A MIXED METHODOLOGY APPROACH TO EXTEND UNDERSTANDING OF THE SUCCESS FACTORS OF PERFORMANCE-BASED CONTRACTING

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Performance-based contracting (PBC) is an outcome-based product support strategy that provides efficient performance solutions for buyers. Suppliers under performance-based contracting are rewarded after achieving desired performance objectives. While current scholarship has deepened our knowledge of the benefits of PBC, the particular factors behind effective and efficient performance-based contracts (PBCs) are still vague. Thus, this dissertation will focus on essential dimensions for the successful PBC. There remains a great deal that is not understood about the success factors for effective PBCs. When looking at the critical criteria for the selection of suppliers in the context of PBC, even less is known. This dissertation contains three essays with the purpose of: (1) investigating the effect of supply chain collaboration and upfront investments on the benefits of the PBC; (2) exploring supplier selection criteria for successful PBC; and (3) examining the effect of contract length and fleet size on upfront investments for effective and efficient PBC. These three essays offer a solid foundation for theoretical and practitioner understanding for effective PBCs.

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INTRODUCTION

Given changing customer expectations, there is growing demand for an outcome, instead of a product, in any industry. Performance-based contracting (PBC) is an outcome-based product support strategy that provides affordable performance solutions for buyers. It differs from the transaction-based approach in that suppliers, under performance-based contracting, are rewarded when they achieve desired performance objectives. Thus, it is significant to show the key factors on which suppliers must concentrate to attain desired outcomes in performance-based contracts (PBCs). While current scholarship has deepened our knowledge of the benefits of PBC to create a win-win situation between supplier and customers, there is a great deal that remains to be learned. While many more studies are needed to extend its theoretical framework, empirical research is required to understand the success factors behind successful PBCs. As such, logistics scholars and practitioners alike must examine the main dimensions behind effective and efficient performance-based contracts. There is a need to know how collaboration within the supplier, in conjunction with upfront investments, affects the benefits of PBCs. Also, considering the selection of suppliers in performance-based arrangements, even less is known about critical criteria for selecting the best supplier in this context. Furthermore, practitioners need to better understand contract features of PBCs, such as contract length and fleet size, to determine significant factors for the decision of upfront investments in the context of PBCs. Given this need, the purpose of these three essays is to examine the effect of supply chain collaboration and investments on the benefits of PBCs, to highlight significant supplier selection criteria for effective PBCs, and to analyze the impact of contract length and fleet size on the decision of suppliers for effective and efficient PBCs.

Essay 1, “The Effects of Supply Chain Collaboration in Performance-Based Contracts,” investigates the effects of collaboration within the supplier to understand the value offerings created in performance-based contracts. Although implementations of PBC in different industries continue to increase, it is not clear what the primary value drivers of PBC are. Many studies show that SCC seems to create a significant advantage. There has been no investigation, however, that recognizes its value in performance-based contracts. There is also a lack of empirical evidence showing the main factors behind effective PBCs. Thus, this essay examines how supply chain collaboration (SCC), in conjunction with investments, contributes to the benefits of PBCs. Additionally, the impacts of SCC and investments, which provide future cost avoidance for suppliers, on the benefit of PBCs were not investigated based on the empirical study. Essay 1, which sheds light on the effects of SCC and investments on PBC benefits, reveals the characteristics of investments in PBC and contributes to the body of knowledge by providing empirical findings and theoretical insights in a PBC context.

Essay 2, “The Selection of the Supplier in Performance-Based Contracts,” builds upon findings in the PBC literature in Essay 1 to explore key criteria for supplier selection in PBCs. While a buyer transfers risk to the supplier for the achievement of outcomes, and the supplier gets the freedom to act and assumes greater responsibility in PBC, this characteristic of a PBC environment creates a relationship in which buyers are dependent on the supplier. (Sols & Johannesen 2013). Selecting the best providers is becoming more significant for buyers in performance-based arrangements. Taking into account this dependency on suppliers in PBC, and buyers’ inability to observe suppliers’ actions in PBC, buyers must mitigate risk by avoiding the selection of the wrong supplier in PBCs (Gardner, 2008). The risks associated with the supplier mean that selecting the right supplier for desired targets becomes a key criterion for effective and efficient PBCs (Sols & Johannesen 2013, Ziegenbein & Nienhaus, 2004). This essay explores supplier selection criteria for buyers in PBCs to highlight a convenient decision tool for buyers to select the best supplier in PBCs. In contrast to supplier selection criteria for transaction-based contracts, this study reveals the importance of selection criteria in PBCs by using grounded theory exploration technique.

Essay 3, titled “Understanding the Impacts of Contract Length and Fleet Size in Performance-Based Contracts,” centers on the dimensions of “Investment” and “PBC Benefits” from Essay 1. This essay investigates the impacts of contract features such as contract length and fleet size on reliability investment, inventory, supplier’s profit, and annual unit cost of the system for a buyer in a mathematical model. This study’s results advance understanding of the impact of fleet size and the length of contracts on decisions made by suppliers for the reliability and inventory investments in PBCs and extend the use of a revenue model in PBC. Additionally, practitioners will benefit from the results to build effective and efficient PBCs.

Taken together, the three essays offer a solid foundation for theoretical and practitioner understanding of effective and efficient PBCs, contributing to the literature with empirical findings and theoretical insights in a PBC context. Essay 1 explores the impacts of supply chain collaboration and investments on PBC benefits by using the empirical results in the proposed model. The next essay explores crucial criteria for selecting suppliers to achieve desired performance outcomes in PBC, drawing on grounded theory exploration technique. Finally, Essay 3 examines how contract features, the length of contract, and fleet size, affect suppliers’ decisions and costs.

ESSAY 1

THE EFFECTS OF SUPPLY CHAIN COLLABORATION IN PERFORMANCE-BASED CONTRACTS

Introduction

Currently, there is growing interest to get performance or outcome for high life cycle cost products, rather than to attain them. We see this transformation of demand in various industries and services, from hospitals to the defense industry, as well as in building and road construction. When the readiness of products or systems is more critical to the buyer, focusing on outcomes amounts to a far more effective and efficient solution. Because of its success in providing an amount of performance rate in a much more effective and efficient way, PBCs are becoming a more desired option for buyers in various industries.

Sustaining complex systems is more expensive than attaining them, due to high life-cycle costs, such as an operational and maintenance costs. Considering the processes in the supply chain, e.g., inventory management, maintenance, and repair services, the cost of sustaining this type of product at the determined level entails expensive and time-consuming efforts for buyers. For instance, at the Department of Defense (DoD), 72% of total funds in the life cycle costs of weapon platforms are used for sustaining systems (Berkowitz, Gupta, Simpson, & McWilliams, 2005). Low availability rates of systems under traditional-based contracts have also intensified the shift from attaining a product to getting an outcome. Alongside these disadvantages, by attaining products, buyers lack the power to motivate suppliers to increase the quality of products. But because suppliers' revenue grows with demand in spare parts and services, suppliers are not eager to make upfront investments to increase system quality and reliability. This is particularly the case in manufacturing industries where a few suppliers are dominant, e.g., the defense industry, where alternatives for suppliers are limited to changing the direction of this relationship. Because of these advantages, buyers are more eager to attain performance rather than burden all the risks and costs to sustain these high life cycle cost systems.

In the past decade, this type of performance-based or outcome-based contracts can be seen from manufacturing to service industries including private and public sectors (Hypko, Tilebein, & Gleich 2010a; Selviaridisa & Wynstrab, 2015). Performance-based contracts have also called for outcome-based contracts in the service industry (Ng & Nudurupati, 2010). In the private sector, early examples of this type of agreement were evident in Roll Royce's "power by the hour" model, in which the supplier's payment depended on engine flight hours (Ng & Nudurupati, 2010). On the other hand, in the public sector in 2001, performance-based logistics (PBL) contracts became a preferable logistics support approach for the Department of Defense (DoD) to maximize system readiness and reduce post-production service costs (Berkowitz, Gupta, Simpson, & McWilliams, 2005; Boudreau & Naegle, 2003; Devries, 2005).

The shift toward a focus on performance characterizes the defense industry. In the late 1990s, DoD devised an outcome-based contract strategy based on paying for the contractor's performance (Geary & Vitasek, 2005). Because of a lack of new systems, many weapon systems, whose projected life has ended, remain in service in DoD's extensive inventory (Kratz & Buckingham, 2010). Since 1970, C-5 Galaxy, for example, has been in use in U.S. Air Force inventory (Griffin, 2005). Thus, the longevity of systems brings about high life cycle costs in DoD, due to extended maintenance, hardware extinction, and structural tiredness (Berkowitz, Gupta, Simpson, & McWilliams, 2005; Devries, 2005; Kobren, 2009; Kratz & Buckingham, 2010). The cycle of traditional-based contracts results in huge expenses, amounting to 72% of life cycle cost for sustaining the systems (Berkowitz, Gupta, Simpson, & McWilliams, 2005). Additionally, since the intended life of most war systems has ended, keeping them operational requires more maintenance, which results in the reduction of systems readiness. The additional high financing requirements of maintaining the sustainability of these systems results in a budgetary decline in research and in the development of replacement systems. These legacy systems remain in service, requiring greater maintenance and operational costs (Agripino et al., 2002). Since more than 70% of DoD's multi-billion-dollar budget is dedicated to logistics services for the sustainment of weapon systems, minimizing the life cycle cost of systems has become a fundamental objective of product support strategy there (Kobren, 2009; Kratz & Buckingham, 2010; Sols, Nowicki, & Verma, 2007). Alongside these high operation and maintenance costs, continued budgetary pressure forced DoD to find new approaches to decreasing life-cycle costs while maintaining the readiness of systems (Kobren, 2009; Kratz & Buckingham, 2010).

In traditional-based contracts (TBC), maintenance, labor, and material costs are the main components of high expenses. In TBC, because of high profit in after-sales support, contractors whose business model depends on post-production support are not concerned with the life cycle cost of products (Hunter; 2006b; Gansler & Lucyshyn, 2006). For instance, for DoD, TBC is becoming more inefficient for government-owned depots, considering the 31% increase in maintenance costs over a one-year period (Randal, Pohlen, & Hanna, 2010; GAO, 2005). Parallel to this increase in maintenance costs, the decrease in the availability of systems forced buyers to change their existing transaction-oriented approaches. Given the opportunistic behavior of the supplier, TBC could not align the buyer's requirements with the supplier's preferences (Keating & Huff, 2005). Furthermore, this approach places the burden of risk entirely on buyers (Quick, 2011). As a result, to overcome these problems, high product support costs, and insufficient mission readiness of systems, DoD transformed its logistics support strategy from a traditional-based contract to a performance-based contract (Geary & Vitasek, 2005).

The fundamental structure of performance-based contracting (PBC) is built on the evaluation of outcomes (Ng, Maull, & Yip, 2009). PBC offers an approach for merging a payment system with the buyer's desired objectives. Unlike TBC, in PBC, suppliers are rewarded when they reach the desired objectives (Berkowitz, Gupta, Simpson, & McWilliams, 2005; Geary & Vitasek, 2005, Ng & Yip, 2010). PBC manages to improve the system, subsystem, or component readiness, and reduce the costs of after sales supports (Berkowitz, Gupta, Simpson, & McWilliams, 2005; DoD, 2014).The 2010 investigation of the Assistant Secretary of Defense, which looked at the impact of a performance-based approach on life-cycle costs of systems, showed that average annual cost-saving with PBCs is approximately 5-20% (DoD, 2014).

The performance-based contracting approach marks a paradigm shift in logistics support strategy. It not only affects payment methods to the supplier but also changes the whole process in the supply chain. In the PBC, the buyer outsources the objectives to the main contractor to provide desired outcomes. Because of the contract's incentive structure, risks are transferred from the buyer to the supplier (Gansler & Lucyshyn, 2006; Vitasek et al., 2007). Responsibility and the freedom to act are also transferred from the buyer to the supplier (Sols & Johannesen 2013; Caldwell & Howard 2014).

The success of suppliers in PBC depends on their ability to provide innovative solutions that require investment and collaboration in the entire supply chain. Taking into account the incentive structure of PBC, which depends on rewards and penalties, is not only significant for achieving desired performance, but is also essential to attaining these objectives more efficiently to increase revenue. Thus, the need to find cost avoidance solutions for future costs requires collaborative efforts in the entire supply chain. Supply chain collaboration (SCC) represents cooperation of at least two firms in order to create efficient and productive operations and to obtain mutual advantages over what can be done working alone. (Simatupang & Sridharan, 2002; Simatupang & Sridharan, 2005). Collaborative efforts of firms, such as sharing information and resources, is significant for sustaining efficient and flexible supply chains in a dynamic environment (Cao & Zhang, 2011). Coordinating the flow of resources between suppliers is also critical to obtaining a competitive advantage and to enhancing productivity by getting complementary resources (Kalwani & Narayandas, 1995; Mentzer et al., 2000; Park et al., 2004).

Although the implementations of PBC in various industries continue to increase, the primary value drivers of PBC remain unclear. While many studies demonstrate that supply chain collaboration offers a significant advantage (Min et al., 2005), there is no investigation that recognizes its value in performance-based contracts. This paper investigates the impact of supply chain collaboration in performance-based agreements, in conjunction with investments, to show how this close cooperation between autonomous partners creates mutual benefits for whole partners. To understand the benefits of PBC for supplier and buyer, it is essential to know how PBC motivates the supplier to collaborate and leverage their resources and information to attain mutually beneficial results. Furthermore, although many studies emphasize the need for cost avoidance actions in PBC (Cohen, M. A., & Netessine, S., 2007; Devries, 2005; Gansler 2006; Randal et al. 2012, 2014), researchers have not presented the fundamental features of these solutions.

Thus, the objective of this study is to investigate how supply chain collaboration and investments contribute to PBC. It also unveils the characteristics of upfront investments in PBC, which provide future cost avoidance and expand the existing research by providing theoretical insights and empirical findings for PBC. The research questions in this study are: What are the effects of supply chain collaboration and investment on the benefits of performance-based contracts? What is the mediation effect of investment between SCC and PBC benefits?

Addressing the lack of theoretical studies in PBC research, which depends on practical implementation prospects (Selviaridis & Wynstra, 2015; Essig, Selviaridis, & Roehrich, 2016), this study contributes to an understanding of the benefits of supply chain collaboration in PBC. Furthermore, it defines and conceptualizes cost avoidance investments in PBC. It generates valid and reliable instruments to measure investment factors and PBC benefits, while investigating these constructs in the form of second-order construct. The findings support future research on PBC. Furthermore, predictive validity is examined by testing the impact of SCC on the benefits of PBC and mediation effects of investment between SCC and PBC benefits.

The critical dimensions of the supplier relationship in PBC have been analyzed and tested based on principal-agent theory, resource dependency theory, and transaction cost economics. Using web surveys by suppliers across the US, through the Amazon Mechanical Turk (Mturk), this research also develops reliable and valid instruments for investment and benefits in PBC by forming a second order construct validation.

This paper proceeds as follows. After presenting related literature in [Literature review], theoretical paradigms of this study are explained in [Theoretical paradigms]. These are followed by conceptual development and the research hypothesis. Data analysis and results were done in [Data analysis] and [Results], respectively, before concluding with a general discussion in [General Discussion and Implications].

Literature Review

Performance-based contracting is a type of outcome-based contracting that consists of objectives explicitly selected by the buyer and metrics that measure the performance of the contractor. Based on the supplier's performance, rewards like performance bonuses and penalties, such aslower revenue or termination of the contract, are the primary incentives of this kind of contracting. In PBC, all supply chain activities must be designed to reduce the cost of ownership for sustaining systems (Gansler & Lucyshyn, 2006; Vitasek et al., 2007; Buchanan and Klinger, 2007). Straub (2009) showed how performance-based contracts lead to cost savings for suppliers, which results in high revenue, and thatperformance-based maintenance contracts decrease costs compared to traditional-based approaches that rely on transactions. Specifically, in a study by Vitasek et al. (2006), PBC was determined to be a requirement rather than an option for systems that require high life cycle cost. The authors proved the effectiveness of this concept using the result of a two- case defense industry study: F117 Propulsion System and Shadow. They found that PBC reduces risk and costs across the supply chain by aligning goals with performance measures. In addition to these studies, Boyce and Banghart (2012) examined the effectiveness of the PBC based on 21 performance-based arrangements. They found that performance-based arrangements had successfully incentivized suppliers and reduced performance costs while increasing system readiness and availability. On the other hand, Sols et al. (2007) proposed that shifting from an existing traditional-based approach to a performance-based approach requires weighing the remaining life of systems. They advise this transition when there is enough service life left for the systems to operate. Alongside this proposition, long-term contracts are considered necessary for the supplier to spread the costs of upfront investments such as reliability enhancement (Straub 2009, Randall et al., 2012). Straub (2009) stressed the importance of long-term contracts and the early involvement of suppliers in PBC to compensate suppliers' investments in product quality and repair processes. In particular, Randall et al. (2012) differentiated the motivations of suppliers for investments in long-term and short-term contracts. They found that while suppliers are eager for more innovative processes that translate knowledge into quality investment solutions in long-term arrangements in PBC, in the short term, they are more keen to enhance existing processes, such as inventory management, transportation, and repair services. In both cases, investments for cost avoidance solutions in PBC dictate collaboration of suppliers.

Supplier integration in supply chain management, strategic partnerships, and incentivizing outcomes are critical enablers of performance-based arrangements according to a study by Berkowitz at al. (2005). Besides the integration of suppliers, Stauss et al. (2010) considered PBC as an exceptional win-win-situation model for buyers and suppliers. In a study that investigated the implementation of PBCs as a business model, Vitasek and Geary (2007) extended this integration in the supply chain, adding more specific propositions. Based on their study, the scope of planning efforts should be extended in the supply chain, and goals should be aligned with understandable and measurable performance metrics. Additionally, suppliers' core competencies should be carefully considered, and other service providers' capabilities should be improved to increase benefits. As seen here, the success of performance-based arrangements calls for considering improvements in the whole supply chain. The importance of supplier integration in PBC leads scholars to look more deeply at the relationship between providers in the supply chain. Ng and Nudurupati (2010) found that aligning expectations, teamwork, information, and materials sharing are primary factors that mitigate challenges in PBC.

Randall, Pohlen, and Hanna (2010) proposed a theoretical framework for PBCs based on grounded theory, using the basics of serviced dominant logic (SDL). As in SDL, they found that knowledge, inter-firm supply chain relationships, and customers are a critical source of value offerings, that knowledge competency can be increased by collaboration in the supply chain, and that financial performance can be increased by collaborative knowledge-based value creation. They emphasized the importance of collaboration dynamics and organizational leadership in the supply chain that affect the decision process in the supply chain for value creation in PBC. In addition to these factors, Randall et al. (2011) proposed investment climate in the supply chain, relational exchange, and leadership as critical antecedents on which system operators must focus for the successful PBC in for-profit and not-for-profit sectors. Additionally, Ng et al. (2009) identified performance and outcome-based contracts as an application of SDL. Ng et al. (2009) uncovered outcome-based agreements as a driver for SDL, especially for complex service systems. They showed that performance-based contracting is the right approach for organizations that want to shift from Goods-Dominant logic to Service-Dominant logic, and they also emphasized the parties' collaborative efforts in efficient value creation in PBC. Another qualitative study by Randall et al. (2014) emphasized that SDL is particularly consistent with performance-based arrangements. This perspective is corroborated by the analysis of Hypo et al. (2010), which clarifies the concept of PBC in manufacturing industries. They found that not only manufacturers, but also other service providers can offer PBC that includes value offerings for customer-like maintenance activities. Randall et al. (2012) proposed that successful implementation of outcome-based contracts requires knowledge of the whole supply chain, from providers to customers in PBC, which is seen as a supply chain context of SDL (Randall et al., 2014). This knowledge also includes technical expertise concerning the entire system, while a new knowledge source leads to innovation in the whole chain.

