Explaining the effectiveness of performance-based logistics: a quantitative examination

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Abstract

Purpose – Performance-based logistics (PBL) strategies are providing governments and for-profit organizations with a contractual mechanism that reduces the life cycle costs of their systems. PBL accomplishes this by establishing contracts that focus on the delivery of performance not parts. 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. While work has been done to outline an overall PBL theoretical framework, the underlying theory explaining the enablers that lead to organizational and team-level, team-goal alignment associated with the PBL governance structure requires testing. The purpose of this paper is to quantitatively test previously posited relationships between enablers of PBL and PBL effectiveness. An additional objective is to explore any differences in PBL effectiveness between different business sectors.

Design/methodology/approach – A multiple regression model was developed, tested and validated to explain the effectiveness of PBL. The model was externally validated with exploratory cross-sectional survey data of 61 practitioners.

Findings – This study strongly supports recent PBL theory explaining PBL effectiveness. Key antecedents include investment climate, relational exchange, PBL leadership, and business sector. Further, government organizations lag behind their commercial counterparts in PBL effectiveness and PBL leadership.

Practical implications – PBL business arrangements are more effective in more favorable investment climates. Thus, leaders should welcome new ideas, empower employees, and encourage entrepreneurship. Since PBL effectiveness increases with relational exchange, building trust and communicating with suppliers is key. Leadership is also important to PBL effectiveness. Leaders should accept risk, focus on long-term affordability and performance, and align activities to achieve end-user goals.

Originality/value – This research is the first quantitative test of previously posited factors affecting PBL effectiveness. Additionally, this research unveils key differences in business sectors' use of PBL strategies.

Keywords Logistics management, Leadership, Performance-based logistics, Investment climate, Sustainment, Outcome-based contracting, Post-production support, Logistics, Supportability

Paper type Research paper

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1. Introduction

The post-production logistics and product support costs associated with sustaining large-scaled, complex systems such as aircraft fleets, rail, and power generation facilities quite often exceed two to three times the research, development, and production costs associated with these systems (Berkowitz *et al.*, 2003). Adding complexity to this costly reality is the fact that as systems age post-production logistics and support costs tend to increase (MaClean *et al.*, 2005). These costs represent a significant logistics-related segment of the economy. For instance, the US commercial airline industry spends in excess of $40 billion on maintenance, repair, and overhaul (MRO) annually (Flint, 2007). For many systems, such as rail, power generation, and aviation, the logistics, operations, and support costs during the post-production phase often reflect the majority of the system's total life cycle cost. Further, extending the life of such systems requires more funds for repair, upgrade, and replacement.

Increasing costs and narrowing profit margins have caused system operators and original equipment manufacturers (OEM) to seek strategies for post-production support that moves away from the traditional mentality of purchasing spares and repairs as a series of independent transactions (Sols *et al.*, 2007). Seeking improved business models, system operators are engaging in multi-year, performance based, contracting approaches with their post-production logistics and support service providers. Commonly called performance-based logistics (PBL), the objective of these strategies is to provide a contractual structure that encourages investments that controls cost, maintains profit margins, and decreases end-customer price (Randall *et al.*, 2010). For the OEMs and their partners, the goal is to meet customer requirements in a cost effective, yet profitable manner, while also opening up new markets (Hypko *et al.*, 2010).

PBL offers a means to achieve these critical outcomes. It does so by laying out a multi-year contractual framework, typically a firm-fixed price (FFP) contract, that rewards suppliers when they make smart investments in material, technology, and logistics processes which drive down life cycle cost (Kim *et al.*, 2010; Sols *et al.*, 2007). Key to the PBL strategy is an innovation and investment governance structure (Geary and Vitasek, 2008). However, the exact organizational enablers that influence a manager to accept the risk associated with the shift to an investment-based business model are not well understood (Geary *et al.*, 2010).

This research uncovers and investigates the key enablers of PBL. This is important as PBL is suggested to reduce cost and increase performance of large-scale, complex systems, during their post-production logistics and support phase (Fowler, 2008). PBL accomplishes this by providing contractual incentives for suppliers to infuse new materials, technologies, and logistics processes that reduce life cycle cost (Randall *et al.*, 2010). Yet, it is unclear which factors system operators need to focus on in order to maximize PBL effectiveness. The purpose of this study is to develop a set of hypotheses, derived from an emerged theory of PBL enablers, and to empirically test these hypotheses. Following that we explore whether the for-profit and not-for-profit sectors share the same capabilities to implement and manage a PBL strategy.

This paper is organized in the following manner. First, we provide an overview of PBL literature and develop a conceptual model with hypothesis. We then test three antecedents in a multiple regression model to explain PBL effectiveness. Lastly, the study offers a summary discussion, including conclusions and implications.

2. Literature review and conceptual model development and hypothesis

To identify the most relevant organizational predictors of PBL effectiveness, we first examine the existing background on PBL. Next the underlying economics of PBL are explained. The fundamental business model of PBL involves investing in innovations that decrease system life cycle cost while maintaining a required performance level (e.g. system up time, or percentage of assets ready to perform a mission). In this framework, the knowledge, skills and abilities of the supplier network partners are incontrovertibly linked to the underlying economics of PBL. Since knowledge, skills and abilities play a prominent role in determining the economics of the PBL contract and the achievement of a performance outcome in PBL, we review service-dominant logic (SDL), an emerging knowledge-based exchange framework, for insights into the theoretical underpinning of the PBL phenomenon.

2.1 Background on PBL

PBL is receiving increased attention in supply chain research (Kim *et al.*, 2010, 2007; Ng *et al.*, 2009; Nowicki *et al.*, 2008; Randall *et al.*, 2010; Sols *et al.*, 2007). Quite often the logistics ecosystem associated with PBL is a three-tier system comprised of suppliers, system integrators, and customers. We will refer to this three-tier system with its resources, technologies, policies, procedures, and flows as the PBL ecosystem. PBL is a post-production service strategy that is highly dependent on the supply chain supporting its logistics ecosystem. Complex systems being supported through a PBL strategy rely on activities and decisions that span across a broad array of functional areas including research and development, engineering, operations, maintenance, support, logistics, purchasing, and supply chain. An example in the defense industry is the Joint Strike Fighter (JSF) with Pratt & Whitney (supplier) supplying the engines to Lockheed Martin (system integrator and OEM) who will then integrate all of the components to provide mission capable JSFs for the US Department of Defense and its allied partners (F-35 Program Office, 2011). There are similar relationships in the commercial industry, such as the high-speed rail industry where the operator, the end customer and the OEM are different agencies (Siemens, 2011). Other examples can be found in the transportation sector (Transportation Research Board, 2009) and health services sector (Administration for Children & Families, 2011; The World Bank, 2008).

