role (engineering, SCM, finance).
Two	Select managers for baseline study.	Select managers whose self-description and supervisor feedback suggest their risk propensity.
Three	Identify the neuronal correlates of desired behavior.	Confirm risk predisposition and corresponding neural substrates based on gender, culture, and propensity.
Four	Design a neurofeedback-based training program that will produce changes in neuronal substrates to optimize situational positive risk propensity.	Demonstrate the ability to change risk predisposition with regard to managerial tasks.
Five	Validate the training program by iterating Step 3 until the desired behavioral outcome is achieved.	Confirm that the neurofeedback creates desired results.
Six	Create baseline training modules for organization position in the supply chain, specific workplace positions, and generalized risk correlates (e.g., gender, propensity, culture).	Develop baseline training to efficiently influence the knowledge conversion process.
Seven	Develop a scale to determine risk propensity.	Develop method to accurately and efficiently determine risk propensity with our supervisor insight or fMRI. Ability to measure change in risk propensity.

In an attempt to develop a testable conceptual model of outcome-based decision-making, we distill literature streams to understand the confluences among SDL, supply chain management, PBL, and neuroeconomics. The dataset utilized in this research was taken from Randall et al.'s (2010) top-level model of PBL.

We found out that not only does conversion of knowledge into value involve an awareness of information and then a decision-based response but it is also a process that is highly influenced by the individual's mind-set. From our analysis, we identified five main themes:

- PBL requires significant knowledge and knowledge response infrastructure.

- The amount of knowledge and the ability to act on that knowledge (e.g., capital) varies based on the position in the supplier network.

- The contract structure is a significant moderating factor of the knowledge-incentive-investment-decision loop.

- Individuals within a firm have a predisposition to engage in an entrepreneurial fashion.

- Organizations as a whole may tend to have a certain predisposition to act in an entrepreneurial fashion (e.g., the customers are more risk adverse than the OEM).

Based on the framework-for-knowledge conversion process provided by SDL and PBL, we propose an SDL knowledge conversion decision model that is significant and relevant for desired outcomes (Figure 3). We make the following research propositions that need to be empirically tested:

- Proposition 1: Available potential applied knowledge positively influences applied knowledge awareness.

- Proposition 2a: Manager predisposition to search for applied knowledge moderates applied knowledge awareness.

- Proposition 2b: Manager genetic background moderates applied knowledge awareness.

- Proposition 2c: Manager cultural background moderates applied knowledge awareness.

- Proposition 3: Applied knowledge awareness positively influences decision response.

- Proposition 4: Predisposition to act entrepreneurially positively influences decision response.

- Preposition 5a: Manager genetic background moderates decision response.

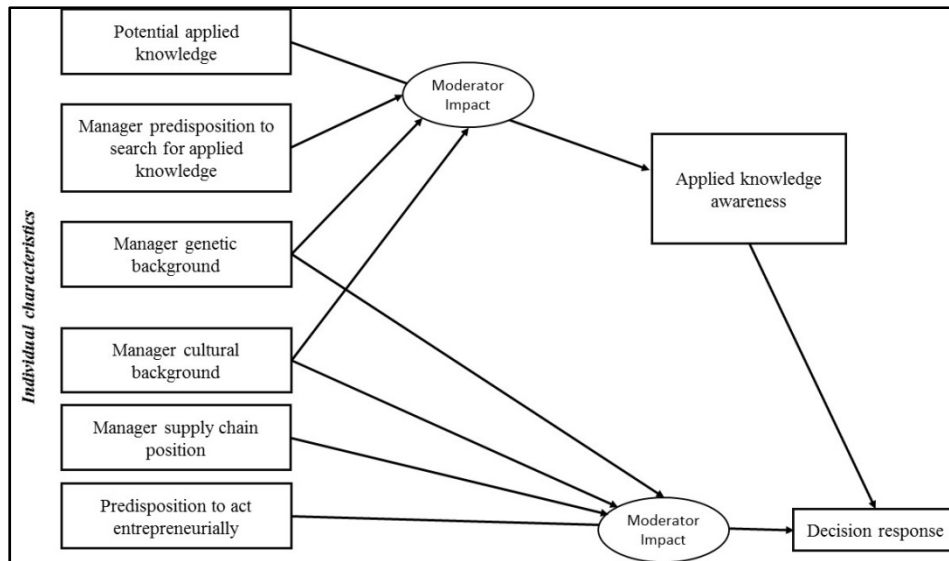- Proposition 5b: Manager cultural background moderates decision response.