In the study by Randall et al. (2015) where the authors investigated inter-firm team-level factors associated with innovation in successful PBC, they found that interdependent goals align with inter-firm relationships to create innovative investment solutions. Innovative solutions lead the supplier to make strategy decisions that achieve desired outcomes, such as making an upfront investment to increase reliability, holding spare parts to improve readiness, and increasing service capacity to reduce the mean time to repair. Determining the spare parts inventory level, which includes attaining and maintaining costs for suppliers, closely related to the feasibility of reliability improvement of products. In PBC, growth in spare parts inventory levels has a slight impact on the availability of high-reliablity systems (Jin et al. 2012; Mirzahosseinian & Piplani, 2011). Doerr et al. (2010) investigated these decision alternatives for suppliers under the PBC to enhance benefits. They linked readiness risk to multiple interdependent determinants of readiness, such as time to failure, time to repair, transportation delays, and spare parts inventory. Mirzahosseinian & Piplani (2011) investigated how component reliability, maintenance facility, and inventory management affect the availability of systems under PBCs. They found that the base stock level of the spare parts had an insignificant impact on system availability. The negligible effect of increasing spare parts inventory was also shown by a study by Jin et al. (2012), which demonstrated that under a more extended service agreement in PBC, suppliers are eager to invest in reliability improvement (Randall et al., 2012). In his experimental study, based on real data from Rolls-Royce company, Guajardo et al. (2012) illustrated how product reliability is 25%–40% higher under PBC than under time and material-based strategy. The importance of upfront investment for reliability improvement, in order to make savings in acquiring and holding additional assets, was also proven by Kim et al. (2015), who investigated the interaction between investment in spare assets and product reliability under traditional resource-based contracts and performance-based contracts. In addition to these studies, Selçuk and Agrali (2013) found that service-level capacity is a significant factor that affects reliability improvement efforts under PBC. Because of the importance of service-level capacity, the authors suggested that process investment is a critical point for suppliers to efficiently achieve desired outcomes.

Based on studies to date, the supplier, in order to achieve desired outcomes by getting performance metrics, must enhance the quality of products and must invest in processes like repair and maintenance services, rather than increase spare stock. These two requirements improve product reliability and processes in the supply chain that they must undertake collaborative efforts to transfer their resources, knowledge, and skills to innovative solutions that increase benefits and the proposed value to the buyer (Randall et al., 2012, 2015).

Suppliers have different resources, including inventory management, quality management, production management, knowledge management, and supply chain management, that could potentially offer competitive advantages (ElMaraghy & Majety, 2008). PBC enables suppliers to direct these collaborative efforts within innovative administration and business actions to attain desired outcomes for the buyer while reducing the total life-cycle cost for sustaining a system (Gansler & Lucyshyn, 2006; Mahon, 2007). Because of the characteristics of the PBC, the supplier is motivated to find cost avoidance solutions in the future, requiringcollaborative efforts and innovative solutions to confront existing problems for the purposes of efficiently achieving their objectives. These include investments to increase reliability that reduces total service costs, spare parts acquisition, and holding costs (Cohen, M. A., & Netessine, S., 2007; Devries, 2005; Gansler 2006).

Although numerous studies in PBC research have examined the benefits of these contracts and trade-offs between actions (reliability improvement and spare parts increasing), scholars lack experimental findings that show how inter-firm relationships between suppliers lead to upfront investments and PBC benefits. Studies of the characteristics of collaboration efforts in PBC are inadequate. The impacts of collaboration on innovation and benefits in PBC should be analyzed and tested.

Based on this literature review, which covers the significant points of PBCs, Appendix A presents a visual systemigram (Boardman & Sauser 2008). The Systemigram, developed by Boardman and Sauser (2008), provides a powerful tool for analyzing systems in written form. Using the systemigram, we break down key points, presenting the flow of information and creating a compelling instrument to better understand the whole system. In Appendix A, only the final scene of the systemigram is presented.

Theoretical Background

In PBC, shifting risk from buyers to suppliers motivates performance providers to come up with innovative solutions that create cost avoidance solutions in future. These specialties and the suppliers' freedom to act creates a collaboration environment for maximizing profit that also satisfies buyers' needs that are specified in targeted performance measures. Because of these main features, this study examines the impact of supply chain collaboration and investment on PBC benefits from the perspectives of transaction cost economics, resource dependency theory, and principal-agent theory.

Transaction Cost Economics (TCE)

Williamson (1981) formalized TCE theory as an economic approach to studying the formation of organizations and their overarching governance structures. The governance structure, which refers to the organization of transactions, affects transaction costs. Based on the TCE perspective, a firm should search for opportunities to minimize the costs of transactions and must decide whether it should produce or obtain from outside (Williamson, 1981). So, TCE focuses on the firm's ‘‘make or buy’’ decision, or whether to produce the product within firm boundaries or buy it from other companies (Williamson, 1975). Additionally, transaction costs affect firm decisions about what should be produced and what kind of transactions should be managed in house.

Williamson (1975) identifies hierarchies and markets as two organizing methods. Understanding relationships between suppliers and the decisions of firms to use either market mechanisms or vertical integration/hierarchies can be explained by monitoring costs that arise under the assumptions of opportunism and bounded rationality (Williamson 1971, 1975). Williamson (1998) claimed that these two assumptions are the source of agreements between parties. Bounded rationality refers to firms' inability to manage too many transactions internally, due to limited time and managerial capacity. The other most significant assumption of TCE theory is opportunism, which is defined as “self-interest seeking with guile” by Williamson (1979). According to Williamson, because people intend to act on their interests rather than those of the other party in the contract, especially using imperfect information, all transactions are affected by opportunism.

The most critical dimensions of the transaction, as Williamson (1975) suggested, are the uncertainty of information and the environment, the frequency or amount of occurrence of related transactions in a specified period, and the amount of transaction specific asset (TSA) that is required. For TSA, Williamson described three significant types of asset specificity: location, physical asset, and human asset. The TSA has been a considerable concern in TCE, such as when investment cannot be quickly redeployed to other possible relationships, resulting in high risks (Williamson, 1975).

From the perspective of PBC, the performance-based approach also creates an environment to organize that helps avoid problems arising from both hierarchies and markets. With the alignment of goals in this outcome-based approach, suppliers can reduce the costs of monitoring and opportunism through collaboration and mutual trust. Also, incentive structure of PBC increases the probability that suppliers behave in the best interest of their partnership and increase collaborative efforts between suppliers. Furthermore, based on the TCE, supply chain collaboration can be classified in two directions: vertical collaboration between customers and suppliers, and horizontal collaboration between competitors and non-competitors (Barratt, 2004). On the other hand, rather than vertical integration or market exchange, collaboration between suppliers represents hybrid governance of TCE theory (Cao & Zhang, 2011).

Resource Dependency Theory

Resource dependency theory (RDT), which builds on power dependency theory and social exchange theory, sheds lights on inter-firm relationships in performance-based contracting. RDT focuses on inter-firm governance to merge special or unique resources that may be outside the realm of the organization (Heide, 1994; Fynes et al., 2004). Based on the RDT, firms can combine their resources with the complementary resources of other companies to achieve a sustainable competitive advantage and respond to environmental uncertainty (Salancik & Pfeffer, 1978). A performance-based approach that produces mutual benefits in buyer-supplier and within supplier relationships depends on cooperation and coordination among supply chain partners, which is consistent with RDT. As previously mentioned, in PBC, the buyer outsources the task of delivering the system’s performance to the contractor (Helander & Moller, 2008). The buyer incentivizes the supplier with rewards based on the achievement of performance outcomes. Using awards as form of non-coercive power to integrate the goals of the system and the buyer can be explained by power dependency theory (Emerson, 1962; Gaski, 1984).

Besides rewards, advantages of cost avoidance solutions in PBC structure incentivize upstream suppliers to integrate their resources. RDT enables cost avoidance solutions that incentivize suppliers in PBC to combine their physical and operant resources to produce innovative solutions. Operant resources, such as knowledge and skills, within the supply chain is essential to enhancing performance by influencing decision processes for upfront investments (Randall, Pohlen, and Hanna, 2010; Ng and Nudurupati, 2010). Thus, resource dependence can lead to cost avoidance solutions that increase the benefits for all partners. The structure of PBC thus increases dependency on suppliers. PBCs that produce mutual interests in buyer-supplier and within supplier relationships depend on cooperation and coordination among supply chain partners can be explained by resource dependency theory.

Principal-Agent Theory

In PBC, the buyer outsources the task of delivering the system's performance to the supplier (Helander & Moller, 2008). This relationship between the supplier (agent) and buyer (principal) creates the agency problem that emerges when the preferences and goals of the principal and agent conflict (Eisenhardt, 1989). The principal-agent theory centers on the relationship between the two parties under the contract that governs this interaction (Bergen, Dutta & Walker, 1992). The theory's primary aim is to design an efficient arrangement that can mitigate potential agency problems and maximize principal utility (Jensen & Meckling 1976). Considering the agent's utility maximization, however, the possibility exists that the agency will not behave in the principal's interest. The fundamental agency problems stem from asymmetric information between the principal and the agent, which causes a moral hazard, conflicting objectives, adverse selection, opportunistic behavior, differences in risk aversion, and outcome uncertainty (Eisenhardt, 1989; Firchau, 1987). These problems are classified as pre-contractual and post-contractual issues (Bergen, Dutta, and Walker, 1992). Pre-contractual problems are related to the "adverse selection" of the agent, due to "hidden information" in the terms of the contract offered to the agent. Post-contractual issues are related to problems that stem from "hidden action" and "moral hazard" in the term of contractual relationships (Bergen, Dutta & Walker, 1992). Thus, problems related to the post-contractual period within suppliers can be mitigated with the incentive structure of PBC, which leads to collaboration within suppliers to achieve desired objectives in the contract.

Conceptual Model and Hypothesis

Given the incentives in PBC, supply chain partners should work collaboratively as a single enterprise to maximize their utility, benefits, and revenue. By doing so, suppliers can be more creative to find the best optimal solutions to maximize their benefits by accessing and using one another's resources. Although they will behave opportunistically, acting in their best interest will also increase the benefits of buyers in PBC by aligning the goals of both sides with incentives. With this outcome-based approach, buyers have non-coercive power to affect the suppliers' decisions and force them to invest in the best efficient solution in the long term. The incentive structure of PBC brings together suppliers and creates effective and efficient solutions to achieve outcomes desired for their associated benefits. Such collaboration can lead to investment and enhance PBC benefits for the supplier and buyer. As shown in Figure 1.1, these direct effects are captured in a framework.

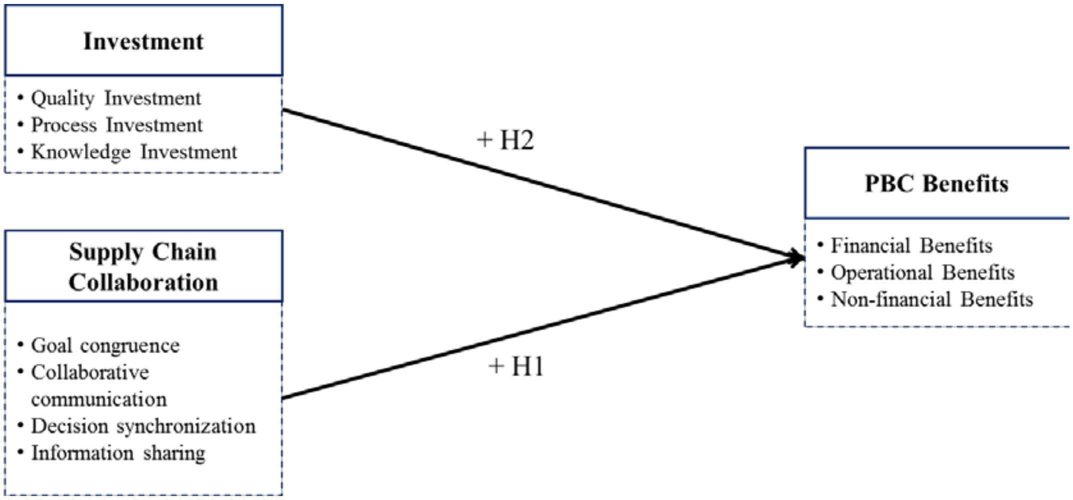


Figure 1.1: Impact of supply chain collaboration and investment on PBC benefits.

Supply Chain Collaboration

Supply chain collaboration (SCC) has been viewed as the joint working of supply chain partners toward common objectives to obtain mutual advantages (Mentzer et al., 2001; Stank et al., 2001; Simatupang & Sridharan, 2002; Cao & Zhang, 2011). Bowersox et al. (2003) defined SCC in a far more relational perspective, where supply chain partners build a long-term relationship in which they work together by sharing resources, information, and risks to achieve common goals. Scholars view SCC as significant for creating efficient and productive operations (Simatupang & Sridharan, 2002) to attain a collaborative advantage (Cao & Zhang, 2011) and a competitive advantage (Mentzer et al., 2000), by coordinating the flow of resources and information between suppliers. A supply chain consists of partnerships that are the source of knowledge and skills to create value propositions for performance-based outcomes (Vargo & Lusch 2004; Randall et al., 2011). So, the most effective and efficient solutions can be found with collaboration between key suppliers. This collaboration of entire supply network entities—involving processes, material, and information around the same goals—is critical to creating innovative solutions to increase the readiness of systems with less cost (Randall et al. 2015).

In a study by Randall, Pohlen, and Hanna (2010), which uses a grounded theory methodology and includes over 60 interviews with PBL managers and suppliers, collaboration emerges as one of the antecedents of their proposed framework. Based on the suppliers' core abilities, extending the scope of planning efforts by including the sub-suppliers and aligning the goals of key supply partners with measurable, and more important, with understandable performance metrics, are fundamental characteristics of performance-based contracts to offer efficient solutions to achieve desired outcomes (Vitasek & Geary, 2007). This research identifies four factors that comprise SCC. For the components of the supply chain collaboration in PBC, this study depends on a Cao et al. (2010)'s study, in which the authors synthesized the literature of SCC. These four interrelated components that define SCC are goal congruence, collaborative communication, decision synchronization, and information sharing (Fig.1). While defining each dimension, we emphasized the importance of each component in performance-based contracts.

Goal Congruence

Goal congruence between supply chain partners is the extent to which each supplier realizes their targets are satisfied by achieving all mutual objectives (Cao & Zhang, 2011). Goal alignment is one of the basic tenets of PBC between buyer and customer, as well as within suppliers (Vitasek et al., 2006; Vitasek & Geary, 2007). Alignment goals within suppliers can be achieved in PBC. The incentive structure of PBC, which depends on achieving outcomes, will force to suppliers to align their goals with the buyer's objectives.

Collaborative Communication

Collaborative communication refers to message transmission between supply chain partners. Frequent contacts of suppliers and the existence of open and two-way communication channels are the main items of collaborative communication in the supply chain. Although communication between suppliers and customer is regarded as a key feature for PBCs (Randall et al. 2011), the existence of communication channels within suppliers is also an essential element to finding innovative solutions for increasing benefits in PBC, such as revenue, service, and quality of products.

Decision Synchronization

Decision synchronization refers to jointly taken decisions and planning by supply chain partners to efficiently achieve objectives (Simatupang & Sridharan, 2002). Decision processes in PBC are critical to creating continuous value for the buyer and all supply chain partners (Randall, Pohlen, & Hanna, 2010). In particular, decisions for upfront investment, such as reliability investment, require complete decision synchronization between key suppliers in PBC. Therefore, orchestrating decision processes is critical for selecting investment solutions to increase the benefits of PBC for buyer and supply chain partners.

Information Sharing

Information sharing refers to prompt sharing of appropriate, accurate, and relevant information within supply chain partners (Cao et al. 2010) and is critical to achieving outcomes in PBC (Ng and Nudurupati, 2010; Ng, Ding, & Yip, 2013). In PBC, information sharing is not only essential for improving responsiveness, by sharing data such as inventory levels, but is also critical to finding innovative solutions to reduce future costs by relaying confidential data such as technical knowledge of products. Thus, in the PBC context, information sharing appears as the essential requirements for innovative solutions (Kleemann & Essig, 2013).

Although there are studies about a theoretical framework for PBC (Randall et al., 201), its effectiveness (Randall et al., 2011), and quantitative modeling of PBC (Kim et al., 2007; Kim et al., 2010; Guajardo et al., 2012), these studies have failed to seriously consider the importance of supply chain collaboration in performance-based contracting. Accounting for the challenges and risks of executing PBCs, such as the unpredictability of costs for reliability investments, or dependability to suppliers to increase the quality of products, these difficulties could be mitigated through shared information and resources and mutual expectations of suppliers (Ng & Nudurupati, 2010). Therefore, this study develops the following hypothesis:

Hypothesis 1. Supply chain collaboration has a significant positive effect on PBC benefits.

Investment

In PBC, it is critical for the whole supply chain to increase benefits by avoiding future costs such as maintenance, repair, and spare parts. Investments refer actions for effective and efficient performance providing which result in avoiding future costs. The incentive structure of PBC, as well as shifting risks from the buyer to supplier to achieve objectives, creates an investment climate for the supplier and forces them to seek new knowledge, make an upfront investment for high-quality products, and enhance processes in the whole supply chain to be more efficient and effective in attaining desired objectives. Randall et al. (2011) emphasized the importance of this investment climate and relational exchange of suppliers for continuous value creation in performance-based arrangements. This research identifies three factors that comprise investments in PBC. These are: knowledge investment, quality investment, and process investment.

Knowledge Investment

Knowledge investment refers to the extent to which a supplier works with supply chain partners to search, explore, and acquire new and relevant knowledge to develop solutions for existing problems related to new processes, products, or services (Cao & Zhang, 2011). The success of PBC depends on the knowledge of all supply chain partners, such as technical knowledge for sustaining the system, supply chain knowledge to build effective and efficient support, and knowledge for sources of innovation for processes, services, and products (Randall, Brady, & Nowicki, 2012). In performance-based contracting. which is considered as an application of SDL, knowledge is the source of value creation that can be attained by inter-firm supply chain relationships with the customer's value offering(Ng et al. 2009; Randall, Pohlen, & Hanna, 2010; Randall et al. 2012; Randall et al. 2014).

Quality Investment

Quality investment refers to the supplier's investment with supply chain partners to offer a high-quality product that is highly reliable, durable, and long-lasting, thus creating value for customers and entire supply chain partners. PBC motivates suppliers to make the upfront investment for highly durable and dependable products with powerful incentives, which enable savings in acquiring and holding additional assets (Kim, Cohen & Netessine, 2015). In PBC, under a longer term, contract suppliers are eager to invest in product reliability improvement (Jin et al. 2012; Randall et al. 2012), which requires the collaboration of all suppliers. Studies of the tradeoffs between increasing spare parts and reliability investment show that the base stock level of spare parts had an insignificant impact on performance (Mirzahosseinian & Piplani, 2011; Jin et al. 2012;

Kim, Cohen & Netessine, 2015). Therefore, suppliers must enhance the quality of products through upfront investments for component reliability, rather than increasing the stock of spares.