PBL strategies have been credited with reducing the life cycle costs and improving system performance when compared to the more traditional, transactional approach to post-production logistics and support. Programs that have adopted PBL have experienced system up time increases of 40 percent, logistics response times cut by 70 percent, all while generating billions of dollars in savings over traditional approaches (Fowler, 2009, 2008). For instance, the US Navy saved $688M on the F/A-18 program using PBL, and the UK Defense Ministry saved $250M converting its CH-47 post-production logistics and support contract to PBL (Fowler, 2008). There are similar PBL success stories dealing with projects in the for-profit sector. For instance, one recent study of a major Dutch housing project showed that life cycle cost was reduced by 20 percent using a PBL approach (Straub, 2009).

In order to compare and contrast PBL with traditional approaches to logistics and post-production support we provide a series of systemigrams. Systemigrams provide researchers an ability to convey in a conceptual manner the inter-relationships of a complex system (Boardman and Sauser, 2008). Figure 1 shows a systemigram

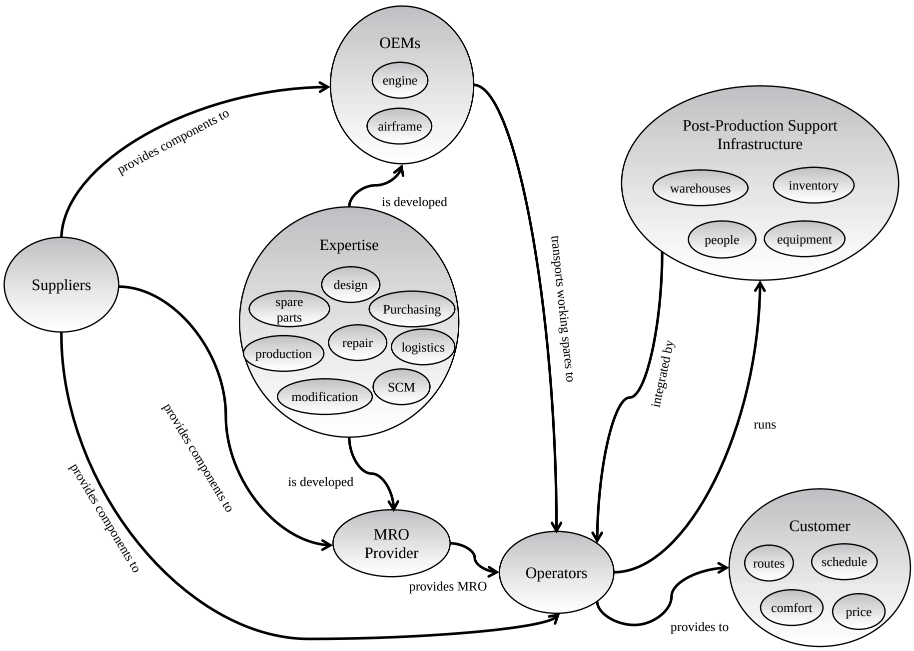

Figure 1.
A traditional post-production logistics and support systemigram representation

of traditional post-production logistics and support. In the traditional post-production logistics and support the major business entities are: suppliers, OEMs, MRO providers, system operators, and customers. Here we use the airline and rail industry as an example of the traditional post-production support structure. The overarching concern of the system operator (e.g. airline or rail company) is to meet customer requirements while profitably operating the system. For the airline and rail industry this means profitably operating routes and schedules at a particular price and comfort level (Flint, 2007; Siemens, 2011).

As shown in the Figure 1, the system operator's primary core competency revolves around determining profitable routes and schedules and operating a system that meets these schedules requirements while dealing with disruptions (e.g. weather, change in customer desire) as they occur (Randall *et al.*, 2010; Siemens, 2011). Within a traditional post-production logistics and support system, the operators (e.g. the airline or the rail company) manage a network of warehouses, inventory, equipment, and people that keep the system in service or return the system to service when it breaks (Hypko *et al.*, 2010; Kim *et al.*, 2010). Considering the complexity of determining routes and price, it can be argued that running, maintaining, and integrating the post-production logistics and support infrastructure is a secondary competency of the rail and airline operator. This model has little benefit for the end customer and the system operator who are saddled with such issues as corrosion, diminishing manufacturing sources (e.g. parts that are no longer being produced), and fatigue (MaClean *et al.*, 2005). As issues emerge, the system operators typically do not have the expertise, time, or funding needed to control and reduce the life cycle costs of the system (Cited from *Air Force-Magazine* Online, March 19, AirForce Magizine.com, 2010). Further, the operator, who is not the OEM, typically has little in-house capability to improve the reliability and design of the fielded system. Unfortunately the organization most capable of reducing life cycle cost, the OEM, typically moves on to the next research design and production effort leaving post-production support in the hands of a hodgepodge of suppliers and operators (Randall, 2009).

This structure establishes competing objectives (e.g. OEM/supplier desire to sell more spares and repairs) with little incentive to invest in life cycle cost reduction beyond production (Geary and Vitasek, 2008). Without innovation and involvement from the OEM and suppliers the efficiency of the post-production support infrastructure; characterized here as the operator's ability to integrate its warehouse, inventory, transportation, procurement, and labor functions, is limited (Randall *et al.*, 2010). As shown in Figure 1, a great deal of the expertise needed to run the post-production infrastructure actually resides with the OEMs and MRO providers. Further, the operator seldom has the technical capability to control, much less reduce, cost as systems age and fatigue, manufacturing sources diminish, and corrosion takes a toll (MaClean *et al.*, 2005).

As shown in Figure 2, PBL corrects incentive misalignment in the post-production logistics and support network, and transfers roles and responsibilities to entities most capable of performing these tasks efficiently and effectively (Randall *et al.*, 2010). As a result, PBL manifests itself as a solution that effectively leverages the existing expertise that resides with the OEMs, suppliers, and MRO providers. PBL drives a governance structure that codifies the role of a systems integrator as the entity that establishes and performs critical supply chain integration functions across the life cycle of the system (Randall *et al.*, 2010). Since the system integrator is now responsible for integrating and orchestrating the post-production logistics and support infrastructure

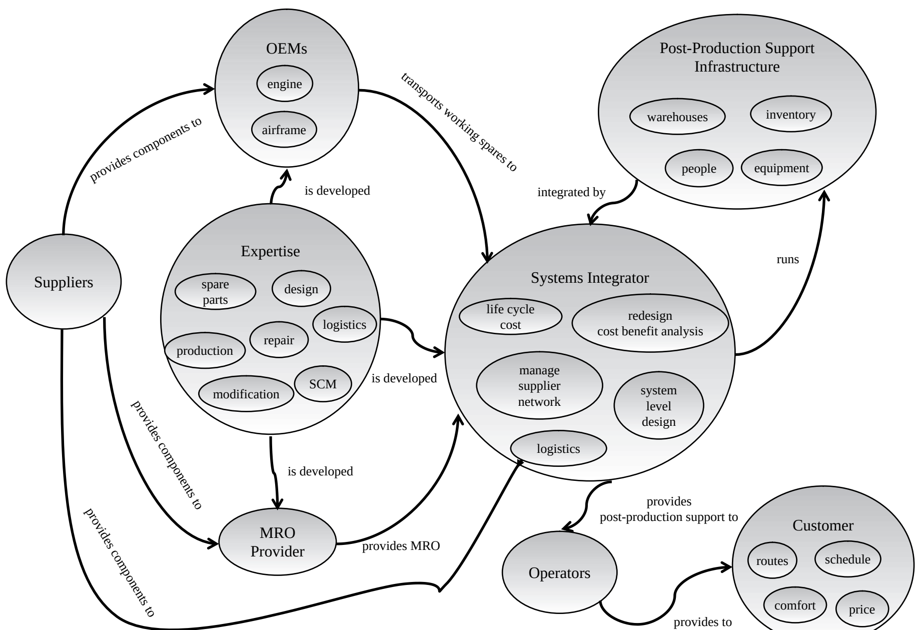

Figure 2.
A PBL post-production logistics and support systemigram representation

(e.g. warehouses, inventory, and transportation), the operators are now free to focus on their expertise – the actual operations of the system (e.g. route scheduling and pricing).