Figure 3. **The SDL Knowledge Conversion Decision Model**
(Randall et al., 2013a)

For practice, the implication of this research is envisioning manager mind-set as the key determinate of knowledge conversion efficiency and effectiveness. The implication of our research to theory is the provision of a conceptual model of a knowledge conversion process consistent with SDL. This model suggests that competitive success involves an ability to continuously acquire and apply knowledge in an entrepreneurial fashion. Ultimately, we suggest that this knowledge conversion view of competition requires managers to recognize opportunity and utilize knowledge to switch from the product focus of a return-on-sales business model to an evolving value proposition focus of a return on investment paradigm.

Collectively, our research explores implications for conceptualizing decision-making as the key production process in the evolution from a product to knowledge-based view of the economy. We show how SDL and neuroeconomics provide the theoretical foundation for describing how decisions convert knowledge from supplier networks into value .

Are the PBL Prophets Using Science or Alchemy to Create Life Cycle Affordability? Using Theory to Predict the Efficacy of Performance-Based Logistics

[The research in this section is documented in Randall (2013)]

This research advocates for a theory in defense acquisition management using the tenants of PBL to provide a theoretical framework that enhances life-cycle affordability and governance structures. There has been considerable debate on the effectiveness and thus success of PBL. While PBL in the short term generates quick wins in classic logistics (i.e., warehousing, transportation, and inventory), the longer

term drives an affordable and reliable life cycle for sustainable business results (Hypko, Tilebein, & Gleich, 2010; Randall et al., 2010). Organizations can achieve success by(a) aligning incentives to avoid sub-optimization (Randall et al., 2010); (b) leveraging long-term contracts to spur investments (Sols et al., 2007); and (c) creating a governance structure that is based on longterm relationships, stable cash flow, clear scope, and intelligent metrics (Kratz & Diaz, 2012).

Governance, for that matter, is very critical to business and economic theory. It is therefore not surprising that research funded by the NPS ARP and conducted by the University of North Texas Complex Logistics Systems Cluster found the following: "PBL establishes a metric based governance structure where suppliers make more profit when they invest in logistics process improvements, or system redesign, that reduces total cost of ownership" (Randall et al., 2011).

Effective PBL strategies demonstrate that monopoly is not synonymous with opportunism. Good PBL governance structure can mitigate potential opportunism by aligning profit-based incentives (Guajardo, Cohen, Kim, & Netessine, 2012). PBL reverses the situation where postproduction spend significantly exceeds the productions spend. It does this by treating repair and redesign similar to make or buy. The goal in make (repair) or buy (redesign) is to seek the most cost-efficient approach to satisfy the demand for some item. In situations where the supplier develops a new process, reducing the cost to redesign a part, the PBL strategy subsequently shifts from repair to redesign. Figure 4 graphically illustrates the idea of make or buy for repair or redesign. The ability of the PBL governance to use innovation and investment to move the parts near the middle from repair to redesign is the essence of life-cycle affordability.
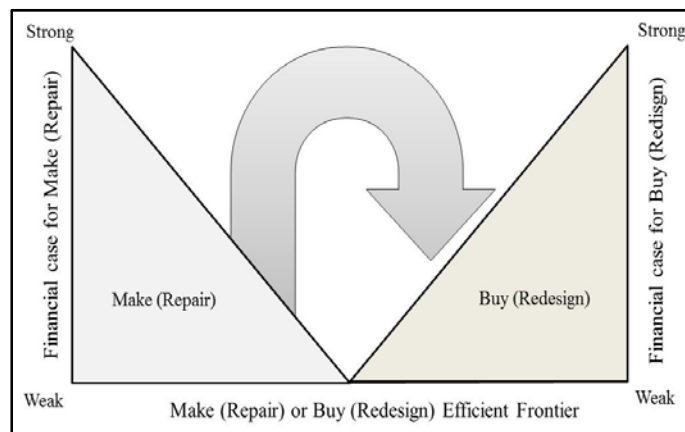