Process Investment

Process investment refers to investment for process efficiency to obtain desired performance objectives, as stipulated in the contract. The process could be post-production services, such as maintenance, repair services, and logistics processes. Considering the entire supply chain with a systems thinking approach to make upfront investment for the processes that creates continuous value in PBC requires collaborative thinking, which is essential for translating knowledge to process investment. Based on the findings of Randall et al. (2012), short-term PBL arrangements in particular enable improvements in existing processes, such as inventory management and repair/maintenance services. On the other hand, in a study by Selçuk and Agrali (2013), service level capacity was found to be a significant factor that affects reliability improvement efforts under PBC. In the defense industry, however, awarded performance-based contracts show enhancements in whole processes, regardless of the term of the contract, from reducing the time it takes to diagnose a problem and the time it takes to repair failure items to maintenance improvements attained by innovative teaming and process management, usage of ‘lean six sigma’ quality process, and the visibility of all process by integration of data sharing within the whole supply chain (Kirk & DePalma 2005; SoD, 2016).

Regardless of the term of contract, the success of PBC relies on investment solutions. In PBC, while long-term PBL contracts allow for translating knowledge into innovation, such as reliability improvement, short-term PBL arrangements enable improvements in existing processes, such as warehousing, inventory, transportation, and repair (Randall et al. 2012). Therefore, this study develops the following hypothesis:

Hypothesis 2. Investment has a significant positive effect on PBC benefits.

Hypothesis 3. Investment mediates the positive effect of the SCC on PBC benefits.

PBC Benefits

PBC offers an exceptional model, a win-win-situation for buyers and suppliers (Hypko, Tilebein, & Gleich 2010). Therefore, the benefits of PBC should be considered in a dyadic perspective. However, in this study, the benefits of PBC are examined only from the perspective of performance providers. This research identifies three factors that comprise the benefits of PBC. These include financial, operational, and non-financial benefits.

Financial Benefits

Financial benefits refer to how well suppliers fulfill their financial goals for this PBC engagement. The incentive structure of PBC enables suppliers to obtain additional revenue (e.g., awards) that result in profit growth. In addition to direct incentives for the supplier to achieve objectives, freedom of suppliers in their decisions to provide desired performance metrics leads suppliers to upfront investments that reduce future support costs, such as maintenance, inventory, and logistics. All efforts to achieve the desired outcomes in PBCs, such as maintenance services, quality investment, or inventory management, are designed to reduce the cost of ownership for sustaining systems (Gansler & Lucyshyn; 2006; Vitasek et al., 2007). For instance, investment for reliability will increase the availability of systems while reducing the total service cost, spare parts acquiring, holding costs, and logistic footprint (Cohen, M. A., & Netessine, S., 2007; Devries, 2005; Gansler & Lucyshyn, 2006). Furthermore, the study of Boyce and Banghart (2012), based on 21 PBC arrangements, shows that PBCs successfully incentivized suppliers and reduced life-cycle costs while increasing system readiness and availability.

Operational Benefits

Operational benefits refer to how well the performance provider offers value to exchange partners through system improvement. PBC enables improvements in product, or overall system performance, and helps increase the availability and readiness of systems by enhancing their sustainability, maintainability, and supportability (Mirzahosseinian & Piplani, 2011; Guajardo et al., 2012; Jin, Tian, & Xie, 2014; Kim et al., 2015).

Non-Financial Benefits

Not all business objectives can be defined in financial terms. Non-financial benefits refer to how well suppliers attain intangible benefits, including developing the company's image and branding, as well as bolstering the company's reputation.

Data Analysis

Instrument Development

For the construct of "supply chain collaboration" in PBC, scale items were adapted, based on the existing literature (Cao et al., 2010). To generate measurement items for the construct of "Investment" and "PBC Benefits," the PBC literature was reviewed, and a primary list of potential items was compiled. Five meetings were held with academic experts to assess the content validity of the scales for each construct by checking the relevance of each construct's description and the wording of items. The items were also reviewed by another expert via e-mail. Scale items were then sent to doctorate students in business programs, and they were asked to categorize the items into matching constructs. Using their feedback, redundant, or questionable and unclear items were removed or modified. As a final step in pre-assessing the validity and reliability of the items, four pilot studies were conducted. After each pre-test, we carried out explanatory factor analysis. Based on the results of the principal component analysis with varimax rotation, 45 items with low factor loadings and high cross-loadings were eliminated from 83 scale items. As a result, 38 scale items that are shown in Appendix B were developed in this study. For the four components of "supply chain collaboration" twelve items, for the three components of "investment" fifteen items, and for the three components of "PBC Benefits" eleven items were used. To indicate the extent to which respondents agreed or disagreed with each statement, a five-point Likert scale was used where 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree.

Data Collection

In this study, data were collected through a survey targeting the population of the United States. A sampling of this study includes single informants whose primary job functions are logistics, supply chain, and operations management. In this research, the Amazon Mechanical Turk (Mturk) platform was used to find a suitable sample frame. Usage of Mturk to recruit respondents has been validated and found to yield results that are comparable to traditional surveys (Buhrmester et al., 2011). Also, Mturk is considered an adequate platform to reach participants with work experience in supply chain management, logistics, and operations management (Knemeyer & Naylor, 2011). Recruiting respondents from diverse backgrounds and locations, Mturk's sample ensures greater generalizability (Buhrmester, Kwang, & Gosling, 2011). To recruit respondents, we used the techniques of Schoenherr et al. (2015) to obtain valid responses.

An online questionnaire was created, using Qualtrics, and was posted on Mturk for recruiting participants. Screening questions were asked at the beginning of the survey to limit participation to those who hold a title of manager, supervisor, senior manager, senior director, or member of a management/executive board at firms. Sample respondents were also screened with questions about whether their job function is supply chain management, operations management, or logistics management. If respondents did not satisfy the screening criteria, the online survey was terminated. Additionally, attention check questions were used in Mturk throughout the survey to inspect whether respondents were reading the questions in their entirety. If participants failed to pass attention check questions, the survey was terminated, and they were excluded from participation. For the last measure, only one response per one IP address was accepted. Participants who completed the survey received monetary compensation for completing the assigned task. Based on these screening questions (job function and position level), out of 1709 attempts to participate the survey, 548 respondents were able to take it. Out of 548 respondents, based on attention check questions, 407 respondents be able to complete the survey. However, 13 responses were removed because of less-than-average time to read and answer questions. Also, 13 more responses using straight-line responses are removed from analysis. After cleaning the data, 381 responses are used in our analysis. Demographic data for the respondents are summarized in Table 1.1.

Table 1.1: Sample demographics (N = 381)

		n	%
Primary Job Function	Logistics management	74	19
	Operations management	164	43
	Supply chain management	143	38

(table continues)

		n	%
Job Title	Member of management/executive board	25	7
	Senior director/director	21	6
	Senior manager	121	32
	Supervisor	65	17
	Manager	149	39
Firm Size	Less than 250 employees	123	32
	Between 251 and 500 employees	107	28
	Between 501 and 750 employees	30	8
	Between 751 and 1000 employees	58	15
	Greater than 1001 employees	63	17
Annual Revenue	<$10 million	110	29
	$11 - $50 million	76	20
	$51 - $100 million	56	15
	$101 - $200 million	53	14
	$201 - $500 million	32	8
	$501 million - $1 billion	26	7
	>$1 billion	28	7
Experience in SCM	1-5	172	45
	6-10	138	36
	11-15	47	12
	16+	23	6
Experience in PBC		221	58
Gender	Male	213	56
	Female	168	44
Age	18-25	45	12
	26-32	149	39
	33-40	120	31
	41-47	32	8
	48+	35	9

(table continues)

		n	%
Education	Some high school, no diploma	2	1
	High school graduate, diploma or the equivalent	27	7
	Some college credit, no degree	98	26
	Bachelor’s degree	186	49
	Master’s degree	60	16
	Doctorate degree	8	2

Data Analysis Methods

In the first part of the data analysis, confirmatory factor analysis was used to check unidimensionality, convergent validity, construct reliability, discriminant validity, and second-order construct validity, respectively. In the final part of the data analysis, structural equation modeling through AMOS 18 was used to explain the relationship between supply chain collaboration, investment, and PBC benefits. Unidimensionality is checked by the overall model fit indices. Comparative fit index (CFI), root mean square error of approximation (RMSEA), normed fit index (NFI), non-normed fit index (NNFI), Goodness-of-Fit Index (GFI), Adjusted Goodness-of-Fit Index (AGFI), and normed chi-square (χ^2) were used to assess the overall model fit (Bentler & Bonnet, 1980; Bentler, 1990; Byrne, 1989; Chau 1997; Hair et al., 2010; Hooper et. al., 2008; Joreskorg & Sorbom, 1993). Values between 0.80 and 0.89 show an adequate fit (Segars & Grover, 1998), and values equal to or higher than 0.90 represent evidence of a good fit for CFI, NFI, and NNFI (Bryne, 1989; Joreskog & Sorbom, 1986). Values equal to or greater than 0.90 for GFI and AGFI indicate an acceptable fit (Joreskog & Sorbom, 1986). For RMSEA, values less than 0.08 show a good fit (Hair et al., 2010). Normed chi-square (χ^2) values smaller than 2.0 prove a good fit, and values lower than 3.0 indicate a reasonable fit (Hair et al., 2010). The significance of t-values for each measurement indicator were used to assess convergent validity. Also, the values for factor loadings were at least 0.5, and preferably 0.7 or higher, representing a good fit for convergent validity (Hair et al., 2010). Measurement factor loadings and the average variance extracted (AVE) of a construct were used to assess construct reliability. The computation of CR and AVE are done using CFA results through AMOS (Anderson & Gerbing, 1988; Bagozzi & Yi, 1988; Hair et al., 2010). Values for AVE above 0.50 (Fornell & Larcker, 1981) and values for construct reliabilities (CR) above 0.70 represent the reliability and internal consistency of components (Hair et al., 2010). For discriminant validity, the procedure represented by Fornell and Larcker (1981) was used. Based on this method, an AVE for each construct that was higher than the squared correlation between that construct and any other, indicates discriminant validity. In the last step of the first part of data analysis, *T* coefficient was used to check the validation of second-order constructs. The values for *T* coefficient above 0.8 indicate existence of second-order constructs. Calculating this value was done by the ratio of the first-order model's chi-square (χ^2) to the second-order model's chi-square (χ^2) (Doll et al., 1995). In the second part of the data analysis, a structural equation model through AMOS was conducted to test the hypotheses in the framework.

Results

Measurement Results

To confirm unidimensionality, convergent validity, construct reliability, discriminant validity, and second-order construct validity, we used the method of CFA through AMOS 18. The construct of "supply chain collaboration" was represented by four dimensions and 12 scale items (see Appendix B). First, the overall fit indices for the measurement model were acceptable results and demonstrated good unidimensionality. (Anderson & Gerbing, 1988; Bagozzi & Yi, 1988).

These fit indices were: a Joreskorg and Sorbom (1993) Goodness-of-Fit Index (GFI) of 0.958, a Bentler (1990) Comparative Fit Index (CFI) of 0.969, an Adjusted Goodness-of-Fit Index (AGFI) of 0.928, a Non-Normed Fit Index (NNFI) of 0.956, a Root Mean Square Error of Approximation (RMSEA) of 0.057, a normed chi-square (χ^2) of 2.223, and a chi-square (χ^2) of 102.278 with 46 degrees of freedom (see Table 1.2).

Table 1.2: Confirmatory factor analysis results for supply chain collaboration.

Construct	Items	Loadings (λ)	t-value	CR	AVE
Goal Congruence				0.805	0.580
	GC1	0.745	(set to 1.0)		
	GC2	0.775	13.926		
	GC3	0.764	13.758		
Collaborative Communication				0.842	0.640
	CC1	0.806	(set to 1.0)		
	CC2	0.741	11.075		
	CC3	0.850	10.748		
Decision Synchronization				0.763	0.518
	DS1	0.753	(set to 1.0)		
	DS2	0.726	11.025		
	DS3	0.678	10.712		
Information Sharing				0.765	0.521
	IS1	0.741	11.545		
	IS2	0.753	11.664		
	IS3	0.669	(set to 1.0)		

CFA global fit indices: Chi-square=102.278; df=46; Normed Chi-square=2.223; GFI=0.958; AGFI=0.928; NFI=0.946; NNFI=0.956; CFI=0.969; RMSEA=0.057.

Second, as evidence of convergent validity, measurements of factor loadings were all significant at $p < 0.01$, based on t-values, and all standardized item loadings (λs) ranging from 0.669 to 0.850 were above 0.5 (Hair et al., 2010). Estimates of AVEs for four factors, ranging from 0.518 to 0.640, were greater than the critical value of 0.50 (Fornell & Larcker, 1981). The variance captured by the construct was greater than the variance due to measurement error. Construct reliabilities (CR) for four factors, ranging from 0.763 to 0.842, were above the critical value of 0.70 (Hair et al., 2010) (see Table 1.2).

Third, the procedure demonstrated by Fornell and Larcker (1981) was used to analyze for discriminant validity. As presented in Table 1.3, a squared correlation between any two constructs is higher than either of the constructs' AVE. Discriminant validity is supported because all composite reliability scores on diagonal are higher than off-diagonal correlation coefficients in Table 1.3. Correlation estimates among the six latent constructs are all statistically significant. These results indicate acceptable levels of internal consistency, convergent, discriminant, and construct validity (Hair et. al., 2010).

Table 1.3: Discriminant validity measures for supply chain collaboration.

	CR	AVE	Decision Synch	Collaborative Comm	Goal Cong	Info Sharing
Decision Synchronization	0.763	0.518	**0.720**			
Collaborative Communication	0.840	0.637	0.396	**0.798**		
Goal Congruence	0.805	0.580	0.446	0.698	**0.761**	
Information Sharing	0.765	0.521	0.463	0.618	0.783	**0.722**

The same process was followed for the construct of investment, which was represented by three dimensions and 15 items (see Appendix B). First, the overall fit indices for the measurement model were also acceptable results and demonstrated good unidimensionality. These fit indices were: the Joreskorg and Sorbom (1993) Goodness-of-Fit Index (GFI) of 0.942, the Bentler (1990) Comparative Fit Index (CFI) of 0.971, the Adjusted Goodness-of-Fit Index (AGFI) of 0.912, the Non-Normed Fit Index (NNFI) of 0.961, the root mean square error of approximation (RMSEA) of 0.054, the normed chi-square (χ^2) of 2.093, and the chi-square (χ^2) of 188.383 with 90 degrees of freedom (see Table 1.4).

Second, as evidence of convergent validity, the measurements of factor loadings were all significant at $p < 0.01$, based on t-values and all standardized item loadings (λs), ranging from 0.650 to 0.834 that were above 0.5 (Hair et al., 2010). Estimates of AVEs for three factors, ranging from 0.575 to 0.599, were greater than the critical value of 0.50 (Fornell & Larcker, 1981). The variance captured by the construct was greater than the variance due to measurement error. Construct reliabilities (CR) for three factors, ranging from 0.870 to 0.882, were above the critical value of 0.70 (Hair et al., 2010) (see Table 1.4).

Table 1.4: Confirmatory factor analysis results for investment.

Construct	Items	Loadings (λ)	t-value	CR	AVE
Knowledge Investment				0.883	0.558
	KI1	0.747	13.062		
	KI2	0.782	13.290		
	KI3	0.715	(set to 1.0)		
	KI4	0.745	15.252		
	KI5	0.737	13.016		
	KI6	0.755	13.011		
Quality Investment				0.882	0.599
	QI1	0.744	15.285		
	QI2	0.809	16.929		
	QI3	0.800	(set to 1.0)		
	QI4	0.736	15.104		
	QI5	0.778	16.145		
Process Investment				0.870	0.575
	PI1	0.650	11.578		
	PI2	0.748	12.221		
	PI3	0.788	13.416		
	PI4	0.832	13.451		
	PI5	0.759	(set to 1.0)		

CFA global fit indices: Chi-square=188.383; df=90; Normed Chi-square=2.093; GFI=0.942; AGFI=0.912; NFI=0.946; NNFI=0.961; CFI=0.971; RMSEA=0.054.

Third, the same steps of Fornell and Larcker (1981) were applied for discriminant validity analysis. As shown in Table 1.5, discriminant validity is supported because all composite reliability scores on diagonal are higher than off-diagonal correlation coefficients in Table 1.5. The correlation estimates among the three latent constructs are all statistically significant. These results indicate acceptable levels of internal consistency, convergent, discriminant, and construct validity (Hair et. al., 2010).

Table 1.5: Discriminant validity measures for investment.

	CR	AVE	Quality Investment	Knowledge Investment	Process Investment
Quality Investment	0.882	0.599	**0.774**		
Knowledge Investment	0.883	0.558	0.634	**0.747**	
Process Investment	0.870	0.575	0.568	0.653	**0.758**

For the construct of "PBC benefits," represented by three dimensions and 11 items (see Appendix B), the same process was followed. First, overall fit indices for the measurement model were also acceptable results and demonstrated good unidimensionality. These fit indices were: the Goodness-of-Fit Index (GFI) of 0.9710, the Comparative Fit Index (CFI) of 0.987, the Adjusted Goodness-of-Fit Index (AGFI) of 0.950, the Non-Normed Fit Index (NNFI) of 0.981, the Root Mean Square Error of Approximation (RMSEA) of 0.043, the normed chi-square (χ^2) of 1.692, and a chi-square (χ^2) of 65.791 with 39 degrees of freedom (see Table 1.6).

Second, as evidence of convergent validity, the measurements of factor loadings were all significant at $p < 0.01$, based on t-values, and all standardized item loadings (λs) ranging from 0.657 to 0.902 were above 0.5 (Hair et al., 2010). Estimates of AVEs for three factors, ranging from 0.568 to 0.653, were greater than the critical value of 0.50 (Fornell & Larcker, 1981). The variance captured by the construct was greater than the variance due to measurement error.

Construct reliabilities (CR) for three factors ranging from 0.808 to 0.849 were above the critical value of 0.70 (Hair et al., 2010) (see Table 1.6).

Table 1.6: Confirmatory factor analysis results for PBC benefits.

Construct	Items	Loadings (λ)	t-value	CR	AVE
Financial Benefits				0.867	0.568
	FB1	0.657	12.503		
	FB2	0.705	14.444		
	FB3	0.780	16.441		
	FB4	0.835	(set to 1.0)		
	FB5	0.779	16.395		
Non-financial Benefits				0. 849	0.653
	NFB1	0.752	16.247		
	NFB2	0.902	(set to 1.0)		
	NFB3	0.762	16.495		
Operational Benefits				0.808	0.584
	OB1	0.701	12.984		
	OB2	0.786	(set to 1.0)		
	OB3	0.802	14.451		

CFA global fit indices: Chi-square=65.791; df=39; Normed Chi-square=1.692; GFI=0.970; AGFI=0.950; NFI=0.968; NNFI=0.981; CFI=0.987; RMSEA=0.043.