PBL integration is therefore particularly effective when the integrator (e.g. the OEM) keeps elements of the research, design, and production supplier network in place to manage and logistically support the system during post-production (Randall *et al.*, 2010). This means that the integrator and suppliers are now capable of balancing and optimizing the cost of inventory, transportation, warehousing, and on-equipment maintenance and MRO against the potential to reduce those costs through redesign. This makes sense for a number of reasons. The OEM and the suppliers are in the best position to make initial forecasts of the reliability and subsequent demand for parts, and then to update those forecast models as the system evolves during use (Kim *et al.*, 2010; Randall *et al.*, 2010). Further, the OEM and suppliers are typically most capable of affordably redesigning components to drive out costs or bad actors (Randall, 2009). As new technology, materials, and logistics processes become mature, these same suppliers are most capable of improving the design of both consumables and repairables to infuse those improvements into the system as the system fails – thus reducing future logistics costs.

There are two keys differences between a PBL contract and traditional post-production support. The first involves contracting for performance, or an outcome, rather than repeatedly contracting for discrete products and services (Geary and Vitasek, 2008). Under a PBL arrangement the buyer contracts for system performance, typically characterized as system "up time" as opposed to contracting for spare parts and repair services. System "up time" is defined as the amount of time the system is ready to perform (e.g. aircraft fleets) or does perform (e.g. power generation networks) divided by the amount of time possible for that system to be "up." The supplier is then free to ensure this contractual "up time" is achieved as efficiently and effectively as possible (Geary and Vitasek, 2008). The second key to PBL involves its reliance on a multi-year relationship. The multi-year relationship gives the supplier network time to determine whether certain reliability issues might be better served through redesign as opposed to continued procurement of support resources and services such as spares and repairs (Randall *et al.*, 2010). These contract dynamics of PBL result in a structure where the integration, accountability, and risk for achieving performance objectives is left with those organizations who have the greatest set of relevant knowledge, skills, and abilities (Randall *et al.*, 2010).

2.2 The economics of PBL: investment driven by cost avoidance

The multi-year contract of the PBL strategy provides the supplier network the incentive to trade the cost of a system redesign against the future cost of spares, repairs, MRO, transportation, and warehousing associated with future failures (Kim *et al.*, 2007, 2010). In this way, PBL provides managers insight into the tradeoff between classic logistics functions (procurement, inventory, warehouse, and transportation) and improved system design (Randall *et al.*, 2010). Ultimately, PBL provides a strategy where the goal is to "design out" logistical demand by reducing the frequency (i.e. improving the reliability) for the need for spares, transportation, and warehousing.

PBL changes the basic business model of post-production support. Both PBL and non-PBL managers focus on gaining efficiency and effectiveness with regard to inventory management, repair, and overhaul. Yet for the PBL manager, the money spent purchasing spares, repairs, and overhaul is continuously calculated against an investment in new materials, processes, and technology that will improve reliability and correspondingly drive out demand for that particular spare part (and its warehouse, inventory, and transportation cost), along with repair or overhaul tasks (Kim *et al.*, 2010, 2007; Randall *et al.*, 2010). The PBL contract uses 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. Figure 3 shows this pictorially. This figure, or some variation of it, has been shown in nearly all PBL research, seminars, education and training, and conferences[1].

In a traditional post-production support business model, the customer pays a transactional fee for each task required to keep the system in service (e.g. spare parts, overhaul, and repair). This transactional business model has no avenue for investments focused on reducing cost. As systems age, the repairable parts wear out, fatigue accumulates, sources of supply diminish, performance degrades, and the cost of post-production support increases (MaClean *et al.*, 2005). In Figure 3, this is shown as the cost increases over time by the lines labeled traditional industry price and traditional industry cost. 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 post-production 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 continuous transactional spending of traditional post-production support (e.g. MRO) into large pools of cost avoidance (Randall *et al.*, 2010). This potential pool of cost avoidance represents the area under the traditional price (for post-production support services). The PBL strategy encourages suppliers to make initial investments (as shown at the left side of Figure 3) that reduce total life cycle costs (as shown at the right side of Figure 3).

Typically, PBL uses some type of multi-year, FFP contract to create an incentive structure that encourages supplier investment in innovation (Garnder, 2008). Under a FFP contract, the supplier assumes the risk of performance since it agrees