Figure 4.   **The Make or Buy of Spare and Repair**
(Randall, 2013)

While PBL governance structures minimize the cost associated with filling demand for parts, it continuously reevaluates how new materials, processes, and

technologies can improve reliability and repair efficiency, reduce the demand for parts, and decrease life-cycle cost. We are of the view that a PBL-based life-cycle affordability framework (see Table 2) for an affordable PBL governance structure can be achieved either through reducing the supply chain cost associated with meeting the demand for parts (X-axis) or reducing the demand for parts and cost of repair (Y-axis). The life-cycle affordability framework provides leaders of organizations with the ability to explain, predict, refine, and advocate for PBL strategy. When PBL strategies are implemented across the network of firms affordable, complex systems are created.

Table 2.   Life-Cycle Affordability Framework
(Randall, 2013)

Supply Chain Network Resilience: Economic Considerations and Metrics

[The research in this section is documented in Nowicki et al. (2013a)]

The advance of global supply chian management has resulted in a corresponsing increase in supply chain resiliency research. Extended supply chains amplify the impact of supply chain disturbances which often have severe and long lasting effects. Currently, resiliency research is largely focused on building theories and definitions of resilience. We develop a time-dependent, supply chain resiliency definition and create a supporting mathematical model. We introduce two stochastic order optimization problems that capture the notion of supply chain resiliency and create a novel, heuristic solution. We take a systems approach to supply chain resiliency by analyzing the resiliency of a multi-echelon sustainment network that supports large-scale, complex systems such as a fleet of aircraft. The supply chain resiliency model systematically quantifies the vulnerability of each node in the

sustainment network and the investment necessary to fully restore the network's operation. We implement our solution by using an existing example published in the literature.

Modeling Approach

In defining our novel supply chain resiliency approach, we incorporated Nowicki et al.'s (2012b) heuristic algorithm that has been shown to improve the computational efficiency of the general class of Multi-Echelon Technique for Recoverable Item Control (METRIC) problems. METRIC-based algorithms are a proven, system-based sparing approach successfully used to analyze sustainment networks of large-scale, complex repairable systems such as those prevalent in the defense and aerospace industries (Graves, 1985; Muckstadt, 1973; Nowicki et al., 2008; Sherbrooke, 1968, 1986, 2004). The overall objective of a METRIC-based modeling approach is to determine the location and quantity of spares that either maximize the operational availability of a system subject to a budget constraint or minimize the systems costcost subject to an operational availability target. The greatest benefit of a METRIC approach is its systematic inclusion of all items at all locations prior to making a decision. This approach is in contrast to an item-based approach where decisions are made by individually evaluating only one item at one location. Schmitt and Singh (2012) analyzed disruption risk in a multi-echelon supply chain and reported that most resiliency literature is limited to single facilities or pairs of echelons. Conversely, most disruptions have lasting effects throughout the supply chain regardless of the number of echelons. They also stated that there are very few papers that include analytical models of resiliency. We address the gaps dealing with number of echelons and analytical models of resiliency by providing a multi-echelon, supply chain resiliency model. We also believe we advance the literature by taking a time-dependent systems approach to our modeling.

Under system-based modeling approaches, where all items at all locations are evaluated prior to making a stocking decision, modeling complications arise because spares can be located anywhere within the hierarchy of maintenance and support locations and are echelon dependent. Multi-item, multi-echelon spare parts inventory models have been reported extensively in the literature to address these intricacies (Caggiano, Jackson, Muckstadt, & Rappold, 2009; Clark, 1972; Graves, 1985; Kalchschmidt, Zotteri, & Verganti, 2003; Kennedy, Patterson, & Fredendall, 2002; Muckstadt, 1973; Nowicki et al., 2008; Rappold & Van Roo, 2009; Sherbrooke, 1968, 2004). We analyze a multi-item, multi-echelon sustainment network that simultaneously considers multiple items at multiple storage and repair locations when making stocking decisions (location and quantity) for each spare

item. The network of storage and repair locations is often referred to as a multi-echelon support infrastructure.