Third, discriminant validity is supported because all composite reliability scores on diagonal are higher than off-diagonal correlation coefficients in Table 1.7 (Fornell & Larcker, 1981). Correlation estimates among the three latent constructs are all statistically significant. These results also show acceptable levels of internal consistency, convergent, discriminant, and construct validity (Hair et al., 2010).

Table 1.7: Discriminant validity measures for PBC benefits.

	CR	AVE	Non-financial Benefits	Financial Benefits	Operational Benefits
Non-financial Benefits	0.849	0.653	**0.808**		
Financial Benefits	0.867	0.568	0.529	**0.754**	
Operational Benefits	0.808	0.584	0.659	0.599	**0.764**

Additionally, for the discriminant validity of entire scale items, we conducted whole items together in CFA. The overall fit indices for the measurement model were also acceptable results and demonstrated good unidimensionality. As shown in Table 1.8, discriminant validity is supported because all composite reliability scores on diagonal are higher than off-diagonal correlation coefficients.

Table 1.8: Discriminant validity measures for whole constructs.

	DS	KI	FB	QI	PI	GC	NFB	IS	CC	OB
DS	**0.720**									
KI	0.710	**0.745**								
FB	0.346	0.438	**0.754**							
QI	0.452	0.636	0.511	**0.770**						
PI	0.687	0.665	0.502	0.578	**0.749**					
GC	0.445	0.533	0.456	0.646	0.455	**0.761**				
NFB	0.460	0.531	0.528	0.565	0.547	0.631	**0.824**			
IS	0.465	0.520	0.435	0.607	0.490	0.784	0.577	**0.722**		
CC	0.428	0.547	0.607	0.613	0.544	0.697	0.623	0.644	**0.774**	
OB	0.557	0.626	0.598	0.619	0.669	0.545	0.655	0.624	0.568	**0.764**

CFA global fit indices: Chi-square=1121;997 df=643; Normed Chi-square=1.745; GFI=0.872; AGFI=0.845; NFI=0.875; NNFI=0.933; CFI=0.942; RMSEA=0.044. DS = Decision Synchronization; KI = Knowledge Investment; FB = Financial Benefits; QI = Quality Investment; PI = Process Investment; GC = Goal Congruence; NFB = Non-financial Benefits; IS = Information Sharing; CC = Collaborative Communication; OB = Operational Benefit

Validation of Second-Order Constructs

In this study, second-order model was used to show covariations among first-order factors. The validation of second-order constructs can be evaluated by target (*T*) coefficient. This value (*T*) was calculated by the ratio of the first-order model's chi-square to the second-order model's chi-square (Doll et al., 1995). The values for *T* coefficient above 0.8 indicates the existence of second-order constructs (Marsh & Hocevar, 1985). The *T* coefficients for supply chain collaboration, investment, and PBC benefits are 0.811, 0.989, and 0.992, respectively. These results show that the second-order models should be accepted.

Table 1.9: Fit Indices for second-order model.

Construct	Model	χ^2 (df)	Normed χ^2	T coefficient
Supply Chain Collaboration	First-order	150.860 (77)	1.959	81.08%
	Second-order	193.288 (80)	2.416	
Investment	First-order	188.383 (90)	2.093	98.86%
	Second-order	201.102 (95)	2.117	
PBC Benefits	First-order	65.971 (39)	1.692	99.17%
	Second-order	68.260 (40)	1.706	

Hypotheses Testing Results

The last stage of the analysis examines the casual relationship between latent constructs (see Figure 1.2). For Hypotheses 1, 2, and 3 proposed in this study, structural equation modeling (AMOS) was used to assess the model fit with the data. Casualty is the primary focus of the study and captures the evidence of nomological validity between variables. Fit indices for the model indicate a satisfactory fit (χ^2= 1228.221, df = 675, Goodness-of-Fit Index (GFI) = 0.853, Adjusted Goodness-of-Fit Index (AGFI) = 0.831, Non-Normed Fit Index (NNFI) = 0.918, Bentler and Bonett’s Comparative Fit Index (CFI) = 0.925, Root Mean Square Error of Approximation (RMSEA) = 0.049).

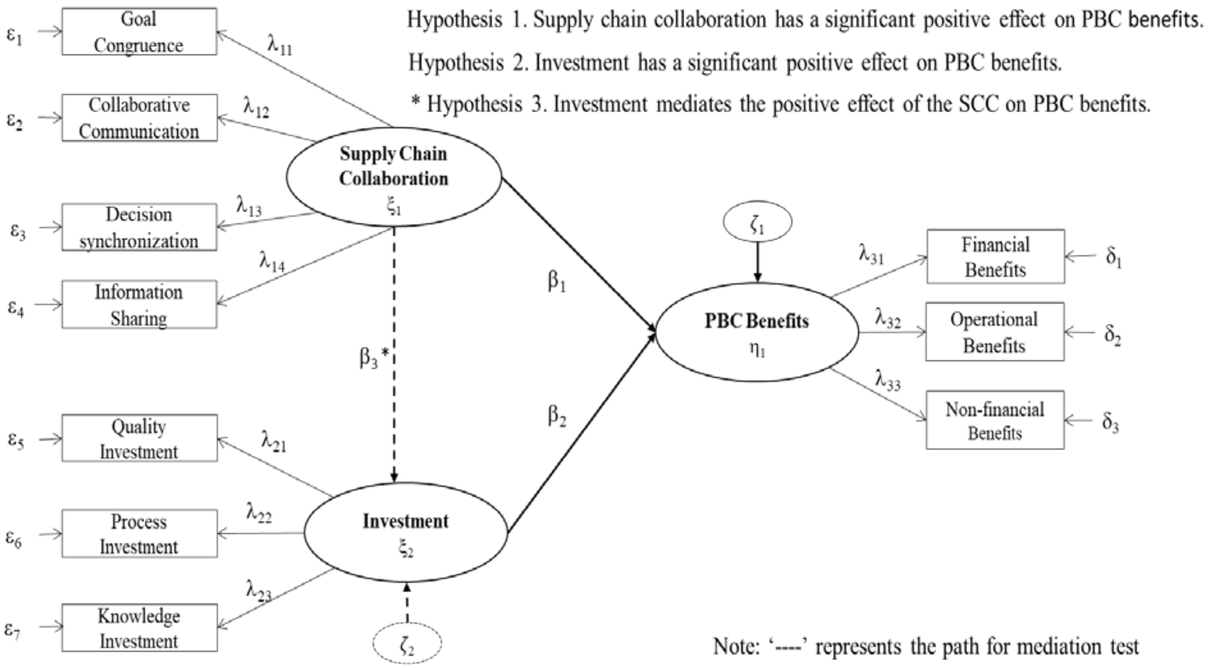


Figure 1.2: Hypotheses test using structural equation model.

Structural modeling revealed an R-square of 0.857 for PBC benefits. The results suggest that exogenous variables of supply chain collaboration and investment were all significant and positive predictors of PBC benefits at the 95% and 99% confidence level, respectively. The results of the SEM analysis are presented in Figure 1.3, Table 1.10, and Table 1.11. The results indicate the following.

Hypothesis 1 is supported. The AMOS path coefficient is 0.368 (t = 2.199), which is statistically significant at the level of 0.05. This supports the hypotheses that supply chain collaboration has a significant and positive impact on PBC benefits.

Hypothesis 2 is also confirmed. The AMOS path coefficient is 0.582 (t = 3.332), which is statistically significant at the level of 0.01. This indicates that investment has a significant and positive direct impact on PBC benefits.

Hypothesis 3 is also supported by the indirect path coefficient of 0.521 (p = 0.044), which is statistically significant at the level of 0.05 (see Table 1.11). This indicates that investment mediates the positive effects of supply chain collaboration on PBC benefits.

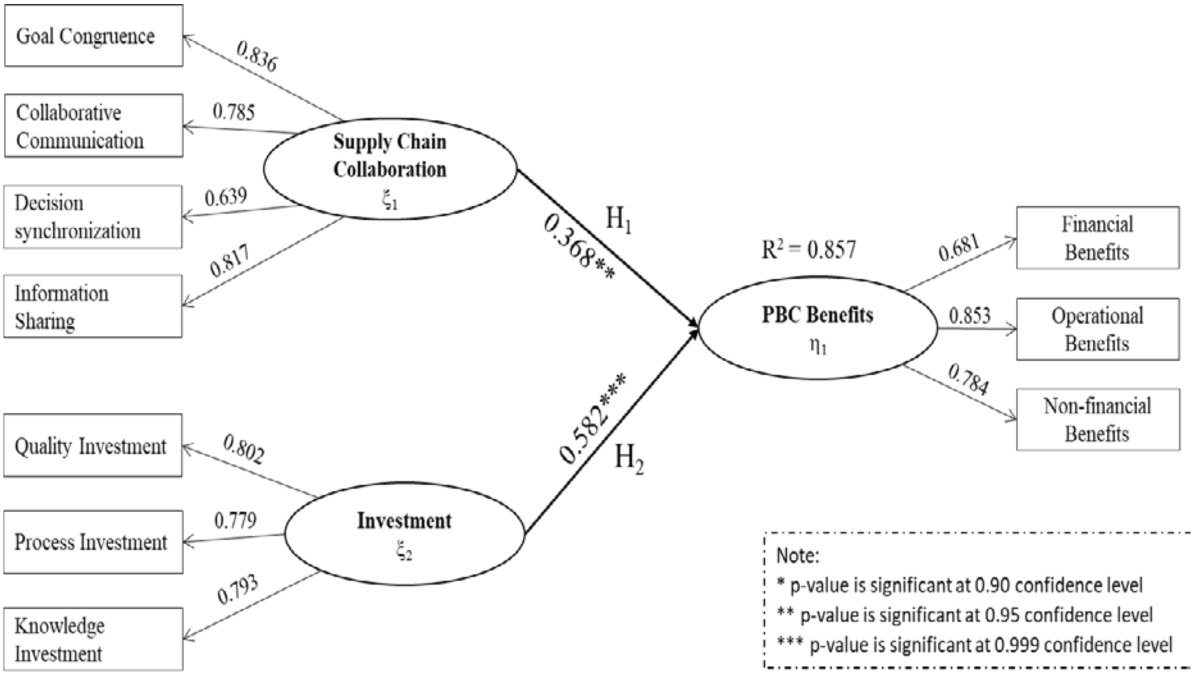


Figure 1.3: Structural equation model results (path and measurement).

It is also critical to note that supply chain collaboration has a positive indirect impact on PBC benefits along the path of investment solutions. The indirect path coefficient with bootstrapping is 0.521 (p = 0.044), which is statistically significant at the level of 0.05. Therefore, investment solutions in PBC are essential to obtaining effective and efficient results in performance-based arrangements.

Table 1.10: Estimates of structural equation model.

	Construct		Standard Estimate	t-Value	R square
Supply Chain Collaboration (ξ_1)	Goal Congruence	λ_{11}	0.836	(set to 1.0)	
	Collaborative Communication	λ_{12}	0.785	10.096	
	Decision Synchronization	λ_{13}	0.639	8.524	
	Information Sharing	λ_{14}	0.817	9.713	

(table continues)

Construct			Standard Estimate	t-Value	R square
Investment (ξ_2)	Quality Investment	λ_{21}	0.802	10.429	
	Process Investment	λ_{22}	0.779	9.738	
	Knowledge Investment	λ_{23}	0.793	(set to 1.0)	
PBC Benefits (η_1)					0.857
	Financial Benefits	λ_{31}	0.681	(set to 1.0)	
	Operational Benefits	λ_{32}	0.853	10.198	
	Non-financial Benefits	λ_{33}	0.784	10.188	
Test of Hypotheses	SCC to PBC Benefits	β_1 H1	0.368	2.199 **	
	Investment to PBC Benefits	β_2 H2	0.582	3.332 ***	
Global Model Fit Diagnostics	χ^2 (df)		1246 (671)		
	p-value		0.000		
	normed chi-square (χ^2)		1.857		
	GFI		0.857		
	AGFI		0.834		
	NFI		0.861		
	NNFI		0.923		
	CFI		0.930		
	RMSEA		0.047		

Note: See Figure 1.2 for a visual representation of parameters. * p-value is significant at 0.90 confidence level, ** p-value is significant at 0.95 confidence level,*** p-value is significant at 0.999 confidence level

The mediated relationship was verified using the bootstrapping test (Preacher & Hayes, 2008). The mediation effect was tested using 1000 bias corrected bootstrapping resamples in AMOS. Direct and indirect effects were analyzed for potential partial mediation (discovered while fitting the model). Only indirect effects were analyzed for establishing partial mediation. The results, summarized in Table 1.11, indicate that there is a partial mediation between supply chain collaboration and PBC benefits through investment. The bootstrapping mediation test shows that while direct effect of SCC on PBC benefits is statistically significant without mediation at the level of 0.001, direct effect of SCC with mediation is still is statistically significant mediation at the level of 0.05, and indirect effect on PBC benefits along the path of investment is also statistically significant at the level of 0.05 (see Table 1.11).

Table 1.11: Testing results of mediating effects of investment.

Mediation	Direct Beta w/o Med	Direct Beta w/Med	Indirect Beta	Mediation type observed
SCC-I-PBCB	0.889***	0.368**	0.521**	Partial mediation

CFA global fit indices: Chi-square=1246; df=671; Normed Chi-square=1.857; GFI=0.857; AGFI=0.834; NFI=0.861; NNFI=0.923; CFI=0.930; RMSEA=0.047. *p-value is significant at 0.90 confidence level, ** p-value is significant at 0.95 confidence level, *** p-value is significant at 0.999 confidence level.

General Discussion and Implications

Given the lack of theoretical studies in extant PBC research (Selviaridis and Wynstra, 2015), this study contributes to our understanding of the benefits of SCC in PBC by offering theoretical insights and empirical findings. It also reveals the feature of investment in PBC that provides future cost avoidance, while contributing theoretical insights and empirical findings for PBC.

This research examines the impacts of supply chain collaboration and investments on benefits of performance-based contracting with empirical findings. Supply chain collaboration is identified with four interrelated components that build effective supply chain collaboration: goal congruence, collaborative communication, decision synchronization, and information sharing. Additionally, this study developed the main features of investment in PBC that provide future cost avoidance for suppliers. The construct of "investment" consists of a set of three interconnecting dimensions: quality investment, process investment, and knowledge investment. The PBC benefits recognized under three main interconnected aspects that make effective and efficient performance-based contracting are: financial benefits, operational benefits, and non-financial benefits. Also, valid and reliable scale items were developed for investment and PBC benefits through a literature review, expert meetings, and pilot studies. All scale items have been tested through confirmatory factor analysis for unidimensionality, convergent validity, construct reliability, and the validation of second-order construct. All instruments are shown to meet the qualifications for validity and reliability. These items can therefore be used in future studies. Accurate definitions and measures of investment have provided a structured understanding of the necessities for effective and efficient PBC.

The study found that effective supply chain collaboration and investments have a positive effect that increases PBC benefits. Research results highlight the critical role of supply chain collaboration and the amplifying function of investment between SCC and effective PBCs. The results empirically confirm that supply chain collaboration increases the benefits of PBCs (H1). The results also show that investments have a positive significant effect, increasing PBC benefits (H2). Also, we found partially mediation impact of investments between SCC and PBC benefits (H3).Thus, we conclude that better collaboration with key suppliers is critical to creating innovative investment in order to increase benefits by avoiding future costs in PBC (Randall et al. 2015). This finding is consistent and provides empirical proof for the statements of Randall et al. (2011), in which the authors emphasize the importance of this investment climate and relational exchange of suppliers for continuous value creation in PBCs. These results also echo the literature in acknowledging the importance of collaboration for generating benefits in the whole chain (Lavie, 2006; Cao and Zhang; 2011) and the significance of upfront investments for effective and efficient PBCs (Mirzahosseinian and Piplani, 2011; Randall et al. 2011, 2012).

Empirical testing of the proposed model presented in this study advances our understanding of effective and efficient PBCs. The findings offer guidance for managers aiming to achieve better PBC through collaboration and investments. Also, the definition and measures of investment can help managers define specific actions that should be taken collaboratively to increase the effectiveness of PBCs.

Limitations and Future Research

The limitations of this research can be addressed in future studies. The first is data collection that was expedited via the Mcturk online data collection service. Although the usage of Mturk has been validated (Buhrmester, Kwang, & Gosling, 2011), the replication of this study employing non-panel participants would be a potential future research area to confirm the findings presented in this study.

Based on Churchill (1979), for the content validity of each scale, an extensive literature review and consultations with academic and industrial experts should be conducted. Another limitation of this study lies in the item generation process. The content validity of each scale was confirmed based on a literature review and meetings with academic experts. Thus, one of the limitations of this research is these scale items are not validated by industrial experts. For future studies, structured interviews can be conducted to check the applicability and clarity of each construct and scale item.

Also, in this study, we did not consider the experience level of participants in PBCs. Still, many firms lack experience or a full understanding of how to implement PBCs. Firms with different levels of expertise in PBCs may have different views of SCC on PBC benefits. In future studies, researchers can focus on generating valid measurements for experience in PBCs and can examine its effect on the relationship between SCC and PBC benefits.

Furthermore, in future studies, the benefits of PBC can be investigated not only from the perspective of suppliers but also from the viewpoint of buyers. This study defines and conceptualizes investments in PBC within the three interrelated dimensions in the form of second-order construct. The generation of valid and reliable instruments to measure the constructs of investment and benefits of PBC will support future researchers of PBC.

References

Anderson, J. C., & Gerbing, D. W. (1988). Structural equation modeling in practice: A review and recommended two-step approach. Psychological bulletin, 103(3), 411.

Agripino, M., Cathcart, T., & Mathaisel, D. (2002). A lean sustainment enterprise model for military systems. Acquisition Review Quarterly, 9, 274-297.

Bagozzi, R. P., & Yi, Y. (1988). On the evaluation of structural equation models. Journal of the academy of marketing science, 16(1), 74-94.

Barratt, M. (2004). Understanding the meaning of collaboration in the supply chain. Supply Chain Management: An International Journal, 9(1), 30-42.

Bentler, P. M. (1990). Comparative fit indexes in structural models. Psychological bulletin, 107(2), 238.

Bentler, P. M., & Bonett, D. G. (1980). Significance tests and goodness of fit in the analysis of covariance structures. Psychological bulletin, 88(3), 588.

Berkowitz, D., Gupta, J. N., Simpson, J. T., & McWilliams, J. B. (2005). Defining and implementing performance-based logistics in government. Defense Acquisition Review Journal, 11(3), 255-267.

Bergen, Mark, Shantanu Dutta, & Orville C. Walker, Jr. (1992), "Agency Relationships in Marketing: A Review of the Implications and Applications of Agency and Related Theories," Journal of Marketing, 56 (Jul), 1-24.

Boardman, J., & Sauser, B. (2008). Systems thinking: Coping with 21st century problems. CRC Press.

Boudreau, M. W., & Naegle, B. R. (2003). Reduction of total ownership cost. Doctoral dissertation, Naval Postgraduate School. Retrieved from http://stinet.dtic.mil/cgibin/GetTRDoc?AD=A419826&Location=U2&doc=GetTRDoc.pdf.