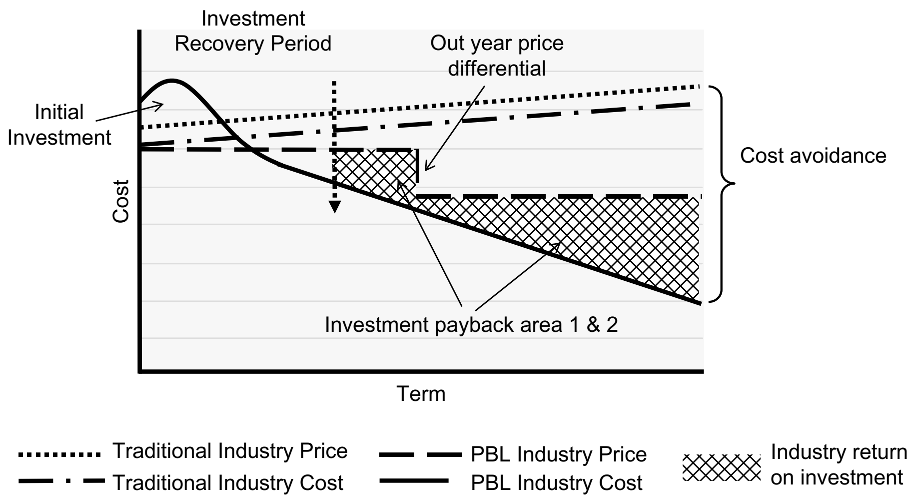

Figure 3.
The economics of PBL

to perform the work for a fixed price. If the work costs more than expected, these additional costs to achieve the contractually agreed upon performance reduce the supplier's expected profit. The incentive works in the opposite direction too; if the supplier can perform below its estimated costs, costs avoided become additional profit. Such a contract structure is critical to create the incentive that encourages the supplier network to invest in some type of innovation that can avoid costs in the future, as shown in Figure 3. For example, one of the managers we interviewed mentioned that prior to initiating a particular PBL contract the customer was faced with a high repair cost due to aircraft engine component that required frequent inspection and overhaul. When the customer and OEM switched to a PBL contract, the OEM redesigned the component to increase the time between inspections and removal. The OEM recouped its investment (i.e. the redesign) within a few years. After the initial investment was recouped, the subsequent savings amounted to a return on the investment. After a contractually agreed to period of time, those savings were passed on to the customer as part of a new, lower PBL price. Under the previous non-PBL relationship, the customer did not have the expertise to perform the redesign, nor did the customer typically have the financial resources in the current or following-year budget to afford the redesign. The OEM had both the expertise and, using a return-on-investment model as justification, corporate funding. Additionally, the OEM is oftentimes able to gain expertise and funding for redesigns from its supplier network.

In order for PBL to be effective, the buyer must foster a climate that encourages and supports investments. For the purpose of this research, we define investment climate as the inclination of the organization to invest in reliability or process improvements. We define PBL effectiveness as the improvement of outcomes through the use of investment and the application of knowledge-based resources. Improvements in performance outcomes are largely influenced by the use of investments and the application of knowledge-based resources. PBL essentially acts on a return-on-investment model that drives innovations to achieve long-term performance and affordability goals for the customer, while improving overall PBL ecosystem profitability. As such, it is posited that:

H1. There is a positive relationship between investment climate and PBL effectiveness.

PBL theory based on SDL. Randall *et al.* (2010) firmly grounded PBL theory in SDL (Vargo and Lusch, 2004). SDL suggests that competitive advantage for the supplier network resides in the supplier network's ability to use their knowledge, skills, and abilities to create value, by meeting service requirements, and this value is likely to evolve over time (Vargo and Lusch, 2004). By focusing on value, as oppose to production, both PBL and SDL draws attention to how supplier networks use knowledge, skills, and abilities to satisfy customer requirements as oppose to focusing on simply providing products which customers, in turn, integrate with other products to satisfy their needs (Randall *et al.*, 2010; Vargo and Lusch, 2004). Using a SDL framework, value is based upon how well the supplier is able to satisfy a customer service requirement while ensuring reasonable long-term profitability for the supplier network. For example, a system operator may take a short-term approach by continuing to order spare parts and repair services, yet what that operator may ultimately need is the long-term vision to redesign the system that maintains operational capability for the lowest total cost of ownership. It is the suppliers, who have detailed system knowledge and knowledge of new material, processes, and technology that have the ability to provide the system operator an available system for less total costs. With the proper contract structure, suppliers are likely to act when redesign is more affordable than continually purchasing spare parts, repairs, and overhauls in a transactional manner. Absent a PBL-SDL framework, the supplier is likely to continue to act in a transactional manner. With an SDL mindset, that is a propensity to act in an entrepreneurial manner, the supplier may seek innovations that better deliver to the customer's ultimate need – better system availability at a lower total cost.

A strength of SDL is that it considers value from both the perspective of the end customer and from the supplier network, thus making SDL a robust supply chain framework (Lambert and García-Dastugue, 2006). Using this framework, Randall *et al.* (2010) found that practitioners essentially operationalized the outcome of SDL by assigning some measure of performance (e.g. system up time) as the desired customer value proposition. This SDL-PBL theory structure provides a contractual ability to measure and reward value for all members of the supplier network. Consistent with successful applications of PBL, value for the supplier network is defined as the ability of the supplier network to gain knowledge of the customer performance requirements, and the supplier network's ability to provide for current requirements while positioning themselves to meet future performance requirements in a manner that is profitable for the supplier network (Randall *et al.*, 2010).

By providing measures of value for all network participants, the SDL-PBL model clearly focuses on collaboration and clear definitions of co-creation (Jaworski and Kohli, 2006). This co-creation between the operator, end customer, integrator, and suppliers brings significant knowledge resources. Those resources are likely to predict the competitive position of the particular supplier network (Randall *et al.*, 2010). These knowledge resources, customer and supplier knowledge, skill, and ability are likely to change over time. Supply chain management, based in an SDL framework and supported by performance-based supplier network theory, then provides an effective mechanism to show how certain PBL ecosystems, their suppliers, customers, and integrator, can efficiently adapt to environmental changes, and thus predict competitive advantage of that network. The key to that competitive advantage is the flow of knowledge-based resources between the supplier network partners as focused on satisfying a customer service requirement.

In SDL, the primary flow is applied knowledge rather than goods (Lusch *et al.*, 2010). The service-based view of SDL facilitates measurement of applied knowledge as it meets service requirements. Since the customer is a co-creator of value, SDL advocates dialogue with the customer about the application of knowledge (Jaworski and Kohli, 2006). SDL is also relational – meaning elements such as co-dependence, mutual trust, commitment, and shared values are important (Vargo and Lusch, 2004). Recent a theory of PBL enablers suggests that cooperative interdependency is a key enabler of objective performance (Geary *et al.*, 2010). We define relational exchange as the inclination to engage in collaboration and trust with a focus on the end customer. Since PBL is grounded in SDL, and since PBL requires long-term relations, it is posited that:

H2. Relational exchange positively influences PBL effectiveness.

Strategies requiring the alignment of substantial resources (human, financial, and material) need solid leadership in order to secure the resources and align them toward a common vision (Eisenbeiss *et al.*, 2008). PBL is no exception. With PBL, mustering and aligning such resources across firms compounds the problem. Theory of PBL enablers highlights the importance of leadership in creating a climate conducive for innovation (Geary *et al.*, 2010). Along these lines, Randall *et al.* (2010) specifically identified firm and network leadership as a key antecedent of a PBL process and outcome. Leaders in PBL promote creative ideas by challenging assumptions, approaching old situations in new ways, and allowing risk taking. These are essential ingredients for PBL. We define PBL leadership as the ability to create a performance-based focus, align activities, and develop an entrepreneurial (risk accepting) culture. Therefore, it is posited that:

H3. PBL leadership positively influences PBL effectiveness.

Business sector. PBL strategies have been highly successful in the not-for-profit (e.g. government) and the for-profit business sectors. In some complex cases, these sectors are combined, where responsibility for the primary systems integrator is shared (Geary *et al.*, 2010). Whether the PBL strategy includes strictly not-for profit or for-profit entities or both, we should expect differing capabilities in PBL implementation and management based upon the business sector due to differences in organizational systems and accountability (Morash *et al.*, 1996; Prahalad and Hamel, 1990).