For example, let us consider a two-echelon sustainment network. The base (e.g., local) locations directly support the operation of a collection of large-scale, complex, repairable systems (e.g., a fleet of aircraft). When a system (e.g., aircraft) fails, a repair demand is generated at the base. Assuming that a spare item is needed for repair, a spare item stored at the base is used to complete the repair. If the required spare item does not exist at the base, a spare is then transported from the depot (ie.g., central) location. If the required spare is not located at the depot, it is then procured from its vendor.

Supply Chain Description

The supply chain network in this study is an arboreal structure without lateral re-supply, as shown in Figure 5. For the system under consideration, there is a one-for-one replenishment policy that is generally valid for relatively expensive, infrequently demanded, repairable items (Graves, 1985; Sherbrooke, 1986).
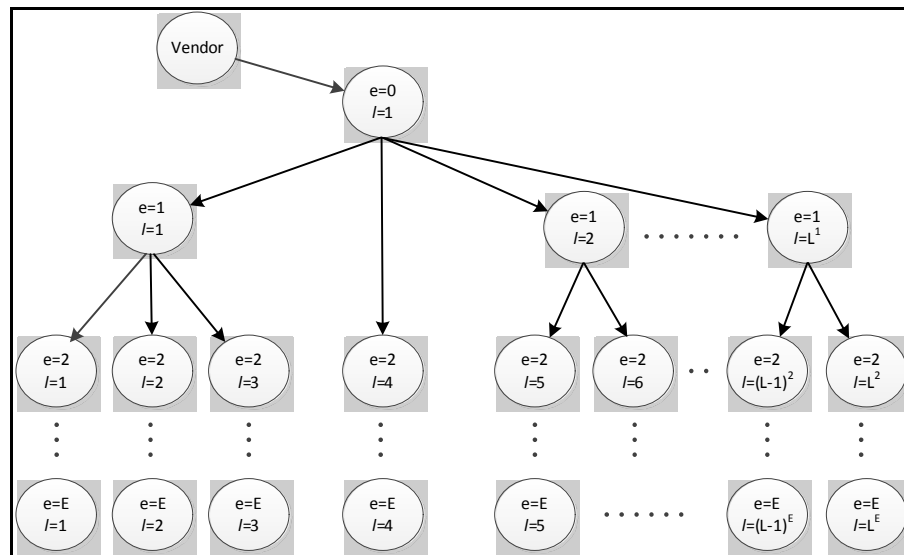
Figure 5.   **Multi-Echelon Supply Chain Network**

Under this model, when the system fails, an item is removed and replaced to restore the system to full operational capability. Such a replacement can only be accomplished if a spare is available at the operational site at the time of system failure. The frequency under which a particular item is needed to restore the system capability in any fixed time interval of length *t* is defined as the expected demand rate of item *i* at location *l* within echelon *e*, $E\left[N_i^{le}\right]$, where $i = 1, \dots |I|$; $l = 1, \dots, |L^e|$; and $e = 1, \dots, |E|$. Demand at the most forward stocking locations (also known as the field, base, or local stocking locations) follows a stationary, Poisson process.

The time for restoration, assuming a spare exists at a base location, is the mean time to repair, $MTTR_i^{le}$. If a spare does not exist locally, replenishment is requested from a supply location. The delay to fulfill this request is defined as the replenishment lead-time, $\underset{R}{\Theta}{}_i^{le} = \mathrm{E}\left[N_i^{le}(t)\right] \times r_i^{le} \times MTTR_i^{le}$. Different maintenance locations often have different capabilities (e.g., labor skills, tools, and support equipment); therefore, we include r_i^{le} in our multi-echelon model. r_i^{le} is the proportion of time that an item is actually repaired at this location. The overall delay to complete the repair will continue to accumulate until a spare is located within the sustainment network or a spare is procured from the vendor. The vendor delay is defined as the procurement lead-time, expressed as $\underset{T}{\Theta}{}_i^{le} = \mathrm{E}\left[N_i^{le}(t)\right] \times (1 - r_i^{le}) \times \underset{R}{\Phi}{}_i^{le}$.