Bowersox, D.J., Closs, D.J., & Stank, T.P., (2003). How to master cross-enterprise collaboration. Supply Chain Management Review 7 (4), 18–27.

Boyce, J., & Banghart, A. (2012). Performance based logistics and project proof point. Defense AT&L, 41(2), 26-30.

Byrne, B.M., (1989). A Primer of LISREL: Basic Applications and Programming for Confirmatory Factor Analysis Analytic Models. Springer–Verlog, NY.

Buchanan, N., & Klingner, D. E. (2007). Performance-based contracting: are we following the mandate? Journal of Public Procurement, 7(3), 301.

Buhrmester, M., Kwang, T. & Gosling, S.D. (2011). Amazon’s Mechanical Turk a new source of inexpensive, yet high-quality, data? Perspectives on Psychological Science, 6(1), 3-5.

Caldwell, N., & Howard, M. (2014). Contracting for complex performance in markets of few buyers and sellers. International Journal of Operations & Production Management, 34(2), 270-294.

Cao, M., Vonderembse, M. A., Zhang, Q., & Ragu-Nathan, T. S. (2010). Supply chain collaboration: conceptualisation and instrument development. International Journal of Production Research, 48(22), 6613-6635.

Cao, M., & Zhang, Q., (2011). Supply chain collaboration: Impact on collaborative advantage and firm performance. Journal of Operations Management, 29 (3) (2011), 163-180.

Chau, P., (1997). Reexamining a model for evaluating information center success using a structural equation modeling approach. Decision Sciences, 28 (2), 309–334.

Churchill Jr, G. A. (1979). A paradigm for developing better measures of marketing constructs. Journal of Marketing Research, 64-73.

Cohen, M. A., & Netessine, S. (2007). 'Power by the Hour': Can Paying Only for Performance Redefine How Products Are Sold and Serviced? Knowledge@Wharton.

Devries, H. J. (2005). Performance-based logistics: Barriers and enablers to effective implementation. Defense Acquisition Review Journal, 11(3), 241-253.

Department of Defense (DoD) (2014). Performance Based Logistics (PBL) Guidebook. Retrieved from https://acc.dau.mil/psa.

Doerr, K. H., Apte, U., Boudreau, M., & Kang, K. (2010). Decision support models for valuing improvements in component reliability and maintenance. Military Operations Research, 15 (N4), 55-68.

Doll, W.J., Raghunathan, T., Lim, S.J., & Gupta, Y.P., (1995). A confirmatory factor analysis of the user information satisfaction instrument. Information Systems Research 6 (2), 177–188.

Eisenhardt, K. M. (1989). Agency theory: An assessment and review. Academy of management review, 14(1), 57-74.

ElMaraghy, A. H., & Majety, R. (2008). Integrated supply chain design using multi-criteria optimization. International Journal of Advance Manufacturing Technology, 37, 371–399.

Emerson, Richard M. (1962). Power-Dependence Relations. American Sociological Review, 27 (Feb), 31-41.

Essig, M., Glas, A. H., Selviaridis, K., & Roehrich, J. K. (2016). Performance-based contracting in business markets. Industrial Marketing Management, 59, 5-11.

Firchau, V. (1987). Information systems for principal-agent problems. In Agency Theory, Information, and Incentives (pp. 81-92). Springer Berlin Heidelberg.

Fornell, C., & Larcker, D. F. (1981). Structural equation models with unobservable variables and measurement error: Algebra and statistics. Journal of marketing research, 382-388.

Fynes, B., De Búrca, S., & Marshall, D. (2004). Environmental uncertainty, supply chain relationship quality and performance. Journal of Purchasing and Supply Management, 10(4-5), 179-190.

Gansler, J. S., & Lucyshyn, W. (2006). Evaluation of performance based logistics. Doctoral dissertation, Naval Postgraduate School. Retrieved from http://www.acquistionresearch.org/ _files/fy2006/umd-lm-06-040.pdf.

Gaski, John F. (1984). The Theory of Power and Conflict in Channels of Distribution. Journal of Marketing, 48 (Summer), 9-29.

Geary, S., & Vitasek, K. (2005). It’s a war of ideas. Aviation Week & Space Technology, 163(17), 57.

Griffin, J. M. (2005). C-5A galaxy systems engineering case study. AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH CENTER FOR SYSTEMS ENGINEERING.

Guajardo, J. A., Cohen, M. A., Kim, S. H., & Netessine, S. (2012). Impact of performance-based contracting on product reliability: An empirical analysis. Management Science, 58(5), 961-979.

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). Multivariate Data Analysis (7 ed.). Upper Saddle River, NJ: Prentice Hall.

Helander, A., & Möller, K. (2008). How to become solution provider: System supplier's strategic tools. Journal of Business-to-Business Marketing, 15(3), 247-289.

Heide, Jan B. (1994). Inter-organizational governance in marketing channels. The Journal of Marketing, 71-85.

Hooper, D., Coughlan, J., & Mullen, M. (2008). Structural equation modelling: Guidelines for determining model fit. Articles, 2.

Hunter, C. (2006b). Public and private partnerships and the future of the Army industrial enterprise. Retrieved from http://www.lexingtoninstitute.org/library/resources/documents/ Defense/public privatepartnerships.pdf

Hypko, P., Tilebein, M., & Gleich, R. (2010). Benefits and uncertainties of performance-based contracting in manufacturing industries: An agency theory perspective. Journal of Service Management, 21(4), 460-489.

Hypko, P., M. Tilebein, and R. Gleich (2010a). Clarifying the Concept of Performance-based Contracting in Manufacturing Industries: A Research Synthesis. Journal of Service Management 21 (5): 625–655.

Jensen, Michael C., & William H. Meckling (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. Journal of Financial Economics 3 (4), 305-360.

Jin, T., & Y. Tian (2012). Optimizing reliability and service parts logistics for a time-varying installed base. European Journal of Operational Research 218(1), 152-162.

Jin, T., Tian Z., Xie M. (2014). A Game-Theoretical Approach For Optimizing Maintenance, Spares And Service Capacity In Performance Contracting Optimizing Maintenance, Spares And Service Capacity In Performance Contracting. International Journal of Production Economics, 31-43.

Joreskog, K.G, & Sorbom, D., (1986). LISREL VI: Analysis of Linear Structural Relationships by Maximum Likelihood, Instrumental Variables, and Least Squares Methods. Scientific Software, Inc., Moorsville, IN.

Kalwani, M.U., & Narayandas, N., (1995). Long-term manufacturer–supplier relationships: Do they pay? Journal of Marketing 59 (1), 1–15.

Keating, S., & Huff, K. (2005). Managing in the new risk supply chain. Engineering Management, 15(1), 24-27.

Kim, S.H., Cohen, M.A., Netessine, S. (2007). Performance contracting in after-sales service supply chains. Management Science 53 (12), 1843–1858.

Kim, S. H., Cohen, M. A., Netessine, S., & Veeraraghavan, S. (2010). Contracting for infrequent restoration and recovery of mission-critical systems. Management Science, 56(9), 1551-1567.

Kim, S. H., Cohen, M. A., & Netessine, S. (2015). Reliability or Inventory? An Analysis of Performance-Based Contracts for Product Support Services. Working Paper.

Kirk, R. L., & DePalma, T. J. (2005). Performance-based logistics contracts: A basic overview (No. CRM-D0012881. A2-Final). CNA Corporation Alexandria United States.

Kleemann, F. C., & Essig, M. (2013). A providers' perspective on supplier relationships in performance-based contracting. Journal of Purchasing and Supply Management, 19(3), 185-198.

Knemeyer, A.M. & Naylor, R.W. (2011). Using behavioral experiments to expand our horizons and deepen our understanding of logistics and supply chain decision making. Journal of Business Logistics, Vol. 32 No. 4, pp. 296-302.

Kobren, B. (2009). What Performance-based logistics is and what it is not - and what it can and cannot do. Defense Acquisition Review Journal, 16(3), 254-267.

Kratz, L. & Buckingham, B. A. (2010). Achieving outcomes-based life cycle management. Defense Acquisition Review Journal, 77(1), 45-66.

Lavie, D. (2006). The competitive advantage of interconnected firms: an extension of the resource-based view. Academy of Management Review, 31 (3), 638–658.

Mahon, D. (2007). Performance-based logistics: Transforming sustainment. Journal of Contract Management, 5, 53-71.

Marsh, H.W., & Hocevar, D., (1985). Application of confirmatory factor analysis to the study of self-concept: first-and higher-order factor models and their invariance across groups. Psychological Bulletin, 97 (3), 562–582.

Mentzer, J.T., Foggin, J.H., & Golicic, S.L., (2000). Collaboration: The enablers, impediments, and benefits. Supply Chain Management Review, 5 (6), 52–58.

Mentzer, J.T., DeWitt, W., Keebler, J.S., Min, S., Nix, N.W., Smith, C.D., Zacharia, Z.G., (2001). Defining supply chain management. Journal of Business Logistics, 22 (2), 1–25.

Min, S., Roath, A. S., Daugherty, P. J., Genchev, S. E., Chen, H., Arndt, A. D., & Glenn Richey, R. (2005). Supply chain collaboration: what's happening? The International Journal of Logistics Management, 16(2), 237-256.

Mirzahosseinian, H. & R. Piplani (2011). A study of repairable parts inventory system operating under performance-based contract. European Journal of Operational Research, 214(2), 256-261.

Ng, I. C., Maull, R., & Yip, N. (2009). Outcome-based contracts as a driver for systems thinking and service-dominant logic in service science: Evidence from the defence industry. European Management Journal, 27(6), 377-387.

Ng, I. L., & Nudurupati, S. S. (2010). Outcome-based service contracts in the defense industry - Mitigating the challenges. Journal of Service Management, 2(5), 656- 674.

Ng, I. C., Ding, D. X., & Yip, N. (2013). Outcome-based contracts as new business model: The role of partnership and value-driven relational assets. Industrial Marketing Management, 42(5), 730-743.

Park, N.K., Mezias, J.M., & Song, J., (2004). A resource-based view of strategic alliances and firm value in the electronic marketplace. Journal of Management 30 (1), 7–27.

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. Behavior Research Methods, 40(3), 879-891.

Quick, Robert M. (2011). Performance-Based Logistics: A Military Logistics Model. Doctoral dissertation. Retrieved from ProQuest digital dissertation database. (UMI No. 3467482).

Randall, W. S., Pohlen, T. L., & Hanna, J. B. (2010). Evolving a theory of Performance-based Logistics using insights from service-dominant logic. Journal of Business Logistics, 31(2), 35-61.

Randall, W. S., Nowicki, D. R., & Hawkins, T. G. (2011). Explaining the effectiveness of performance-based logistics: a quantitative examination. The International Journal of Logistics Management, 22(3), 324-348.

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

Randall, W. S., Nowicki, D. R., Deshpande, G., & Lusch, R. F. (2014). Converting knowledge into value: gaining insights from service dominant logic and neuroeconomics. International Journal of Physical Distribution & Logistics Management, 44(8/9), 655-670.

Randall, W. S., Hawkins, T. G., Haynie, J. J., Nowicki, D. R., Armenakis, A. A., & Geary, S. R. (2015). Performance-Based Logistics and Interfirm Team Processes: An Empirical Investigation. Journal of Business Logistics, 36(2), 212-230.

Salancik, G. R., & Pfeffer, J. (1978). A social information processing approach to job attitudes and task design. Administrative Science Quarterly, 224-253.

Schoenherr, T., Ellram, L.M. & Tate, W.L. (2015). A note on the use of survey research firms to enable empirical data collection, Journal of Business Logistics, 36 (3), 288-300.

Segars, A.H., & Grover, V., (1998). Strategic information systems planning success: An investigation of the construct and its measurement. MIS Quarterly 22 (2), 139–163.

Secretary of Defense (SoD) Performance Based Logistics (PBL) Awards Selection. https://dap.dau.mil/career/log/blogs/archive/2016/11/22/dod-announces-the-winners-of-the-2016-secretary-of-defense-performance-based-logistics-pbl-awards.aspx.

Selçuk, B., & Agrali, S. (2013). Joint spare parts inventory and reliability decisions under a service constraint. The Journal of the Operational Research Society, 2013-03-01, 64 (3), p. 446.

Selviaridis, K., & Wynstra, F. (2015). Performance-based contracting: a literature review and future research directions. International Journal of Production Research, 53(12), 3505-3540.

Simatupang, T. M., & Sridharan, R. (2002). The collaborative supply chain. The International Journal of Logistics Management, 13(1), 15-30.

Simatupang, T. M., & Sridharan, R. (2005). An integrative framework for supply chain collaboration. The International Journal of Logistics Management, 16(2), 257-274.

Sols, A., &Johannesen, L. H. (2013). The role of transition contracts in performance-based logistics initiatives. Systems Engineering, 16(4), 453-463.

Sols, A., Nowicki, D., & Verma, D. (2007). Defining the fundamental framework of an effective Performance-based logistics (PBL) contract. Engineering Management Journal, 19(2), 40-50.

Stank, T.P., Keller, S.B., & Daugherty, P.J., (2001). Supply chain collaboration and logistical service performance. Journal of Business Logistics 22 (1), 29–48.

Straub, A. (2009). Cost savings from performance-based maintenance contracting. International Journal of Strategic Property Management, 13(3), 205-217.

Vargo, S. L., & Lusch, R. F. (2004). Evolving to a new dominant logic for marketing. Journal of marketing, 68(1), 1-17.

Vitasek, K., Geary, S., & Quick, R. (2006). Performance-based logistics: The basics and beyond. Report presented at The International Logistics Society’s 41st Annual International Logistics Conference & Exhibition, Dallas, TX.

Vitasek, K., Cothran, J., & Rutner, S. (2007). Best practices of public private partnering: Developing a win-win strategy for working with depots (White paper). Knoxville, TN: the University of Tennessee and Supply Chain Visions.

Vitasek, K., & Geary, S. (2007). Performance-Based Logistics—Next Big Thing. ProLogis Supply Chain Review, Summer, 1-11.

Williamson, O. E. (1971). The vertical integration of production: market failure considerations. The American Economic Review, 61(2), 112-123.

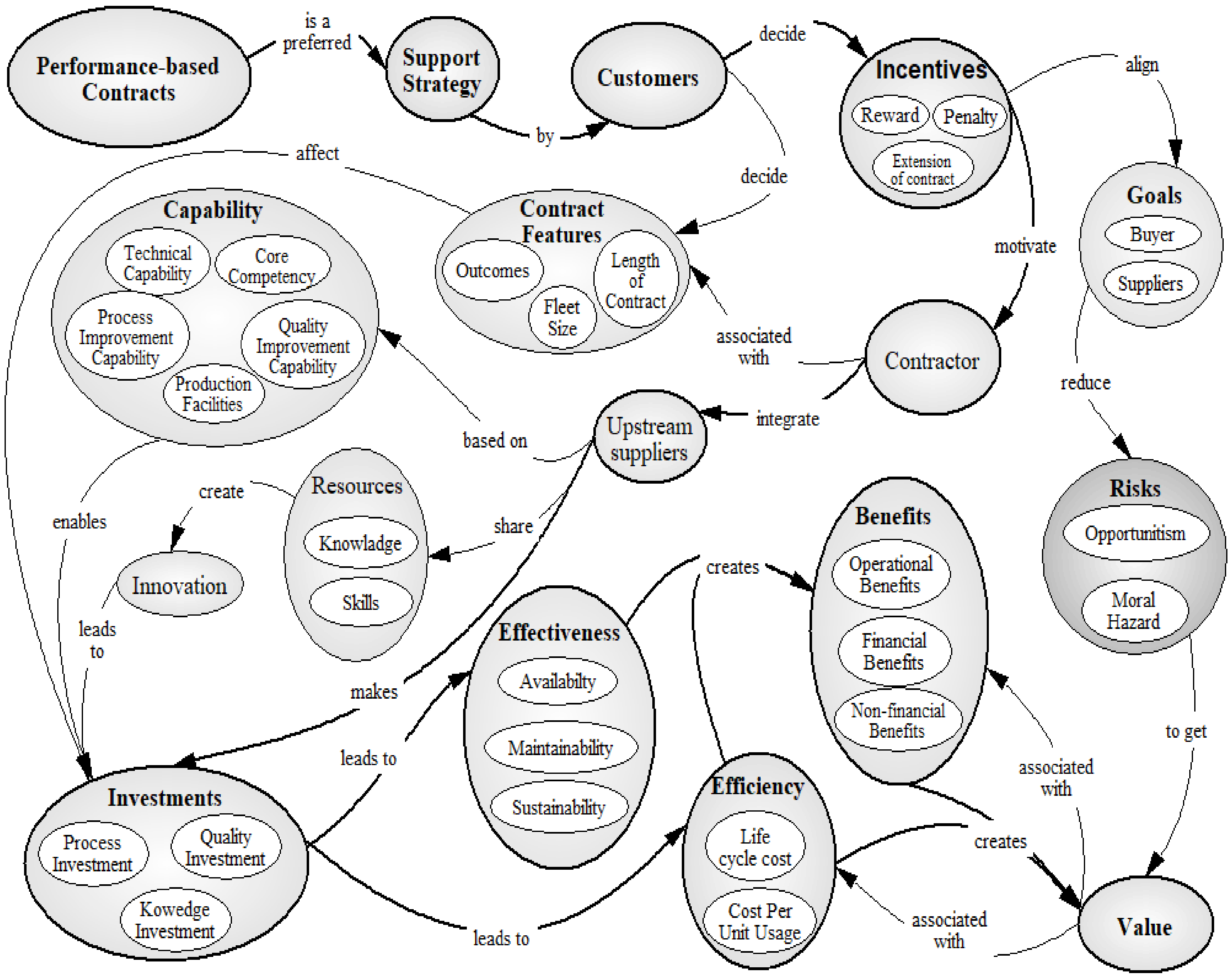
Williamson, O. E. (1975). Markets and hierarchies, New York, 2630.

Williamson, O. E. (1979). Transaction-Cost Economics: The Governance of Contractual Relations. Journal of Law and Economics, 22(2), 233-261.

Williamson, O. E. (1981). The Economics of Organization: the Transaction Cost Approach, American Journal of Sociology, (87:3), 548-575.

Williamson, O. E. (1998). The institutions of governance. The American Economic Review, 88(2), 75-79.