More specifically, we would expect that managers in the not-for-profit sector would have a different implementation result in comparison to those in the for-profit sector. Government procurement is less concerned with efficient outcomes (Husted and Reinecke, 2009; Muller, 1991; Solomon, 1986), and is subject to substantially greater transparency, fairness, and public scrutiny (Harland *et al.*, 2000; Kolchin, 1990; Sheth *et al.*, 1983). Government procurement is highly regulated via federal contracting statutes and regulations (Harland *et al.*, 2000; Kolchin, 1990; Lian and Laing, 2004; Rainey and Backoff, 1976; Sheth *et al.*, 1983; Williams and Bakhshi, 1988) that discourage either close or long-term relationships with suppliers (Hawkins *et al.*, 2011). But, the expected long-term duration of the relationship between a buyer and supplier decreases opportunism (Gundlach *et al.*, 1995; Johnson *et al.*, 2003; Joshi and Randall, 2001; Jap and Anderson, 2003). As such, the numerous regulatory boundaries encircling government procurement encourage discrete transactions versus relational exchange (Dwyer *et al.*, 1987; Harland *et al.*, 2000; Lian and Laing, 2004). Furthermore, government procurement's rigidity devalues, and in many cases explicitly prohibits, the principle tenets of buyer-supplier relations such as durability, consistency, expansion, trust, and commitment (Dwyer *et al.*, 1987; Morgan and Hunt, 1994), resulting in degraded supplier relations (Guinipero, 1984). Since these relational norms are:

- structurally suppressed in government not-for-profit procurement;
- prevalent among for-profit commercial business relationships; and
- necessary for effective PBL, and since these norms reduce opportunism, it is not unreasonable to posit that:

H4. Business sector affects PBL effectiveness.

The fundamental premise of Randall *et al.*'s (2010) theory of PBL is that PBL motivates investments, and that investments ultimately result in improvements in efficiency and effectiveness. These improvements are enabled by organizational factors such as collaboration, leadership, information systems, and by environmental factors

(Randall *et al.*, 2010). In order to reap greater effectiveness using a PBL strategy, organizations must demonstrate higher levels of the enablers. While logical, these propositions have not been quantitatively tested. Therefore, we propose to test, in an exploratory fashion, whether there is an overall perception of improved performance for PBL versus traditional post-production support, and whether the key enablers of PBL are more prevalent in PBL where PBL support strategies are employed:

H5. Measures of PBL effectiveness and enablers of PBL will be greater for PBL than for traditional post-production support.

3. Methodology

This study employed a mixed method design (Creswell, 2003) of qualitative and quantitative analysis. The qualitative work involved discussions with academicians and practitioners to ensure the proposed model achieved face validity and used valid measures of constructs. Further, this research benefited from close relationship with, and access to the data involved in the studies by Randall *et al.* (2010) and Geary *et al.* (2010). Following the development of the constructs, the research involved a regression model (Figure 4) using cross-sectional survey data in order to test the hypotheses. The remainder of this section details the qualitative design, survey development, the sample, data collection, and reliability and validity.

This approach, using a mixed method design, is typical for emerging areas of research and for areas involving new, substantive theory or frameworks. Our approach is similar to other multi-manuscript research projects such as market orientation (Jaworski and Kohli, 1993; Kohli and Jaworski, 1990; Kohli *et al.*, 1993) and service quality (Parasuraman *et al.*, 1994, 1985, 1988) that involved identifying new frameworks, constructs, and relationships using a grounded, qualitative methodology, and then building on that research to test those relationships in subsequent, quantitative investigation.

3.1 Qualitative design

The Randall *et al.* (2010) and Geary *et al.* (2010) research provided a detailed overview of the process involved in generating the constructs adapted in this research. This investigation, therefore, has as its foundation 60 interviews and multiple panels

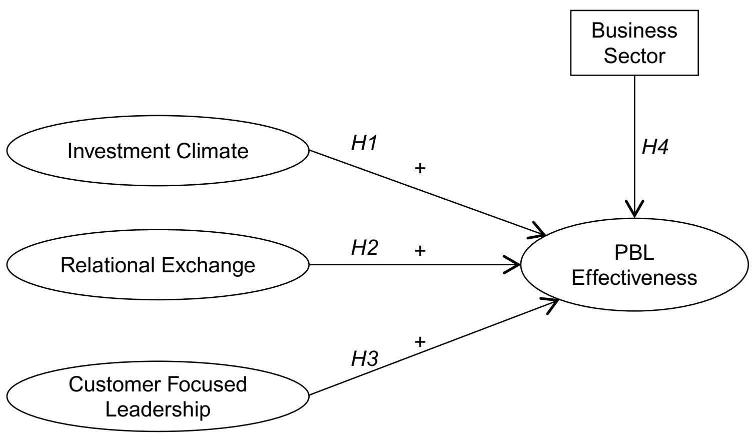

Figure 4.
Factors affecting PBL effectiveness

and conferences with practitioners. Table I provides an overview of the participants involved in the qualitative aspect of this study. This sample builds on the one of Randall *et al.* (2010) by incorporating those interviews from Geary *et al.* (2010).

As shown in Table I, participants were drawn from a number of defense programs. Interviews were conducted with end customers, bill paying customers[2], OEMs, and suppliers. The participants came from a wide variety of corporate functions (e.g. finance, engineering, and logistics). Methodologically, this investigation followed the process similar to Randall *et al.* (2010). That approach gave us the foundation for the constructs to be investigated and for the development of the initial survey. As such, the qualitative portion of this mixed method design was used to establish the hypothesized antecedents.

3.2 Operational measures

This study involves two largely empirically untested concepts, PBL and SDL. Because of this, there are no scales that are readily available or adaptable to this survey investigation. Therefore, the first step associated with the operational measures required us to adapt the findings from the qualitative portion of the investigation and to create initial survey items.

One of the key strengths of the qualitative investigations in general and grounded theory investigations in particular, are that the constructs that emerge in such investigations are captured using the voice of the practitioner. This allows the researcher to simply search back through transcripts to find paragraphs, sentences, and phrases that represent the emerged constructs using the language of the practitioner. This provides the researcher the ability to develop survey items using the words of the practitioner. These words are likely to be more readily recognized and understood by the practitioners – thus improving validity.

Survey items were created and assessed on a five-point Likert-type scale. After the initial items were developed, a group of industry and academic experts reviewed the items for clarity and validity consistent with Dillman (2000). Next, an initial pre-test of the survey was conducted on line. This pretest further refined the individual items, addressed any issues with ambiguity, and tested the flow of the survey itself. Similar to Jaworski and Kohli (1993), specific managers involved in the qualitative research portion of the study, and from varying functions, were asked to complete the pretest. Based on feedback from the pre-test, some items were modified and others were deleted to arrive at the final scale.