The effectiveness of the operating systems are largely influenced by the frequency that a spare is needed and the time it takes for a spare to be on hand to restore the failed system back to operation. If a demand for a spare cannot be immediately fulfilled, there is a back order. The back order delay is defined as

$$\underset{BO\,i}{\Theta}{}^{le} = \mathrm{E}\left[N_i^{le}(t)\right] \times (1 - r_i^{le}) \times \mathrm{E}[BO(N_i^{le-1}(t) \mid s_i^{le-1})] / \sum_{l=1}^{L^e} \mathrm{E}\left[N_i^{le-1}(t)\right]$$

Since unfulfilled demands are a function of the delay scenarios and, as such, depend on the number of existing spares at each location within each echelon, they can be used as a surrogate measure for operational availability. Sherbrooke (2004) showed that the expected back order can be transformed into an accurate predictor of expected availability, as follows: $A_o = 100 \prod_{l=1}^{L^E} \prod_{i=1}^{I^{lE}} \left(1 - \mathrm{E}\left[BO(N_i^{lE}(t) \mid s_i^{lE})\right] / n\right)^n$, when $\left(\mathrm{E}\left[BO(N_i^{lE}(t) \mid s_i^{lE})\right] / n\right) \le 1$ or $A_o = 0$ otherwise.

Nowicki et al.'s (2012b) heuristic algorithm is used to derive the initial optimal complement (location, quantity) of spares, vector $\mathbf{s}_k^e$, that satisfies the system's performance (i.e., operational availability) at minimum cost. The initial allocation, assuming that all sustainment locations are fully functioning, is used as the baseline in our supply chain resiliency algorithm. This algorithm constitutes the original system state S_0. We define element s_{lk}^e (an element of vector $\mathbf{s}_k^e$) as the kth spare allocation strategy indicating the number of spares available at location l of echelon e, with $\mathbf{s}_k^e = \left(s_{1k}^e,\ s_{2k}^e, \dots, s_{L^e k}^e\right)$. The allocation strategy is used within our supply chain resiliency algorithm to determine how the location will recover from a disturbance. The financial ramification of recovery is the investment needed to reallocate inventory when a sustainment location is no longer capable of providing support and is defined as $I(\mathbf{s}_k)$, with $\mathbf{s}_k = \left(\mathbf{s}_k^1, \mathbf{s}_k^2, \dots, \mathbf{s}_{k,}^E\right)$. The system performance,

defined as the operational availability, with a spares allocation, $\mathbf{s}_k$, is represented as $A_o(\mathbf{s}_k)$.

Supply Chain Resilience

The damage caused by disruptive event d_j is defined by vector $\mathbf{v}_j$, with element $v_j(e,l)$ describing whether or not event j leads to the closure of location l in echelon e:

$$v_j(e,l) = \begin{cases} 0 & \text{if location } l \text{ at echelon } e \text{ is damaged} \\ 1 & \text{otherwise} \end{cases}$$

Based on $\mathbf{v}_j$, we define $\mathbf{s}_k^e \mid \mathbf{v}_j = \left(s_{1k}^e v_j(e,1), s_{2k}^e v_j(e,2), \ldots, s_{lk}^e v_j(e,l), \ldots, s_{Lk}^e v_j(e,L^e) \right)$ and $\mathbf{s}_k \mid \mathbf{v}_j = \left(\mathbf{s}_k^1 \mathbf{v}_j, \mathbf{s}_k^2 \mathbf{v}_j, \ldots, \mathbf{s}_k^E \mathbf{v}_j \right)$. Given that disruption event d_j renders a set of locations inoperable, the disruption effect d_j is measured by $A_o(\mathbf{s}_k \mid \mathbf{v}_j)$. This term constitutes the degraded system state S_d.