Appendix A. Systemigram of Performance-based Contracting



Appendix B. Survey Instruments

Constructs	Survey Items
Information Sharing	Our firm and supply chain partners exchange accurate information
	Our firm and supply chain partners exchange relevant information
	Our firm and supply chain partners exchange convenient information
Goal Congruence	Our firm and supply chain partners agree that our goals can be achieved through working toward the goals of the supply chain
	Our firm and supply chain partners agree that our goals can be achieved by getting the desired outcomes
	Our firm and supply chain partners agree that our goals can be achieved by getting the desired performance
Collaborative communication	Our firm and supply chain partners have contact and message transmission
	Our firm and supply chain partners have open and two-way communication
	Our firm and supply chain partners use communication channels frequently
Decision synchronization	Our firm and supply chain partners jointly plan product development
	Our firm and supply chain partners jointly plan inventory
	Our firm and supply chain partners jointly plan on promotional events
Knowledge investment	Our firm and supply chain partners jointly search and acquire new knowledge
	Our firm and supply chain partners jointly search and acquire relevant knowledge
	Our firm and supply chain partners jointly assimilate and apply relevant knowledge
	Our firm and supply chain partners jointly assimilate and apply new knowledge
	Our firm and supply chain partners jointly identify knowledge requirements
	Our firm and supply chain partners jointly research and develop contemporary knowledge
Quality Investment	Our firm with supply chain partners invests for highly reliable products
	Our firm with supply chain partners invests for highly durable products
	Our firm with supply chain partners invests for highly quality products
	Our firm with supply chain partners invests for long-lasting products
	Our firm with supply chain partners invests for excellent products
Process investment	Our firm with supply chain partners invests for maintenance service requirements
	Our firm with supply chain partners invests for repair service requirements
	Our firm with supply chain partners invests for visibility of the whole supply chain
	Our firm with supply chain partners invests for visibility of the whole processes
	Our firm with supply chain partners invests for the logistics processes

(table continues)

Constructs	Survey Items
Financial Benefit	Performance-based contracting enables to reduce maintenance costs that result in growth of profits
	Performance-based contracting enables to reduce repair costs that result in growth of profits
	Performance-based contracting enables to reduce inventory costs that result in growth of profits
	Performance-based contracting enables to reduce holding costs for spare parts that result in growth of profits
	Performance-based contracting enables to reduce post-product support costs that result in growth of profits
Operational Benefit	Performance-based contracting enables to improve maintainability of the products
	Performance-based contracting enables to improve sustainability of the products
	Performance-based contracting enables to improve supportability of the products
Non-financial Benefit	Performance-based contracting does well to increase the reputation of the company
	Performance-based contracting does well to increase the image of the company
	Performance-based contracting does well to increase the branding of the company

ESSAY 2

THE SELECTION OF THE SUPPLIER IN PERFORMANCE-BASED LOGISTICS CONTRACTS

Introduction

Performance-based contracting (PBC) is an outcome-based product support strategy to achieve measurable performance outcomes for buyers. In PBC, suppliers can increase their profits by attaining performance goals, while the customer can lower the life-cycle cost with defined outcomes. In PBC arrangements, the customer is essentially buying performance/outcome instead of repeatedly using material-based contracts to purchase individual products and services such as spare parts and repair services (Randall, Nowicki, & Hawkins 2011). In the defense industry, for example, considering the entire life cycle costs of most systems, 28 percent of all dollars spent are used to acquire the system, while the remaining 72 percent goes to after-sales support (Berkowitz, Gupta, Simpson, & McWilliams, 2005; Kobren, 2009). Particularly for systems that have high life-cycle costs, like the defense industry, PBC has become a preferred approach rather than using transaction-based contracting (TBC), which is material-based contracting that depends on multiple contracts for products and services (Kratz, 2003, Xiang et al., 2017).

Performance-based contracts (PBCs) differ from material-based contracts in enabling high system performance and low life cycle costs for buyers (Geary & Vitasek, 2005; Kim, Cohen, & Netessine, 2007; Kobren, 2009). Suppliers under PBCs are rewarded when they achieve the desired performance objectives (Geary & Vitasek, 2005; Jin, Tian, & Xie, 2014; Randal, Pohlen, & Hanna, 2010). PBCs also differ from transaction-based contracts (TBCs) in that they incentivize suppliers to make upfront investments for supportability by affecting inventory level of spare parts and maintenance/repair services (Kim, Cohen, & Netessine, 2007; Randal, Pohlen, & Hanna, 2010).

In PBCs, is it possible to achieve high performance with lower costs in every contract? For this question, Boyce and Banghart (2012) conducted a study to understand the effectiveness and efficiency of performance-based logistics contracts. Authors in the study “Project Proof Point,” examined 21 system, subsystem, and components under the PBCs. Seven contracts could not exceed performance expectation of availability rates, while five out of these seven contracts reduced costs and two caused cost increases. Also in this study, while four contracts caused an increase in costs, one led to reduced performance expectations. Considering the critical importance of following the right steps for suppliers to get the desired outcomes under PBCs (Sols & Johannesen 2013), perhaps these PBCs have failed because the selection of the right supplier was flawed. Until today, there is no specific research for the supplier selection problem in PBCs.

In PBCs, while buyers are determining what is required, such as the target availability level of the system, the supplier determines how to attain this objective (Kim, Cohen, & Netessine, 2007). Not only are the value-added capabilities of suppliers significant for reaching performance goals, but also the reliability of suppliers is critical for buyers who depend on them in all support processes. The risk in supplier selection should be considered at the strategic planning level that has a long-term effect (Ziegenbein & Nienhaus, 2004). Although under PBCs, risks are transferred from the buyer to the supplier, the buyer continues to shoulder the burden of responsibility for the system’s operational performance, especially in government-controlled industries such as defense. For instance, by outsourcing oil extraction to sub-tier suppliers, British Petroleum (BP) may have thought they were shifting risks to sub-tier suppliers, but the consequences of the Deepwater Horizon oil spill in the Gulf of Mexico affected BP (Sammarco et al., 2013). Shifting risks from the buyer to the supplier thus does not imply shifting the consequences and costs.

The successful implementation of PBCs largely depends on the ability of the buyer-supplier partnership to achieve desired performance targets. PBCs are generally applied to complex, critical systems or subsystems, meaning millions of dollars can be lost when the PBC sustainment strategy fails (Kim, Cohen, Netessine, & Veeraraghavan, 2010). Because of the high risks of these critical systems in industries such as defense and aerospace, choosing the best suppliers is uniquely important. Due to the importance of availability and the readiness of these critical systems for buyers, suppliers must be carefully analyzed and evaluated based on their capabilities before entering into PBCs. Therefore, it is essential to avoid and reduce supplier problems through a long-term strategy that ensures a meticulous supplier selection process (Ziegenbein & Nienhaus, 2004).

Through the performance-based approach, responsibilities and the freedom to act are transferred from buyer to supplier (Sols & Johannesen 2013). This logistics shift from the transaction-based approach to the performance-based approach carries some potential risks for buyers. Considering buyers' inability to observe suppliers' actions in PBC (i.e., imperfect information), buyers must mitigate these risks that arise from a lack of control over suppliers. These risks include supplier opportunism, selecting the wrong supplier, and buyer unreasonableness (Gardner, 2008). Considering these risks associated with the supplier, the selection of the accurate supplier becomes an essential precursor for avoiding supplier problems and for effective PBCs (Sols & Johannesen 2013, Ziegenbein & Nienhaus, 2004).

On the other hand, a plethora of studies investigate optimal incentive contract types between suppliers and customers in PBC literature. In PBCs, suppliers are often the original equipment manufacturers (OEM) of the systems they are hired to sustain. Yet previous research has neglected to explore non-OEM PBC suppliers. Additionally, supplier selection is not only crucial for the buyer, but is also significant for a system integrator in PBC who integrates the upstream suppliers' abilities and knowledge to create continuous value (Randall et al., 2010). Thus the selection of the right suppliers based on experience, knowledge, capabilities, and skills is critical to achieving the desired outcome.

The dearth of research on pre-contractual PBC problems raises the following research questions: Which criteria are the most significant in performance-based contracts (PBCs) when compared to transaction-based contracts (TBCs)? Which steps should buyers take to ensure the selection of the best supplier for their desired outcomes? The primary purposes of this research are to highlight the most significant supplier selection criteria for buyers in PBCs and to show usage of a convenient decision tool for buyers to select the best supplier in the PBCs.

The rest of this paper is organized as follows. After explaining theoretical paradigms of this study, the research method is presented in [Research Method]. Then, a literature review covering TBCs and PBCs supplier selection criteria and performance metrics for the chosen industry is presented in [Literature review]. The discussion continues with an examination of the awarded PBCs and their suppliers in [Investigation of the Awarded PBCs] and with an exploration of the supplier selection criteria in [Exploration of the Supplier Selection Criteria]. These are followed with decision support models in supplier selection and the implementation of a multi-criteria decision support method to solve the supplier selection problem. The paper concludes with a discussion in the last section [General Discussion and Implications].

Theoretical Background: Principal-Agent Theory

As with any contractual situation, an agency problem emerges when the preferences and goals of the principal and agent conflict, and when there is imperfect information between principal and agent (Eisenhardt, 1989). In the principal-agent problem, two different types of problems emerge: a pre-contractual problem and a post-contractual problem (Bergen et al., 1992). In the pre-contractual problem, the buyer (principal) can be exposed to “adverse selection,” which is caused by “hidden information.” In this situation, the supplier (agent) can distort its potential or ability to carry out a contract (Bergen et al. 1992). In the post-contractual problem, which is caused by “hidden action” because of imperfect information about a suppliers’ (agent's) work, it is more difficult to detect whether the agent performed according to the principal’s interest (Eisenhardt, 1989). The buyer can alleviate these problems through supplier selection, information gathering, contract design, and relational exchange (Bergen et al. 1992). Although previous studies of PBC grounded in agency theory (Selviaridis & Wynstra 2015), those researches concentrate only on the post-contractual agency problem. The pre-contractual agency problem is an uninvestigated research area in the PBC literature.

Research Method

This study explores critical supplier characteristics by investigating the logical links in data collected from literature reviews, previous studies, secondary data, and awarded contracts in PBCs. Due to the lack of investigation of supplier selection criteria in PBCs, grounded theory methodology is an appropriate technique to extend understanding of this phenomenon in PBCs. This study employs grounded theory technique because it is a convenient inductive exploratory research tool that allows in-depth research when there is little knowledge to understand the phenomena in question (Charmaz, 2006; Locke, 2007; Merriam, 1998). It generates a holistic approach that generates understanding and allows for the exploration of antecedents based on qualitative analysis of data from the field (Goulding, 1998; Randall & Mello, 2010). Although it has been used widely in social science disciplines, this methodology can also be seen in supply chain management studies, such as the work of Manuj and Mentzer (2008) and Randall, Pohlen, and Hanna (2010). Thus, by enabling the use of multiple data sources, grounded theory technique is an appropriate technique for this study. In comparing the collected data, it highlights similarities that reveal the critical features of suppliers in the performance-based environment (Merriam, 1998).

Data Collection

This study includes a literature review of PBCs and supplier selection criteria, awarded PBCs in the defense industry, and secondary data for leading companies in PBCs in the U.S. defense industry as the primary data source. The literature review of PBCs appears in Essay 1: “The Effects of Supply Chain Collaboration in PBCs.” In using grounded theory, constant data comparison (Creswell, 2003) are undertaken to highlight the critical characteristics of suppliers for effective PBCs.

Data to support this study was collected from academic sources, government sources, and secondary data. To find scholarly publications of PBCs and supplier selection criteria, a large variety of search databases was used, such as EBSCOhost, Emerald, Taylor & Francis, Science Direct, Wiley, and Google Scholar. Defense Acquisition University and the Department of Defense were the principal sources for government documents and reports that support case study research. Statista Database is the primary resource for obtaining data for leading companies in PBCs in the U.S. defense industry.

Analysis of the collected data helped determine essential selection criteria for suppliers that aligned with the fundamental characteristics of PBCs for successful PBCs.

Through the research steps shown in Figure 2.1, this study builds on findings in the PBC literature in Essay 1, and the literature on supplier selection criteria in TBCs and PBCs. After presenting PBC metrics in a selected industry, the awarded PBCs and their key suppliers who are responsible for integrating the entire supply chain were analyzed. Then, based on these criteria and requirements for the buyer's objectives, supplier selection criteria were highlighted for the success of PBCs. In the last step, a multi-criteria decision support tool was used for selecting the right supplier among possible alternatives.

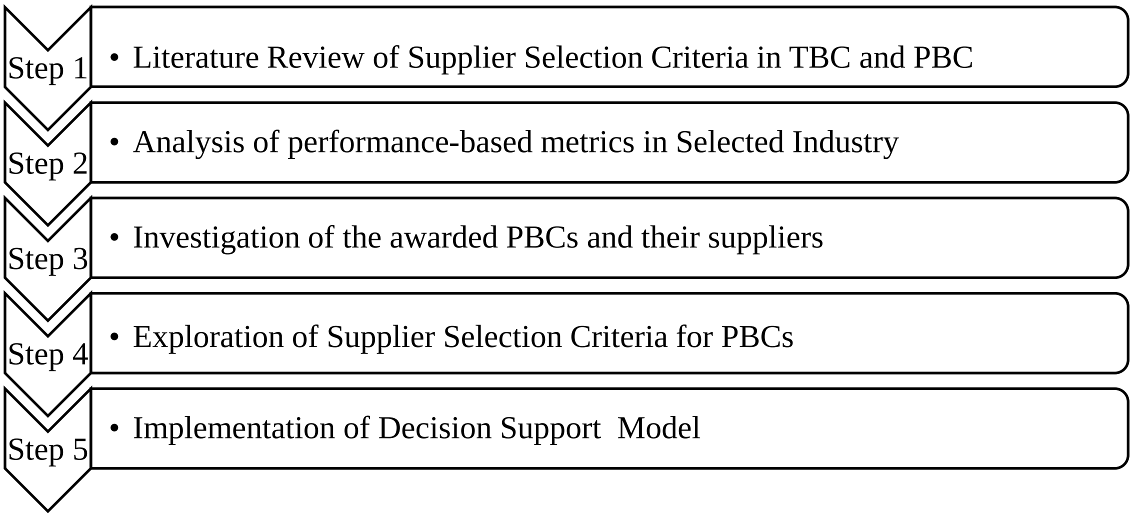


Figure 2.1: Research flows for supplier selection criteria.

Literature Review of Supplier Selection Criteria

After reviewing the supplier selection criteria in TBCs and PBCs literature, this section presents a theoretical background of this study. Taking into account the outcomes specified in each contract, each industry type calls for different performance metrics to achieve desired performance. The success of the PBCs depends on the abilities of performance providers to meet the metrics determined by the buyer. Therefore, before continuing to select the needed criteria for the accurate supplier, performance metrics are specified for the chosen industry. This study is constructed on the performance metrics of the U.S. Defense Industry, where performance-based logistics contracts start to use preferable logistics support strategy since 1993. Thus, the performance metrics that are used as a representation of the outcome in the defense industry was reviewed in the last part of this section.

Supplier Selection Criteria in Transaction-Based Contracts

Previous research has identified various individual and integrated approaches capable of handling multiple quantitative and qualitative factors as solutions to the supplier selection problem. In his seminal study, in which he conducted a survey of 300 organizations, Dickson (1966) highlighted 23 important evaluation criteria for supplier selection. Based on his findings, the importance of these criteria can be seen in Table 2.1, within the ranking column. While his study found that each supplier's ability to meet the required quality was extremely important, the criteria of delivery, performance history, warranties, price, production facilities, and capacity of suppliers were also found to be significant. Weber, Current, and Benton (1991) classified criteria from 74 articles between 1966-1990 that addressed the supplier selection problem. Based on the frequency of each criteria in these papers, they found that price took priority. followed by delivery, quality, production facilities and capacity, and geographical location. Cheraghi et al. (2004) expanded on these studies by reviewing 39 articles between 1996 and 2004 and classifying 31 supplier selection criteria. Based on their findings, the criteria of quality, delivery, price, technical capability, repair service production facilities, and capacity were the most important factors, respectively (see Table 2.1). They also emphasized that the criteria of training aids, operating controls, desire for business, warranties and claim policies, and packaging ability were no longer significant criteria for supplier selection. On the other hand, they found that reliability, flexibility, process improvement, consistency, product development, long-term relationships, professionalism, and integrity were significant new features for supplier selection. Thiruchelvam and Tookey (2011) reviewed articles published between 2001-2010 and classified 37 supplier selection criteria that are shown in Table 2.1. They found that price, delivery, quality, and service have vital importance for most industries. More recently, Kumar and Pani (2014) investigated the importance of different supplier selection criteria. They found product quality, delivery compliance, and price to be criticality important. In this study, these criteria were assessed to determine what was most relevant to supplier selection in PBCs.

Supplier Selection Criteria in PBCs

The supplier selection criteria for PBC remain almost untouched in the literature. Our search uncovered only one source, The Performance-based Logistics (PBL) Guidebook (DoD, 2014) that normatively suggests supplier selection criteria for performance-based arrangements. According to the PBL Guide Book (2014), supplier aptitude can be measured using criteria such as capacity, capability, efficiency, and risk. Capacity is defined as the availability of resources to perform a sustainment activity. Capability is the ability and skill to conduct a sustainment activity. Efficiency means the cost to the supplier for providing a performance outcome in line with industry standards and other alternatives. Risk is the potential for the supplier to be unsuccessful while conducting a sustainment activity (DoD, 2014). To reduce the risk associated with supplier selection, the criteria of financial performance, capacity, quality, and past performance are found as significant indicators for a risk assessment based on their strategic importance for key performance metrics, which vary by the supplier in PBCs (Moore & Loredo 2013).

Table 2.1: Comparison and ranking of selection attributes.

Criterion	(Dickson, 1966) (Survey)	(Weber et al., 1991) (1966-1990)		(Cheraghi et al., 2004) (1990-2001)		(Thiruchelvam and Tookey, 2011) (2001-2010)		Overall		
	Ranking	Papers	(%)	Papers	(%)	Papers	(%)	Papers	(%)	Ranking
Quality	1	40	53	31	79	37	100	108	72	3
Delivery	2	44	58	30	77	36	97	110	73	2
Performance history	3	7	9	4	10	10	27	21	14	10
Warranties and claim policies	4	0	0	0	0	5	13	5	1	17
Production facilities and capacity	5	23	30	10	26	20	54	53	36	4
Price	6	61	80	26	67	37	100	124	83	1
Technical capability	7	15	21	11	28	24	65	50	33	5
Financial position	8	7	9	7	18	17	46	31	21	7
Procedural compliance	9	2	3	2	5	0	0	4	0.5	18
Communication system	10	2	3	4	4	7	19	13	1	13
Reputation and position in industry	11	8	10	1	1	8	22	17	1	11
Desire for business	12	1	1	0	0	2	1	3	0.5	20
Management and organization	13	10	11	7	7	22	59	39	26	6
Operating controls	14	3	4	0	0	0	0	3	0.5	21
Repair service	15	7	9	11	28	11	30	29	19	9
Attitude	16	6	8	5	13	6	16	17	11	12
Impression	17	2	15	2	5	4	11	8	0.5	15
Packaging ability	18	3	4	0	0	4	11	7	0.5	16
Labor relations record	19	2	3	1	3	6	16	9	0.6	14
Geographical location	20	16	21	2	5	12	32	30	20	8
Amount of past business	21	1	1	0	0	2	1	3	0.2	22
Training aids	22	2	3	0	0	0	0	2	0.2	23
Reciprocal arrangements	23	2	3	2	5	0	0	4	0.3	19

Analysis of Performance Metrics in Defense Industry

Because it can potentially reduce more than 15 percent of post-production support costs of systems (Miller, 2008), PBCs are successfully used in many industries, such as defense, aerospace, road construction, transportation, health care, telecommunications, child and family services, and manufacturing support (Administration for Children & Families, 2011; Boyce and Banghart, 2012; Guajardo et al., 2012; Straub, 2009; Transportation Research Board, 2009). In each industry type, and even in the same industry, performance metrics for PBC can be changed based on the buyer's desire. Thus, the metrics should be clearly identified at an early stage of strategy development for the implementation of effective PBCs based on the industry type. PBL contracts are the priority post-product support strategy in the U.S. defense industry since 2003 (DAU, 2005a). Also considering the yearly assessment of PBCs by the Department of Defense (DoD) and the availability of this awarded contracts on their website (www.dau.mil), the U.S. defense industry was considered for exploring supplier selection of criteria in this study.