Primary functional expertise	Logistics	Business strategy	Maintenance	Program management contracting	Engineer	Depot
Overall (%)	35	12	5	20	8	20
Break out by supply chain position						
Customer	53%	Supplier	47%			
Years experience	1-5	6-9	10-14	15-20	20 +	
	9%	5%	12%	39%	33%	

Note: Interviews transcribed (four people interviewed twice, 58 transcribed, 20 not transcribed)

Table I. Participant background for the qualitative step

3.3 Sample and data collection
An online survey was used to collect the data. In order to maximize the response rate, we used Dillman's (2000) *Tailored Design Method* for internet surveys. The survey deployment involved an initial e-mail to approximately 350 managers concerned with PBL strategies. The sample was drawn from an e-mail list used in association with the annual Performance Based Logistics Conference in Crystal City, Virginia. A total of 94 responses were received. However, many were deleted due to missing data. The effective sample size became 61 resulting in a response rate of 17.4 percent. Table II shows respondent demographics.

4. Analysis and results
The following section reports on the analysis and results. The section begins with a review of the reliability and validity of the survey instrument. Next hypotheses are tested and the general model is presented.

4.1 Reliability and validity
The survey was administered with 41 questions that compared PBL to traditional post-production support. Of the questions, 15 were statements to evaluate PBL metrics and the structure of a PBL contract. These questions were both of interest to the researchers in regards to exploring the PBL phenomena further, and were requested by defense industry experts involved in the study. These questions did not deal with the constructs involved in this research. This left 26 survey items targeted towards

	Frequency
Gender	
Male	53
Female	5
Not reported	3
Employer	
US Air Force	3
US Army	1
US Navy	2
US Marine Corps	2
Defense Logistics Agency	4
Non-military Government Civilian	9
Prime Contractor	28
Supplier	7
Other	5
Years of PBL experience	
0-2	17
3-5	15
6-10	14
11-15	12
16 +	2
Not reported	1
Business sector	
For-profit	39
Not-for-profit	24

Table II.
Sample profiles

this study. Table III provides an overview of all the survey items and provides a comparison of mean values based upon the applicability of each question to PBL and traditional post-production support.

Construct validity was assessed through exploratory factor analysis (EFA) using principal components with an equimax rotation. Eigenvalues greater than one was the criterion for determining the number of factors (Hair *et al.*, 2010). In order to ensure sufficient power to detect significant factor loadings given the sample size, items were considered to have loaded to a factor where factor correlations exceeded at least 0.65 on one factor (Hair *et al.*, 2010), and were less than 0.33 on any other factor. Through iterative scale purification (Churchill, 1979), 26 survey items reduced to 17 across the four latent factors. Nine items were removed due to excessive cross loadings. The remaining items loaded on four factors. As evidence of nomological validity, we examined the four factors' correspondence to the constructs identified by Randall *et al.*'s (2010) theory-building article on PBL. "PBL effectiveness" corresponded to Randall *et al.*'s (2010) "continuous value creation" and "effect." "Relational exchange" corresponded to Randall *et al.*'s (2010) "integration" and "co-management." "Investment climate" corresponded to "influence a performance oriented mindset," and "PBL leadership" corresponded to "promote PBL competencies." In each case, the directions of relationships corresponded to the predicted directions posited by Randall *et al.*'s (2010) theory. The reliability of latent constructs was assessed using Cronbach's α. These measures, ranging from 0.64 to 0.94, proved to be sufficiently reliable – exceeding the minimum acceptable threshold of 0.6 for exploratory research (Hair *et al.*, 2010). The final measurement scale used for the EFA is displayed in the Appendix. Table IV displays the factors, factor loadings, and cumulative variance explained.

Often survey data is susceptible to various biases. We tested for common method variance using Harman's one-factor test. Harman's one-factor test revealed that when all of the items were run in a single factor analysis, the unrotated solution did not result in a single factor, nor did it result in a general factor that accounted for most of the covariation (Podsakoff and Organ, 1986). We then tested for non-response bias using the procedure of Armstrong and Overton (1977). In order to preserve power – given the small sample size – while simultaneously distinguishing between early and late responders, we removed ten responses from the center of the data (by response date) and created groups of early and late responses. We tested for differences in-group means across the five variables in the model and across ten additional variables not included in the model but shown in Table III. Continuous measures were tested using ANOVA, and group counts (e.g. sector) were tested using a χ^2 test. Of the 15 tests, one difference was detected in PBL leadership. However, across many tests, some differences will occur by chance. Thus, we concluded that non-response bias did not distort the results.

4.2 Hypothesis testing

The hypotheses were tested using linear multiple regression. Consistent with Hair *et al.* (2010) the scale items were summed on each construct and introduced into the regression analysis. The pertinent assumptions of regression (i.e. normality, heteroscedasticity, and independence of error terms) were first tested as follows. Since the sample size was small, we applied the Shapiro-Wilks test of normality. Only relational exchange was normally distributed; thus, the remaining metric constructs were transformed

Item[a]	PBL	Traditional post-production support
Leadership welcomes new ideas	3.44	3.25
People are empowered to make decisions*	3.48	2.98
People act entrepreneurial*	3.74	2.64
Affordability is improved*	3.83	2.49
System performance is improved*	4.21	2.70
Suppliers are more customer focused*	4.07	2.79
It is hard to change things	3.67	3.87
Industry focuses on creating end customer value*	4.02	2.82
Opportunities pass us by	3.56	3.64
It is easy to get a good idea implemented*	2.93	2.41
Supply chain collaboration is strong*	3.95	2.49
People find creative solutions*	4.10	3.03
Vendors understand war fighter needs*	3.65	3.02
There is a quick response to changes in warfighter requirements*	3.66	2.51
Leadership has a long-term focus on affordability and performance*	3.80	2.62
Leaders align activities to achieve warfighter goals*	3.90	2.95
Leadership accepts risk taking*	3.43	2.62
The sustainment strategy creates alignment between individual tasks and overall sustainment objectives*	4.03	2.81
Support providers make too much profit	2.56	2.80
Best value decisions means taking a life cycle cost perspective*	4.20	3.16
The project team has a shared vision of its purpose*	4.16	3.16
There are clear sustainment objectives*	4.16	3.10
There is a team approach that encourages active participation*	4.33	3.10
Team approach fosters innovation*	4.28	3.11
There is significant innovation*	3.93	2.61
The contract metrics make sense*	3.75	3.00
Cost is avoided*	3.72	2.38
Opportunities for return on investment are good*	4.08	2.83
Metrics create desired performance*	4.20	2.78
Cost avoidance decisions are rewarded*	3.73	2.67
Industry and government trust*	3.51	2.53
People know how their work impacts the end customer*	4.05	3.25
Communication between industry and government is effective*	3.81	2.89
Vendors drive innovations that save money*	3.82	2.52
Depots have long-term viability*	3.82	3.39
Incentivizes investment in reliability*	4.09	2.30
This strategy is likely to find money to avoid costs*	3.79	2.42
We need more expertise to help improve the results of this strategy*	4.39	3.30
Uses knowledge and skill to improve performance and affordability*	4.10	3.07
There is transparency with respect to "true cost" to sustain*	3.34	2.64
Knowledge is only valuable when it is shared by supply chain partners*	3.87	3.64
Investment in reliability improvement requires multi-year contracts*	4.28	3.31