Note that $A_o(\mathbf{s}_k) \geq A_o(\mathbf{s}_k \mid \mathbf{v}_j)$ and a post-disturbance investment is needed to invest in additional inventory and reallocate existing inventory to satisfy demand and restore the performance of the supply chain to its original level. To do so, we define $\hat{\mathbf{s}}_k^e = \left(\hat{s}_{1k}^e, \ \hat{s}_{2k}^e, \ldots, \hat{s}_{L^e k}^e \right)$ as the kth reallocation spare strategy for the locations in echelon e, where $\hat{s}_{lk}^e = 0$ if $v_j(e,l)=0$. Then, the post-disruption spare reallocation strategy for the supply chain is given by $\hat{\mathbf{s}}_k = \left(\hat{\mathbf{s}}_k^1, \hat{\mathbf{s}}_k^2, \ldots, \hat{\mathbf{s}}_{k,}^E \right)$, with associated investment $I(\hat{\mathbf{s}}_k)$ and availability $A_o(\hat{\mathbf{s}}_k)$. This term constitutes the restored system state S_{rc}.

Figure 6 describes the resilience process for the supply considering availability as a performance measure and the sparing strategies with corresponding investment. Thus, supply chain resliency can be represented mathematicall as a function of spare investment and time given disruption e_j. as

$$\text{Я}(e_j) = \frac{A_0(t_r \mid \hat{\mathbf{s}}_k) - A_0\left(t_d \Big| (\mathbf{s}_k \mid \mathbf{v}_j) \right)}{A_0(t_0 \mid \mathbf{s}_k) - A_0\left(t_d \Big| (\mathbf{s}_k \mid \mathbf{v}_j) \right)}$$
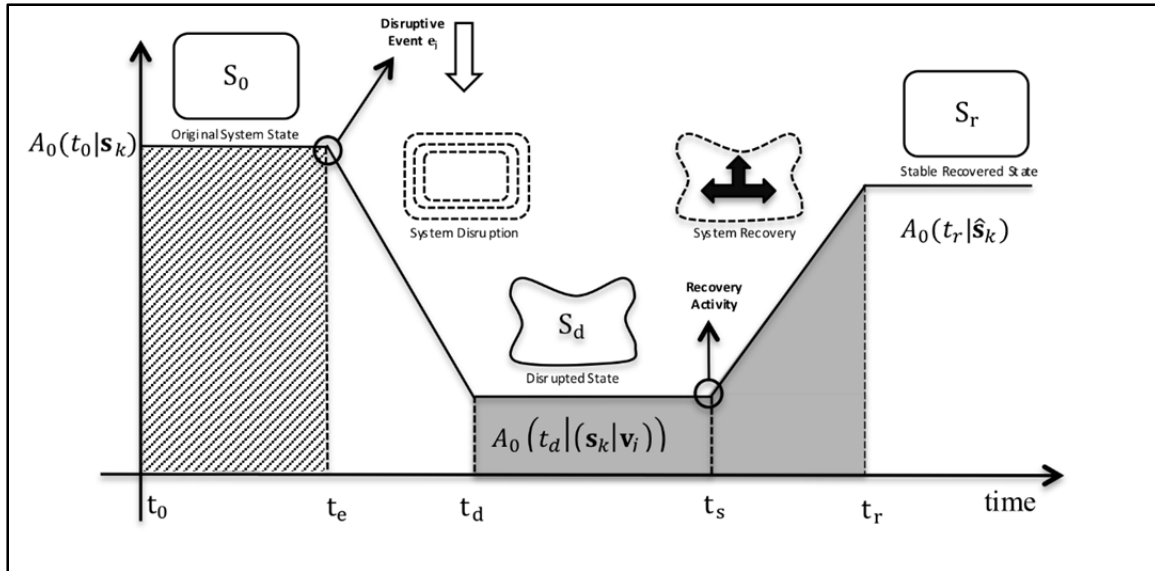
Figure 6. **Supply Chain Resilience Process**