Before examining selection criteria for suppliers in PBCs, performance metrics that are used as a representation of the outcome and alignment of participants' goals need to be clarified. Metrics are necessary in the post-contractual term to create a vision for the entire network and to integrate all capabilities toward the same ends. They are also significant in the pre-contractual term, for the buyer and system integrator, who is responsible for integrating all suppliers' efforts to achieve the outcomes specified by the customer. Before choosing the system integrator by the buyer or choosing upstream suppliers in the network by the systems integrator, the performance metrics - which provide a tangible result of PBC governance – should be defined and understood by all participants (Randall et al., 2015). Choosing inappropriate or irrelevant metrics may cause the selection of the wrong supplier. Selecting appropriate performance metrics that create value can help in choosing a supplier and integrating their knowledge, capabilities, and skills to find cost-efficient and innovative solutions for existing problems (Wittmann et al. 2014).

Several vital metrics focus all the supply chain entities in performance-based arrangements in the defense industry, namely availability, reliability, logistics response time, cost per unit of usage, and logistics footprint (DoD, 2014). The most critical metric in the defense industry for PBCs is operational availability, the amount of time that a system is available for a mission (DAU, 2005, Mahon 2007, Nowicki, Kumar, Steudel, & Verma, 2008). Reliability of systems, subsystems or components is another key metric. Reliability improvement requires an upfront investment that affects the spare parts and repair strategies of suppliers (Kim, Cohen, & Netessine, 2007; Randal, Pohlen, & Hanna, 2010). Thus, PBCs create a necessity for suppliers to make upfront investments (Griffin, 2008). A third key metric, cost per unit of usage, is calculated by dividing the total cost by unit of measurement for a given system (Boudreau & Naegle, 2003, DAU, 2005). The object associated with the cost per unit of usage is to minimize the total service cost associated with the procurement, operation, and maintenance of a weapon system. The fourth metric, logistics footprint, is the size of the support presence required to deploy, sustain, and move a system (DAU, 2005; Mahon, 2007). In the defense industry, the objective associated with the logistics footprint is minimizing support elements needed to sustain a system (Kumar et al. 2007; Mahon, 2007). The last metric, logistics response time, is the period from logistics demand to receiving this request (DAU, 2005).

Investigation of the Awarded Performance-Based Contracts

After presenting performance metrics in the defense industry, this section investigates awarded PBL contracts and their suppliers in the defense industry. The selection of suppliers was made based on the number of PBCs awarded by the Department of Defense between 1995 and 2016. Four major companies were selected to explore the selection criteria: Lockheed Martin Corporation, Raytheon Company, Northrup Grumman Corporation, and The Boeing Company. Since 1995, they have received 20, 12, 7, and 6 awarded contracts, respectively. Based on these companies' repeated achievements, we can say that experience of PBCs and supplier performance history is good indicators of suppliers' future successes of in outcome-based contracts.

To analyze these four companies alongside the other defense contractors, we used Statista Database. For fiscal year 2016, the contract value for these companies among U.S. Department of Defense contractors is as follows: Lockheed Martin is first; the Boeing Company is second; Raytheon Company is fourth; and Northrup Grumman is fifth, with contract values of $36.2 billion, $24.4 billion, $12.8 billion, and $10.8 billion, respectively.

Average expenditures on research and development (R&D) for these four companies are: Lockheed Martin spent $798.5 million (from 2002 to 2016); The Boeing Company $3.2 billion (from 2002 to 2016); Raytheon Company $530.3 million (from 2002 to 2016); and Northrup Grumman $578.7 million (from 2007 to 2016) (see Table 2.2). These R&D expenditures involve experimentation, design improvement, and test activities for these developments for defense systems. There is a close relationship between R&D expenditures and avoiding future costs that are highly significant in PBC. For instance, Lockheed Martin's R&D expenditures for its Sustainability Management Plan Progress reflect a 8.9% increase in supply chain savings, growth of $676 million in realized savings and customer savings, decreases in rates of defects, rework, and repairs in manufactured products, and increases in product quality and reliability in 2015 compared to 2013. Common features of these four companies, financial capacity and R&D

expenditures, indicate the importance of the financial capacity of the suppliers, which is critical for R&D budgets that are necessary for upfront investments for effective and efficient PBCs.

Table 2.2: Selected companies and contracts.

Company	Number of awarded PBCs	Ranking (Contract value)	Research and Development (Million $)	Selected Awarded PBCs
Lockheed Martin Corporation	20	1	798.5 (2002-2016)	F-22 (Lockheed Martin, 2008)
Raytheon Company	12	4	530.3 (2002-2016)	F/A-18 (FIRST) (Boeing, 2007)
Northrup Grumman Corporation	7	5	578.7 (2007-2016)	Joint Stars (Northrup Grumman, 2000/2011)
The Boeing Company	6	2	3,200 (2002-2016)	ARL 67 Radar Warning System (Raytheon, 2008)

To explore essential criteria for supplier selection, we also look into four PBCs conducted by these companies. These contracts are: F-22 (Lockheed Martin, 2008); F/A-18 (FIRST) (Boeing, 2007); Joint Stars (Northrup Grumman, 2000/2011); and ARL 67 Radar Warning System (Raytheon, 2008) (Kirk and DePalma 2005, Dau.mil, 2017). The findings of our examination of PBCs awarded to these companies are presented in Table 2.3. We found that innovative teaming and process management, using lean six sigma quality process, and the visibility of all processes by integration of data sharing with the customer are vital factors underlying effective and efficient PBCs. In all four cases, reliability enhancement for the systems was accomplished, and the time from diagnosing a problem to repairing failure items was reduced by using a system engineering approach. Also, technology insertion, reliability and maintenance improvements, obsolescence management, integrated logistics support, and technical assistance were shown as common features behind these awarded PBCs.

Table 2.3: Findings from awarded PBCs in U.S. defense industry.

Company/ Contract/ Year	Findings and Achievements	
Lockheed Martin Corporation F-22 (2008) (DoD, 2008)	Availability	• Highest readiness rates in program history. • 20% improvement in availability.
	Reliability	• Reduce the average of engineering change proposal from an 18-month proposal process to the 8 months proposal process. • 58% improvement in meantime between maintenance (MTBM), over the past three years, %69 improve in MTBM across the F-22 fleet.
	Maintainability	• 35% improvement in non-mission capable supply rates. • Achievement of reducing 47% footprint from 2007 to 2010.
	Management	• System engineering approach. • Innovative teaming and process management. • Innovative public-private partnering, while meeting all 50/50 core requirements.
	Cost	• 39% reduction operations and maintenance budget, saving $500M. • Repair costs per flight hour improved 14% in 2007. • Improved reliability of fifth generation F-22 Raptor is projected to save $14B over the life of the aircraft, saving more than 35% in support costs.
The Boeing Company F/A-18 (FIRST) (2007) (DoD, 2007)	Availability	• Exceed Fleet readiness expectations while reducing total ownership cost. • Operational availability rate for FIRST components of 84.3% and for non-FIRST components of 71%. • 16% increase in mission-capable rates rise from 57% in 2000 to 73% in 2007.
	Reliability	• Increase in Mean Flight Hours Between Demand (9.0 for First, 3.0 for non-first). • Reduce the average of engineering change proposal from 242 days to 39 days.
	Maintainability	• Reduce repair cycle time by 38% for canopies, and 48% tail hooks. • Usage of web-based visibility, online shipping instructions, and lean repair practices that have reduced repair cycle time and logistics footprint.
	Management	• System engineering approach • The implication of “lean six sigma” principles and system engineering approach. • Facilitating the overall life cycle management of FA-18 reliability, supportability, and total ownership costs. • Uniting responsiveness of industry with the expertise and capacity of organic support activities. • Government utilizes financial incentives in FIRST to increase reliability, flexibility, and responsiveness.
	Cost	• Provided $48.3M in savings in spares purchased concurrently with production. • Projected savings and cost avoidance of approximately $430M on a $20M investment for a return in investment 22 to 1. • Cost savings of approximately $40M to date with additional cost avoidance realized over the life of the aircraft.

(table continues)

Company/ Contract/ Year	Findings and Achievements	
Northrup Grumman Joint Stars (2000/2011)	Availability	• 96% mission effectiveness rate (more than 72,800 hours). • Readiness Spares Packages fill rate is above 96% for the life of contract
	Reliability	• Actual flying hours increased approximately from 7,850 hours to 14,000 hours.
	Maintainability	• Reduce minor repairs by 26 days, and major overhauls by 41 days for the number one critical item, the Vapor Cycle Machine. • An average of 450 wholesaler demands processed monthly with an average mission capable delivery of 30 hours. • Stockage effectiveness for all contractor managed items from 2000 to 2010 averages 96.9% for the life of this contract. • Government data interchange, visibility in one interface. • Application of Lean Six Sigma principles and system engineering approach.
	Management	• System engineering approach • Total System Support Responsibility (TSSR) combines of a dozen smaller contracts. • Integrates and coordinates processes and procedures for system evolution, testing, and sustainment. • Awarded 2000 with a six-year basic period and potential 22-year term (earned 12 additional years until 2018).
	Cost	• As of TSSR year 10, savings in the amount of $45.945M. • This saving provides funding for unexpected requirements, such as unfunded software maintenance. • Best value and core competencies.
Raytheon Company ARL 67 Radar Warning System (2008) DoD (2007)	Availability	• Availability metric of 90% was exceeded by 97% on its first combat deployment, Operating Iraq Freedom. • Material availability increased from 68% to 97%.
	Reliability	• Contract guaranteed reliability growth; established metrics for reliability and availability. • Reliability and maintainability data and repair trends are monitored, and technology insertion and corrective actions are taken to improve reliability. • Consistently exceeded the contractual reliability required, currently is greater than 700 hours Mean Flight Hours Between Failures (MTBF) / requirements start at 300 and grow to 450 hours.
	Maintainability	• Advanced interactive repair diagnostic capability. • Actual measured performance delivery within 5 days, consecutively over the last 8 years average is 1.4 days.
	Management	• System engineering approach • First contract 1999 with 6-year base period and additional five-year ceiling priced option. • System engineering approach.
	Cost	• $62.7M savings over the 11 years of the contract ($29.6M base period, $33.1M in the option period). • These savings and cost avoidance are attributed to Raytheon's use of technology insertion and failure diagnostics improvements.

Exploration of the Supplier Selection Criteria in Performance-Based Contracts

The performance-based approach creates a new environment and way of thinking for suppliers of systems whose operation and support costs exceed their production costs (Singh & Sandborn 2006). In the incentive structure of the PBC, the supplier can boost its profitability by creating new solutions for existing problems through investment and innovation to reduce overall costs (Hypko et al. 2010). The PBC incentivizes co-creation of value within suppliers and between the buyer and suppliers. To efficiently obtain desired outcomes, such as availability rates of systems, all suppliers' abilities and knowledge must be integrated with performance requirements (Randall et al., 2010). Because of these new dynamics in the performance-based approach, buyers should have to assess suppliers based on their knowledge, skills, and capacities to mitigate the risks associated with the selection of an inappropriate supplier. Based on our findings, the important criteria for supplier selection in TBCs and PBCs are presented in Figure 2.2.

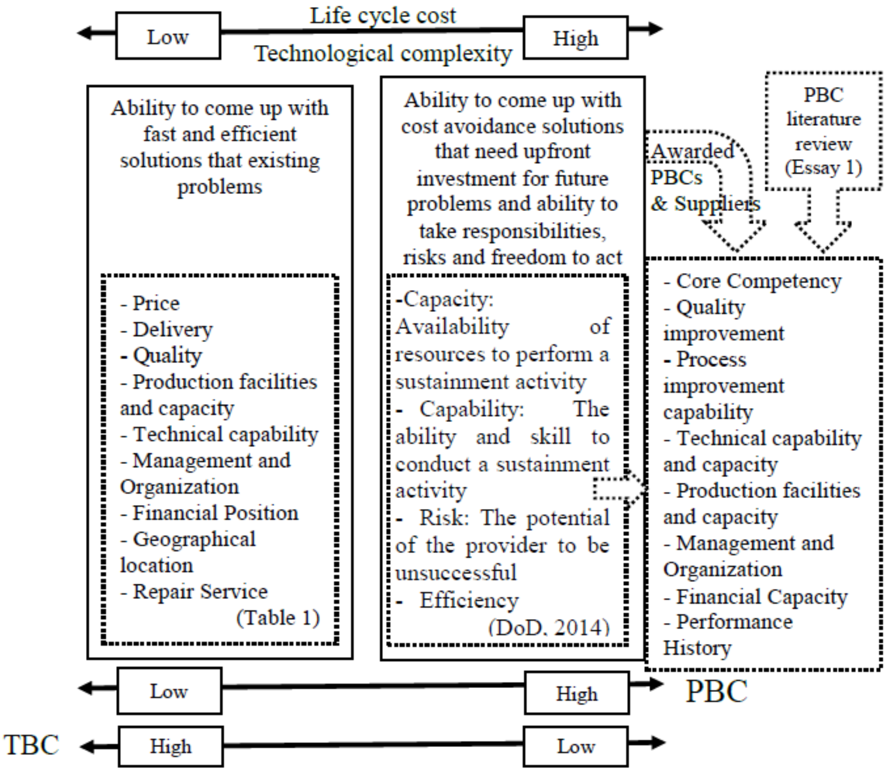


Figure 2.2: Criteria for supplier selection under the TBCs and PBCs.

Unlike supplier selection criteria for the TBCs, this study reveals the importance of a “core competency” and “process improvement capability” as new selection criteria in PBCs. It highlights six more selection criteria that should be considered priorities for buyers.

In PBCs, how to achieve performance metrics depends on the supplier’s decisions. Suppliers in PBCs are not only focused on facilitating the efficiency of logistics processes, but also work to improve the reliability of systems. As shown in our findings of awarded contracts, the suppliers with a system engineering approach increase the readiness of systems and reduce life-cycle costs of systems in the long-term. Additionally, through reliability growth of systems, they reduce demand for spare parts and repairs (Randall et al. 2011, 2015). To increase the reliability growth of systems, suppliers should have a high technical capability and capacity to facilitate the systems’ engineering requirements. For example, a system availability rate, a critical performance metric in the defense industry, can be improved by increasing the mean-time-between-failures through redesigning the systems, subsystems, or components. Taking into account complex systems, making improvements to reliability, and testing long-term impacts on availability rates requires technical capability, which is closely related to the core competency of suppliers. Because of these engineering activities, core competency and comprehensive system knowledge are critical necessities for the selection of the supplier. This criterion is significant in order to see the potential of the suppliers’ ability to increase the reliability of the system, and it will directly impact the decision of suppliers for a trade-off between redesign and inventory of spare parts, which affects the effectiveness of PBCs.

Process improvement and quality enhancement of products in all supply chain networks are significant for creating value for the end user and for all stakeholders in the supply chain. Effective PBCs need collaboration from upstream suppliers and the integration of whole processes to achieve desired outcomes. Additionally, as shown in the findings of awarded contracts, to understand the product and manufacturing defects and to make improvements in quality to reduce maintenance, repair, and overhaul costs are critical for increasing system availability. Identifying early warning signals of product quality issues in the field, based on data, on-site performance monitoring, and customer complaints requires effective quality management. Like in F/A-18 (FIRST) contracts with the Boeing Company, projected savings and cost avoidances of approximately $430M on a $20M investment led to decreases in the number of spare parts, repair transactions, and sustainment costs while increasing system readiness and availability rates ((DoD, 2007).

To find new solutions resulting in cost efficiency and high readiness, experience, skills, and knowledge of suppliers are becoming critical. These specialties can be used to create sustainable value and competitive advantages in the entire value chain. The technical capability of suppliers is also essential for improving logistic processes to develop cost-efficient solutions for providing a sustainment activity and increasing system readiness. Integrating this ability with the knowledge and skills of the supplier network can transform traditional sustainment activities to create new, efficient activities to achieve customer objectives that are specified in PBCs metrics (Randall et al. 2010).

Financial capacity of suppliers is also significant in PBL contracts in order to make upfront investments that have long-term consequences for life cycle cost and system readiness. In particular, upfront investment for the reliability enhancement of systems or subsystems requires R&D expenditures that involve experiment, design enhancement, and systems testing. Although we could not obtain specific reliability investment for each contract, considering the R&D expenditures of the four successful companies discussed above, these high expenditures need the financial capacity to conduct independent research activities that can be absorbed in the long-term. Also, as shown in the cases above, providers have the potential for a longer-term contract in addition to their basic period. For instance, Northrup Grumman earned 12 additional years to its six-year basic period in the Joint Stars contract in 2000. Making process improvements in the entire supply chain not only requires financial capacity but also management and organization capability. Management and organization capability are also required to find block chains in the entire system to improve processes. The performance history of suppliers in the industry is another significant criterion to measure the suppliers' ability to integrate upstream suppliers' objectives with customer goals (Randall et al. 2010). Performance history is also significant for decreasing risk by selecting the most reliable suppliers, due to the potential for a participant in the supplier network to be unsuccessful or cause harm while conducting a sustainment activity (DoD, 2014). Furthermore, this criterion closely relates to the supplier's potential to take a risk to transform knowledge into value-added activities, such as reliability improvement or process enhancement. A PBC risk-reward governance structure provides an entrepreneurial environment for suppliers who have the freedom to act to achieve desired outcomes (Randall et al. 2014). Therefore, this criterion is also significant for understanding suppliers' entrepreneurial potential to decide how to convert knowledge into value.

Proposed Decision Support Model for Supplier Selection

Besides identifying the criteria of suppliers, a methodology is needed to evaluate decision makers' assessments to find the best supplier. Decision makers need to realize the importance of bounded rationality— limits to cognition and imperfect information (Kornov et al., 2000)—to make the adequate assessment in supplier selection. Simon (1982) proposed bounded rationality theory as an alternative basis for the mathematical modeling of decision-making. Based on bounded rationality, decision-makers' rationality is restricted by imperfect information, the limited capacity of their mind, and limited available time to make a decision (Simon, 1982, 1991). Because of these constraints, decision-makers who expect to make rational decisions are limited to making satisfying decisions. In the literature, various methods have been used to address the supplier selection problem. For the supplier selection problem, a typical group decision-making process (Cheraghi et al., 2004), extensive qualitative and quantitative multi-criteria group decision making (MCGDM) approaches have been projected.