Notes: *Statistically significant at: $p < 0.05$; [a]scale 1 – strongly disagree; 5 – strongly agree

Table III.
Mean score comparison, PBL versus traditional support across all survey items

Factor	1	2	3	4
1. Investment climate				
IC1	0.907			
IC2	0.854			
IC3	0.737			
2. Relational exchange				
RE1		0.736		
RE2		0.691		
RE3		0.795		
3. PBL leadership				
L1			0.736	
L2			0.806	
L3			0.736	
4. PBL effectiveness				
PBL1				0.803
PBL2				0.734
PBL3				0.769
PBL4				0.754
PBL5				0.705
PBL6				0.717
PBL7				0.799
PBL8				0.761
Percentage of variance explained	28.45	44.31	58.42	70.60
Factor mean	3.55	3.79	3.71	3.96
Factor SD	1.01	0.63	0.81	0.71
Cronbach's α	0.86	0.64	0.74	0.94

Table IV.
Exploratory factor analysis

(PBL effectiveness – cubed; PBL leadership – squared; investment climate – squared). Only investment climate did not achieve a non-significant Shapiro-Wilks statistic ($p < 0.02$). Next, we tested the constructs for homoscedasticity using the Levene's test (1.59; $p < 0.25$). Results indicated satisfaction of the assumption of constant error variance. Finally, we examined the Durbin-Watson statistic (2.24) to ensure that error terms were independent. Since it was within the range of 1.5-2.5, we concluded that the error terms were independent. Although the independent variables were significantly correlated, all of the variance inflation factors were less than 1.7 indicating that multicollinearity did not pose a problem. Table V displays parameter estimates, significance levels, and the explanatory power of the model. The model is given as:

$$Y^3 = \mathrm{b}_0 + \mathrm{b}_1\mathrm{X}_1^2 + \mathrm{b}_2\mathrm{X}_2 + \mathrm{b}_3\mathrm{X}_3^2 + \mathrm{b}_4\mathrm{X}_4 + \varepsilon_i,$$

where:

Y = PBL effectiveness (PBL).

X_1 = investment climate (IC).

X_2 = relational exchange (RE).

X_3 = PBL leadership (L).

X_4 = business sector.

DV: PBL effectiveness	Standardized coefficient	t	$p > \|t\|$	Sig.
Intercept	−8,939	−0.74	0.46	
Explanatory variables				
Investment climate	0.21	2.04	0.046	**
Relational exchange	0.35	3.51	0.001	*
PBL leadership	0.22	1.89	0.064	***
Business sector	−0.28	−2.73	0.009	*
Adjusted R^2	0.53			
Prob. > F	17.86		0.000	*

Note: Significance level at: * < 0.01, ** < 0.05, *** < 0.10

Table V.
Regression results

Variable X_4 was a dummy variable with the for-profit firms serving as the reference group (coded 0). With a negative coefficient, the not-for-profit group shows lower PBL effectiveness (summated scale mean 31.90) than does the for-profit group (mean 37.96). As an additional test of *H4*, differences in the three key enablers of PBL were tested using ANOVA. Only PBL leadership differed ($F = 17.64$; $p < 0.001$) with the for-profit sector exhibiting significantly greater PBL leadership (mean 12.02) than the not-for-profit sector (mean 9.63). As seen in Table V, all four predictors show significant path estimates, with relational exchange having the greatest effect on PBL effectiveness. Additionally, a respectable amount of variance in PBL effectiveness (53 percent) was explained by the four independent variables. Given these results, the 4 main hypotheses were supported. Correlations among the constructs are shown in Table VI. Turning back to Table III, we note that only four out of the 42 items do not indicate a statistically significant difference. In nearly all items, the means of PBL exceed those of traditional post-production support. Thus, support is found for *H5*.

5. Discussion

The traditional approach to post-production support drives inherent inefficiencies and tension between buyers and suppliers by tying the supplier's profit to the amount of post-production support services they sell. The more parts break, the more service the suppliers are able to sell. This return on sales model demonstrates the negativity associated with a transactional arrangement where the majority of the risk is absorbed by the customer (Sols *et al.*, 2007). The customer ends up bearing the financial burden associated with the uncertainties in reliability, fatigue, corrosion, diminishing manufacturing sources, stock outs, along with warehouse and inventory costs necessary to protect against these uncertainties. For the supplier, the business relationship is satisfactory – but not

	Investment climate	Relational exchange	PBL leadership	PBL effectiveness
Investment climate	*0.86*			
Relational exchange	0.34*	*0.64*		
PBL leadership	0.44*	0.31**	*0.74*	
PBL effectiveness	0.46*	0.44*	0.55*	*0.94*

Notes: Significant at: *$p < 0.01$, **$p < 0.05$; values on the diagonal (italic) represent the construct's reliability

Table VI.
Correlation matrix

outstanding – as the amount of profit available is typically limited to 8-12 percent of sales under a typical sustainment cost-plus contract (Krieg, 2006). While the suppliers have limited risk of loss, they also have a low probability of generating significant profit.

PBL drives behaviors that reduce costs for the operator while providing increased profit potential for the supplier networks. That profit potential is based upon a return-on-investment business model that creates a win-win strategy. In stagnate markets where opportunities for revenue expansion are limited; a PBL profit model provides very real options. For instance, a PBL-driven post-production support cost reduction of $10 million translates directly into profit. For a company with a 10 percent profit margin, $10 million in post-production support cost avoidance would require $100 million in new sales to create an equivalent profit (Randall and Farris, 2009). PBL gives executives, systems engineers, and supply chain managers charged with operating low-profit, high-cost systems a viable approach to battle decreasing revenue and reductions in market share. At the same time, the customer wins through improved affordability and performance, along with the opportunity to harvest cost savings under follow-on contract awards.

Further, PBL is an inherently resource conscious strategy whose underlying economic model is good for the physical environment. The economic model at the core of PBL creates an incentive for manufacturers and suppliers to innovate and reduce total system and life cycle costs. This means that decisions are made to invest in some type of improvement that leads to an out-year cost savings (typically through improved reliability). Those out-year cost savings represent significantly less resource consumption. Systems that do not break use fewer resources and create less waste.

These substantial performance outcomes are only possible by first understanding the organizational enablers that facilitate PBL strategies. Relying on previous theory-building work (Randall *et al.*, 2010) and firmly grounding this investigation in SDL (Vargo and Lusch, 2004), this research finds quantitative support for several of its postulates. Specifically, PBL strategies, and their ensuing performance improvement and cost savings, become more effective where there is a stronger, supportive climate for investment. This means that leadership must welcome new ideas, empower their employees, and cultivate a climate where personnel behave entrepreneurially. To build such a climate, supply chain executives could incorporate innovation as an employee performance evaluation criterion for logistics managers. They could also institute a suggestion program where employees are paid a cash award for adopted innovations. Additionally, supply chain leaders must educate their employees and suppliers on PBL contracts, to include FFP pricing, defining the scope of work, and defining key performance metrics. Suppliers who receive PBL contracts should apportion funds for redesigns and innovations, resembling internal venture capital funds established for new product development.