Degradation and Recovery Rules

The removal of the nodes in the sustainment network is divided into two steps: degradation and reallocation. Degradation reduces the availability of the system. The spares inventory at that location is no longer available to the supply chain. Additional investment is now required to purchase the additional stock needed to restore the supply chain network to fully support the operating systems. We define the second step, allocation, as purchasing additional stock and adjusting stock levels at the undisturbed support locations. The objective of the reallocation step is to recover the availability of the system after the reduction in the stock level. The degradation algorithm is the same for all of the nodes. The reallocation algorithm varies with each node type (e.g., field, intermediate, and central). If a field location (the most forward location) is removed, its demand now needs to be satisfied by other nodes in the sustainment network. The demand of the eliminated field node is prorated to the remaining field nodes prior to reallocation. The increment in the demand rate at each of the remaining nodes is defined as Increment = (Item Demand Rate of the Remaining Node/Reduced Demand)*Removed Demand. When the central node is removed, its stock level is forced to zero and vendor lead-time is added to the intermediate and/or field nodes that it replenishes. A removed intermediate location's replenishment lead-times are now assumed by the locations it replenishes.

Conclusions

Supply chains are more prone to disruptions than ever before due to their complexity and global reach. Firms need to develop mitigation strategies that will soften the potential negative impact that vulnerabilities and risks have on a global

supply chain's ability to handle disruptions. Studies suggest risk management techniques to identify the risks and track the vulnerabilities (Jùttner, Peck, & Christopher, 2003). However, traditional risk management techniques are not enough to deal with the unexpected events (Pettit, Fiksel, & Croxton, 2010). Thus, companies need to enhance their supply chain resiliency in order to cope with unforeseen disruptions. To build and enhance the supply chain resilience, practitioners need to understand the concept of resilience (Kochan, Nowicki, Randall, & Sauser, 2013). Since one of the goals of supply chain resilience is to create competitive advantage (Sheffi, 2005), costs of disruptions over time also need to be considered when making decisions.

We developed a time-dependent, system-based supply chain resiliency definition and created a supporting mathematical model. We introduced two stochastic order optimization problems that capture the notion of supply chain resiliency and created a novel, heuristic solution. As a consequence of this work, decision-makers (e.g., designers, logisticians, program managers, supply chain analysts) are now able to quantify resiliency by understanding the vulnerability of each location within a sustainment network and the financial impact of fully restoring this network when subjected to disturbances. The ability to measure resiliency, understand vulnerability, and quantify financial impact leads to making more informed design, operational, and sustainment decisions.

Project Accomplishments

Publications

Journals

1. Randall, W. S. (2013, October). Are the performance-based logistics prophets using science or alchemy to create life cycle affordability? Using theory to predict the efficacy of performance based logistics. *Defense Acquisition Review Journal*, *20*(3), 325–348.

2. Randall, W. S., Nowicki, D. R., Deshpande, G., & Lusch, R. F. (2013). Converting knowledge into value: Gaining insights from service dominant logic and neuroeconomics. *International Journal of Physical Distribution & Logistics Management*, *44*(9).

3. Randall, W. S., Wittman, C. M., Nowicki, D. R., & Pohlen, T. L. (2013). Service-dominant logic and supply chain management: Are we there yet? *International Journal of Physical Distribution & Logistics Management*, *44*(2).

4. Nowicki, D. R., Sauser, B., & Randall, W. S. (2013). *Service dominant logic and performance based logistics: A systems thinking perspective* (Working paper, Unversity of North Texas).

5. Nowicki, D. R., Hernandez, I., Ramirez-Marquez, J. E., Randall, W. S., Sauser, B., & Kochan, C. (2013). *Supply chain resilience: Economic considerations and metrics* (Working paper, University of North Texas).

6. Randall, W. S., Nowicki, D. R., Hawkins, T. G., Haynie, J. J., Armenakis, A. A., & Geary, S. R. (2012). Performance-based logistics and inter-firm team processes: An empirical investigation. Manuscript submitted for publication.

7. Randall, W. S., Brady, S., & Nowicki, D. R. (2012). Business case analysis and the confounds of innovation driven by performance-based post-production support strategies. *Transportation Journal*, *51*(1), 33–58.