PBL strategies become more effective with stronger relational exchange. Key to fostering effective PBL relationships is trust, communication, and the knowledge of how decisions at various levels of the supply chain affect end customer value. As fewer PBL suppliers replace the many transactional providers of spare parts and repair services, the strategic importance of the PBL supplier should increase. This could necessitate that relationships between executives at each firm be established, and that supply managers be educated on the value of sustaining relational (versus arms-length) exchange.

This research also shows the importance of leadership. PBL effectiveness increases as leaders increasingly accept risks, focus on long-term affordability and performance, and align activities to achieve end-user goals. The need for leadership underscores the importance that supply chain leaders be represented in the firm's executive board room in order to show how PBL can contribute to the firm's strategic goals, and to garner the resources and support necessary to implement PBL arrangements. The need for leadership also suggests that firms hire and retain knowledgeable supply chain leaders who can recognize opportunities, influence system design, motivate suppliers and employees, and design supporting processes. A key supporting process is spend analysis, used to identify the spare parts and repair services that are procured, the number of contracts used, and the number of different suppliers. Supply chain leaders will also need to examine internal maintenance statistics. Armed with this information, supply managers can conduct market research to find leading PBL suppliers, start a dialogue with them, and identify the optimal systems or sub-systems for PBL support strategies. Once determined, supply managers can begin a comprehensive source selection to find the optimal PBL partners.

This research unveils a significant difference in the PBL effectiveness and in one of its enablers, PBL leadership, between for-profit and not-for-profit entities with for-profits having a stronger competence. Thus, systems integrators seeking to win performance-based, post-production business from for-profit clients (e.g. airlines and railroad shippers) should expect greater improved performance outcomes from their PBL efforts. Conversely these integrators should expect less PBL leadership and lower outcomes from not-for-profit clients. Additionally, not-for-profit system operators and bill payers are cautioned when adopting commercial benchmarks of PBL success, while maintaining counter-PBL behavior (e.g. lack of trust, lack of relationship, lack of investment). In fact, the same results may not be realistic.

Another contribution of this study is the development of valid scales to measure PBL effectiveness, investment climate, and PBL leadership. Supply chain scholars can use these scales to conduct further research of PBL strategies. Tools such as this enable further theory testing in a field that appears on the threshold of significant developments and achieving the status of a distinct discipline.

There is a growing body of research applying SDL to supply chain management (Lusch, 2011; Randall *et al.*, 2010). This research adds to that body. Measuring the dependent variable of a service-based outcome presents a challenge. Knowledge-based value propositions are dynamic, intangible, and evolutionary. This dynamism makes their capture difficult. PBL as a theory begins to bridge this gap by articulating a group of metrics that represent customer value. Further, the PBL-SDL framework addresses measurement of value for each of the supplier network members. This has been an elusive task. In this study, we capture network value using the PBL effectiveness construct. In the Randall *et al.* (2010) investigation, they articulated a dependent variable measure of SDL effectiveness as continuous value creation. These two studies, taken together, demonstrate how supplier network value is created by allowing feedback in the form of financial incentive, knowledge of the customer, and strengthening of competitive position through creation of a service-based network competency.

The testing of *H5* appears to support suggestions that SDL in practice – in this case represented by PBL – drives higher performance on a wide range of variables (e.g. leadership effectiveness, relational exchange, innovation) associated with superior competitive position. This is an important finding, one that bolsters the positioning of SDL as an inductively emerged framework representative of what is occurring in market exchange.

The relationship between PBL as a supply chain theory and SDL has important implications for the logistics domain. Addressing deficiencies in supply chain theory is a pressing issue which has implication for SCM as it reaches the status of a distinct discipline (Harland *et al.*, 2000). SCM continues to suffer from a lack of theory-based studies (Defee *et al.*, 2010). PBL theory grounded in SDL provides a key theory to assist in SCM's evolution as a discipline. PBL represents a governance structure that drives responsibility for supply chain transactions to those entities most capable of completing those transactions at the least cost, and lowest risk.

5.1 Limitations and future research

This study is not without limitations. First, the research design relied upon self-reported data from respondents that may introduce common method bias. Second, whereas the model explains 53 percent of the variance in PBL effectiveness, we wonder whether PBL effectiveness, while a distinct construct in the minds of the practitioners, may in fact be multi-dimensional yet highly correlated. There appears to be reason to consider whether PBL effectiveness is in fact an amalgamation of PBL-driven innovation and alignment. Follow-on research should address this possibility. Third, survey responses were drawn from a convenience sample rather than a random sample, and the sample size of 61 is relatively small when making statistical inferences from the data. This could have impacted the normality of investment climate. Fourth, the survey narrowly targeted defense industry applications of PBL. Despite its limitations, the findings are important and, as such, demonstrate the promise of this line of inquiry – which should be expounded. Indeed, the JSF program will use PBL entirely for post-production support. With its $1 trillion life cycle cost, it is the largest government program ever (Government Accountability Office, 2008). Fifth, future research should test other determinants of PBL effectiveness such as team innovation, metric appropriateness, and team learning (Geary *et al.*, 2010). Further, contingency theory could be applied to show contextual differences in PBL effectiveness (Bowersox, 1990; Fawcett *et al.*, 2008; Moorman and Slotegraaf, 1999). Differences could be explored where:

- operators and systems integrators use firm-fixed price versus cost reimbursement contracts; and
- whether PBL effectiveness differs by industry.

Finally, future research should expand the generalizability of findings by expanding the population beyond defense systems.

Notes

1. The first use of this chart known to the authors was by PRTM to the Department of Defense (2005). Versions have also been presented by Randall (WBR PB Log Conference in 2008, 2009 and 2010) based upon dissertation research. University of Tennessee Center of Executive Education has also presented versions of this chart.
2. Complex systems usually involve a bill-paying customer who is often responsible for the initial system creation and operation. This bill-paying customer is many times not the ultimate end-user (or end customer) of the system.

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Appendix

Label	Dimension/items
Investment climate	
IC1	Leadership welcomes new ideas
IC2	People are empowered to make decisions
IC3	People act entrepreneurial
Relational exchange	
RE1	Industry and government trust
RE2	People know how their work impacts the end customer
RE3	Communication between industry and government is effective
PBL leadership	
L1	Leadership has a long-term focus on affordability and performance
L2	Leaders align activities to achieve warfighter goals
L3	Leadership accepts risk taking
PBL effectiveness	
PBL1	System performance is improved
PBL2	The project team has a shared vision of its purpose
PBL3	There are clear sustainment objectives
PBL4	There is significant innovation
PBL5	Cost is avoided
PBL6	Incentivizes investment in reliability
PBL7	This strategy is likely to find money to avoid costs
PBL8	Uses knowledge and skill to improve performance and affordability

Note: Scale items assessed in the context of PBL

Table AI.
Final measurement scale

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