8. Nowicki, D. R., Randall, W. S., & Ramirez-Marquez, J. E. (2012). Improving the computational efficiency of metric-based spares algorithms. *European Journal of Operational Research*, *219*(2), 324–334.

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1. Nowicki, D., Murynets, I., Ramirez-Marquez, J. E., & Randall, W. S. (2011). *Optimal cost avoidance investment and pricing strategies for performance based post-production service contracts.* In *Proceedings of the Eighth Annual Acquisition Research Symposium* (Vol. II, pp. 288–305). Retrieved from http://www.acquisitionresearch.net

Presentations

1. Nowicki, D. R., & Randall, W. S. (2013). *Affordability and performance based logistics.* Presentation at the Industrial and Systems Engineering Research Conference (ISERC), San Juan, Puerto Rico.

2. Nowicki, D. R., & Randall, W. S. (2011). *Service and product design.* Invited talk at the Wharton Service Supply Chain Thought Leadership Forum, Wharton West, San Francisco, CA.

3. Randall, W. S. (2011). *A framework for a PBL system of systems approach.* Presentation at the Military Logistics Summit, Institute for Defense and Government Advancement (IDGA), Washington, DC.

4. Nowicki, D. R., & Randall, W. S. (2010). *Role of performance based logistics (PBL) and readiness.* Invited talk at the Military Air Assets Exhibition and Conference (MAASEC), Jacksonville, FL.

5. Johnson, J., Nowicki, D. R., & Randall, W. S. (2010). *Focus on business case analysis (BCA) structure.* Panelist at the Next Generation of PBL—Performance Based Lifecycle Product Support, Arlington, VA.

6. Johnson, J., Nowicki, D. R., & Randall, W. S. (2010). *Review of the Product Support Assessment Team (PSAT) report.* Panelist at the Next Generation of PBL—Performance Based Lifecycle Product Support, Arlington, VA.

7. Nowicki, D. R., & Randall, W. S. (2010). *Performance based logistics/contracting: How to measure performance and profit.* Workshop conducted at the Military Air Assets Exhibition and Conference (MAASEC), Jacksonville, FL.

8. Randall, W. S., & Nowicki, D. R. (2011). *Performance based logistics/contracting: How to measure performance and profit.* Presentation at the Military Logistics Summit, Washington, DC.

9. Nowicki, D. R., & Randall, W. S. (2010). *Proactive supply chain management in a PBL environment: People, performance, profit and culture.* Presentation at the Military Air Assets Exhibition and Conference (MAASEC), Jacksonville, FL.

10. Randall, W. S., Geary, S. R., & Nowicki, D. R. (2010). *Profitability, competition, transaction costs, and PBL.* Presentation at the Defense Logistics 2010 Conference, Arlington, VA.

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Technical Reports

1. Nowicki, D. R., Ramirez-Marquez, J. E., & Randall, W. S. (2011). *Analytical examination of performance strategies* (Grant No. N00244-10-1-0074). Monterey, CA: Naval Postgraduate School, Acquisition Research Program.

2. Nowicki, D. R., Ramirez-Marquez, J. E., & Randall, W. S. (2012). *Mixed methodological approach to advance the analytical examination of performance based acquisition and sustainment strategies* (Grant No. N00244-11-1-0046). Monterey, CA: Naval Postgraduate School, Acquisition Research Program.

Doctoral Student Research Supported/Supervised

1. Murynets, I. (2010). *Optimal investment and marketing strategies for technologically innovative services* (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. 3428880)

2. Hernandez, I. *Emergency preparedness framework: A multi-objective approach* (Doctoral dissertation in progress). Stevens Institute of Technology, Hoboken, N.J.

Awards

1. Best Dissertation in the School of Systems and Enterprises awarded to Ilona Murynets for her doctoral dissertation, *Optimal Investment and Marketing Strategies for Technologically Innovative Services.*

2. Emerald Literati Awards for Excellence: "Explaining the Effectiveness of Performance-Based Logistics: A Quantitative Examination" published in *The International Journal of Logistics Management* was chosen as a Highly Commended Award Winner at the Literati Network Awards for Excellence 2012.

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