The supplier assessment process consists of four stages: the identification of objectives, selection of criteria, assessment of candidates, and selection (De Boer, van der Wegen, & Telgen, 1998, De Boer, Labro, & Morlacchi, 2001, Chou & Chang 2008). After the previous section identified the most critical criteria for supplier selection in PBCs, we show how decision-makers can use these criteria in their selection process. To determine the most appropriate supplier, multi-criteria group decision-making methods should be used to address the supplier selection problem (Chou & Chang 2008). Ho, Xu, and Dey (2010) and Chai et al. (2013) summarized the literature on decision support models, published between 2000 to 2008 and 2008 to 2012, respectively. Techniques used in the supplier selection include:

(I) Fuzzy set theory (Ordoobadi, 2009; Labib, 2011);

(II) Technique for order preference by similarity to ideal solution (TOPSIS) (Boran et al., 2009; Chen, Lin, & Huang, 2006; Wang, Cheng, & Kun-Cheng, 2009; Zouggari & Benyoucef, 2012);

(III) The analytic hierarchy process (AHP) (Barbarosoglu & Yazgac, 1997; Chan, 2003; Wang, Chin, & Leung, 2009);

(IV) Data envelopment analysis (DAE) (Narasimhan, Talluri, & Mendez, 2006; Seydel, 2005; Talluri, Narasimha, & Nair, 2006; Wu et al., 2007);

(V) Fuzzy extended analytic hierarchy process method (Chan & Kumar, 2007; Chan et al., 2008; Kilincci & Onal, 2011);

(VI) Analytic network process (ANP) (Bayazit, 2006, Gencer & Gurpinar, 2007; Sarkis & Talluri, 2002;);

(VII) Linear programming (Ng, 2008; Talluri & Narasimhan 2005);

(VIII) Integer linear programming (Hong et al., 2005);

(IX) Goal programming (Karpak et al., 2001);

(X) Multi-objective programming (Narasimhan, Talluri, & Mahapatra 2006, Wadhwa & Ravindran 2007);

(XI) Simple multi-attribute rating technique (Birgun, 2003; Huang & Keska (2007); and

(XII) Genetic algorithm (Ding, Benyoucef, & Xie 2005).

Among these methods, DAE, AHP, and TOPSIS are the most popular and extensively used to solve the supplier selection problem (Chai et al. 2013, Ho et al. 2010). Because of imprecise and uncertain information about alternatives and characteristics of the fuzzy environment, linear membership functions are used for capturing the ambiguity of these linguistic assessments of decision-makers (Herrera & Herrera-Viedma, 2000). To contend with many different criteria and alternatives, fuzzy TOPSIS performs better regarding AHP (Lima, Osiro, & Carpinetti, 2014). TOPSIS can be applied when decision-makers have a different priority for various alternatives. Because of the characteristics of supplier selection, which is the typical MCGDM problem, the TOPSIS method will be used to solve the supplier-selection problem under a fuzzy environment in this section (Bottani & Rizzi 2006). The best optimal choice in TOPSIS should have the farthest distance from the fuzzy negative ideal solution (FNIS) and the shortest distance from the fuzzy positive ideal solution (FPIS) (Boran, Genç, Kurt, & Akay, 2009). The steps of the TOPSIS method are presented in Figure 2.3, which is adapted from Chen, Lin, & Huang (2006). The steps are:

Step 1: An establishment of a group of decision-makers, and the determination of evaluation criteria.

Step 2: A selection of the proper linguistic variables for the significance weight of the criteria and linguistic assessments of suppliers.

Step 3: The transformation of linguistic assessments of alternatives into trapezoidal fuzzy numbers.

Step 4: The creation of the fuzzy-decision matrix and the adaption of this matrix.

Step 5: The creation of the weighted adapted fuzzy decision matrix.

Step 6: Calculation of the fuzzy positive ideal solution (FPIS, A^*) and the fuzzy negative ideal solution (FNIS, A^-) of alternatives.

Step 7: Computation of the interval of each supplier from FPIS and FNIS.

Step 8: Computation of the closeness coefficient (CC_i) of each supplier.

Step 9: Based on the proximity coefficient of suppliers, the evaluation status of each supplier and the ranking order of all suppliers.

Step 1

Establish a group of decision-makers, and the determination of the evaluation criteria.

- a set of K decision-makers called $K = (D_1, D_2, \ldots . D_K)$;
- a set of m possible suppliers called $A = (A_1, A_2, \ldots . A_m)$;
- a set of n criteria, C= $(C_1, C_2, \ldots . C_n)$ with which supplier performances are measured;
- a set of performance ratings of $A_i (i = 1,2, \ldots m)$ with respect to criteria $C_J (j = 1,2, \ldots n)$, called $X = (x_{iJ,}\ i = 1,2, \ldots, m;\ j = 1,2, \ldots, n)$.

Step 2

Select the proper linguistic variables for the significance weight of the criteria and the linguistic assessments of suppliers.

The range of aggregated fuzzy rating consists of all decision-makers' fuzzy ratings.

- Trapezoidal fuzzy numbers of fuzzy ratings $R_k = (a_k, b_k, c_k, d_k), k = (1,2, \ldots, K)$ can be defined as: $= (a, b, c, d)$, $k = 1,2, \ldots, K$, where $a \quad = \min\{a_k\}$, $b_{ij} = \frac{1}{K} \sum_{k=1}^{K} b_k$, $c_{ij} = \frac{1}{K} \sum_{k=1}^{K} c_k$, $d_{ij} = \max\ \{d_k\}$
- The fuzzy rating of each decision maker $D_k (k = 1,2, \ldots K)$ can be represented as a positive trapezoidal fuzzy number $R_k (k = 1,2, \ldots K)$ with membership function $\mu_{R_k}(x)$.
- The fuzzy rating and significance weight of the k^th^ decision maker be $x_{ijk}(a_{ijk,}, b_{ijk}, c_{ijk}, d_{ijk})$ and $w_{jk}(w_{jk1,}, w_{jk2}, w_{jk3}, w_{jk4})$; where $i = 1,2, \ldots, m \ and\ j = 1,2, \ldots, n$

Step 3

Accumulate the weight of criteria to get the accumulated fuzzy weight w_j of criterion C_j , and pool the DM's ratings to get the accumulated fuzzy rating x_{ij} of supplier A_i under criterion C_j.

- The aggregated fuzzy ratings (x_{iJ}) of alternatives with respect to each criterion can be calculated as: $x_{ij} = (a_{ij,}, b_{ij}, c_{ij}, d_{ij})$, where $a_{ij} = \min\{a_{ijk}\}$, $b_{ij} = \frac{1}{K} \sum_{k=1}^{K} b_{ijk}$, $c_{ij} = \frac{1}{K} \sum_{k=1}^{K} c_{ijk}$, $d_{ij} = \max\ \{d_{ijk}\}$
- The aggregated fuzzy weights (w_j) of each criterion can be calculated as $w_j = (w_{j1,}, w_{j2}, w_{j3}, w_{j4})$, where $w_{j1} = \min\{w_{jk1}\}$, $w_{j2} = \frac{1}{K} \sum_{k=1}^{K} w_{jk2}$, $w_{j3} = \frac{1}{K} \sum_{k=1}^{K} w_{jk3}$, $w_{j4} = \max\ \{w_{jk4}\}$

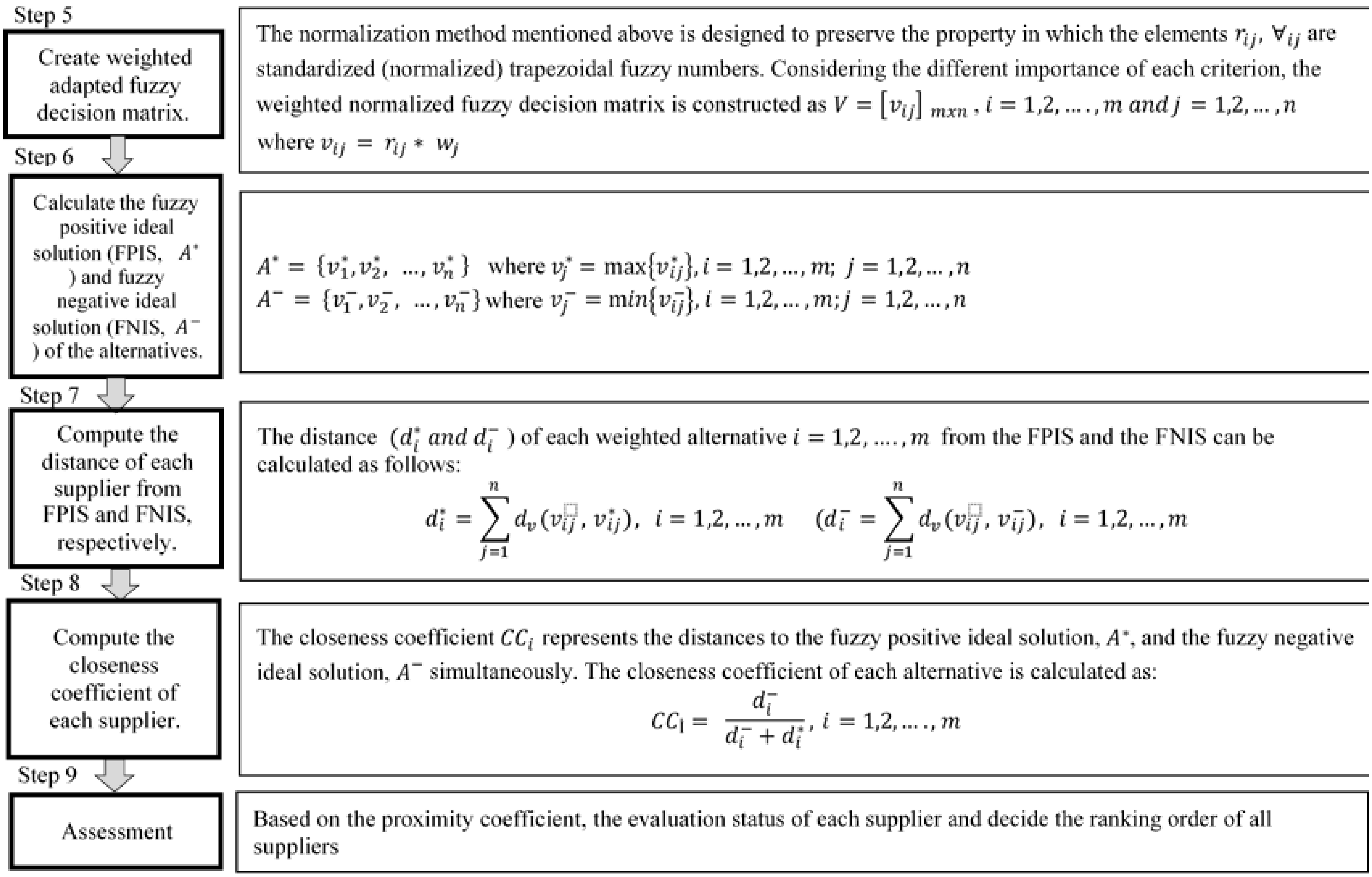
Step 4

Create the fuzzy-decision matrix and the adapted fuzzy-decision matrix.

The set of criteria can be divided into benefit criteria (the larger the rating, the higher the preference) and cost criteria (the smaller the rating, the greater the preference). Therefore, the normalized fuzzy decision matrix can be represented as $R = [r_{ij}]_{mxn}$, $i = 1,2, \ldots, m \ and\ j = 1,2, \ldots, n$ where B and C are the sets of benefit criteria and cost criteria, respectively, and

$$r_{ij} = \left(\frac{a_{ij}}{d_j^*}, \frac{b_{ij}}{d_j^*}, \frac{c_{ij}}{d_j^*}, \frac{d_{ij}}{d_j^*}\right), \quad j \in B; \qquad r_{ij} = \left(\frac{a_j^-}{d_{ij}}, \frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right), \quad j \in C;$$

$$d_j^* = max_i\, d_{ij}, \ j \in B; \qquad a_j^- = min_i\, a_{ij}, \ j \in C$$



Step 5

Create weighted adapted fuzzy decision matrix.

The normalization method mentioned above is designed to preserve the property in which the elements r_{ij}, $\forall_{ij}$ are standardized (normalized) trapezoidal fuzzy numbers. Considering the different importance of each criterion, the weighted normalized fuzzy decision matrix is constructed as $V = [v_{ij}]_{mxn}$, $i = 1,2,\dots,m$ and $j = 1,2,\dots,n$ where $v_{ij} = r_{ij} * w_j$

Step 6

Calculate the fuzzy positive ideal solution (FPIS, A^*) and fuzzy negative ideal solution (FNIS, A^-) of the alternatives.

$$A^* = \{v_1^*, v_2^*, \dots, v_n^*\} \text{ where } v_j^* = \max\{v_{ij}^*\}, i = 1,2,\dots,m;\ j = 1,2,\dots,n$$

$$A^- = \{v_1^-, v_2^-, \dots, v_n^-\} \text{ where } v_j^- = min\{v_{ij}^-\}, i = 1,2,\dots,m; j = 1,2,\dots,n$$

Step 7

Compute the distance of each supplier from FPIS and FNIS, respectively.

The distance $(d_i^*\ and\ d_i^-)$ of each weighted alternative $i = 1,2,\dots,m$ from the FPIS and the FNIS can be calculated as follows:

$$d_i^* = \sum_{j=1}^{n} d_v(v_{ij}^{\square}, v_{ij}^*),\ \ i = 1,2,\dots,m \qquad (d_i^- = \sum_{j=1}^{n} d_v(v_{ij}^{\square}, v_{ij}^-),\ \ i = 1,2,\dots,m$$

Step 8

Compute the closeness coefficient of each supplier.

The closeness coefficient CC_i represents the distances to the fuzzy positive ideal solution, A^*, and the fuzzy negative ideal solution, A^- simultaneously. The closeness coefficient of each alternative is calculated as:

$$CC_{\mathrm{l}} = \frac{d_i^-}{d_i^- + d_i^*},\ i = 1,2,\dots,m$$

Step 9

Assessment

Based on the proximity coefficient, the evaluation status of each supplier and decide the ranking order of all suppliers

Figure 2.3: Technique for ordering preference by similarity to ideal solution (TOPSIS) steps.

Numerical Example of Proposed Method

In this section, a numerical example of the application of the TOPSIS method is presented. As an example of the supplier selection process, we consider five different supplier alternatives (A) for PBCs and three Decision Makers (DM) for the group decision-making process. The hierarchical structure of the decision problem is shown in Figure 2.4.

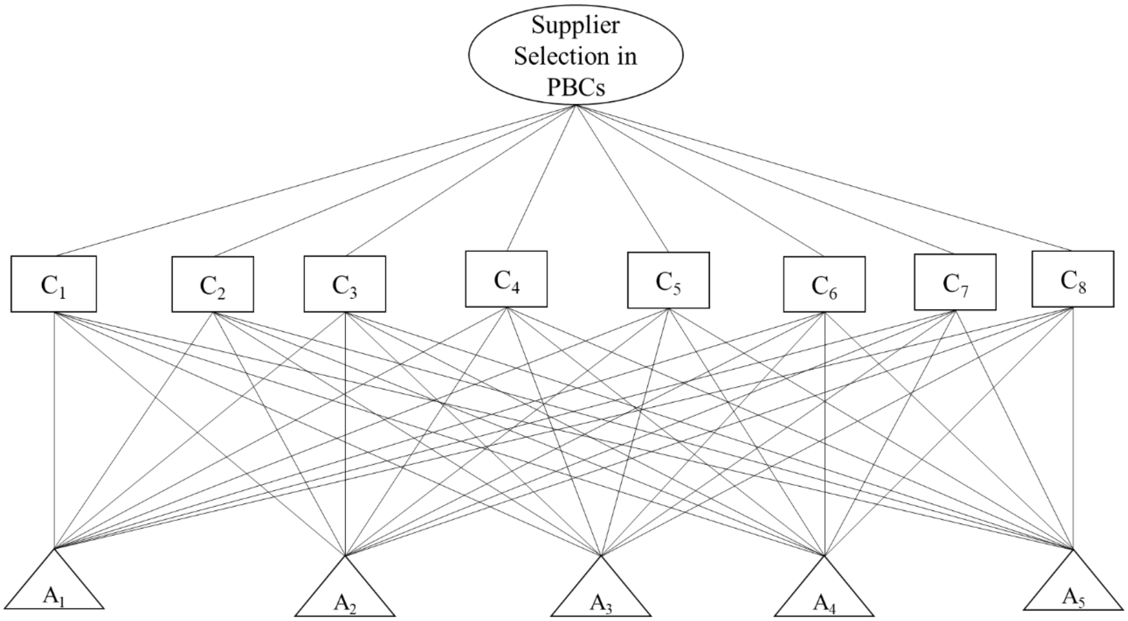


Figure 2.4: Hierarchical structure of multi-criteria decision problem.

In Step 1, a group of decision-makers was established and assessment criteria were identified. The eight selection criteria listed above were used (see Figure 2.2). Three individual staff officers who served in the Turkish Armed Forces formed our group of decision-makers to evaluate alternatives for the performance-based contract described below. This example offers a case that builds upon the major elements of performance-based arrangements.

Case: The supplier in a performance-based contract offers an integrated combination of the system and related support services, such as maintenance, repair, and overhaul. Based on outcomes, the supplier will receive additional revenue or penalties. You are in the position of the purchasing agent, responsible for the selection of a supplier in the Department of Defense. You will make a performance-based contract for a new integrated weapon system that needs complex support. The system requires more sophisticated testing to ensure that all systems interfaces are properly functioning. You want to build your contract with your supplier for 90% availability of this weapon system for a six-year contract with the extended option of a ten-year period. Please put yourself in the position of the purchasing agent responsible for the selection of a supplier to provide 90% availability of this weapon system for a six-year contract. Then, please rate the importance he would attach to each factor while considering potential suppliers. (Note: The names of potential suppliers were not mentioned in the study.)

In Step 2, selection of proper linguistic variables for the significance weight of criteria and linguistic assessments for suppliers was made. The decision-makers use the linguistic variables, and these variables were expressed in positive trapezoidal fuzzy numbers, which are shown in Figures 2.5 and Figure 2.6, to assess the importance of each criterion and the ratings of alternatives. For example, the linguistic variable ‘‘Medium Low (ML)’’ can be represented as (0.2; 0.3; 0.4; 0.5).

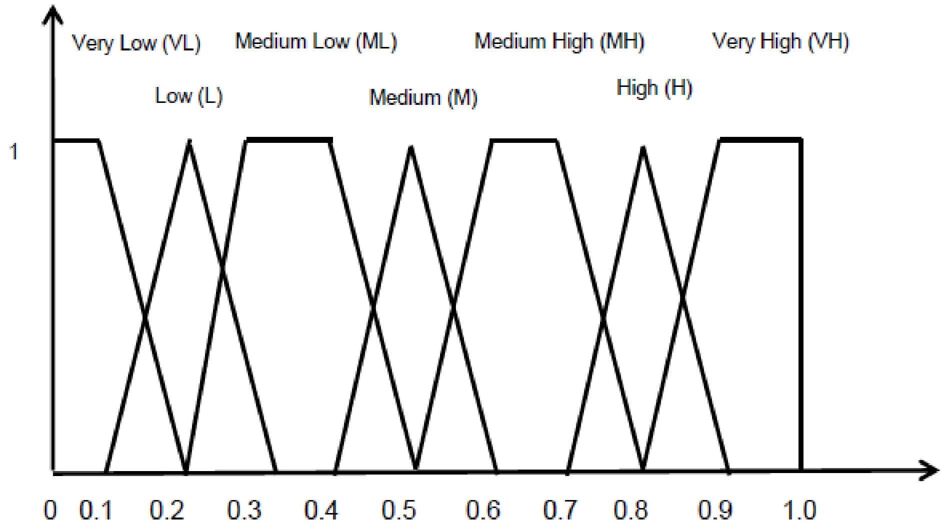


Figure 2.5: Linguistic variables for importance weight of each criterion.

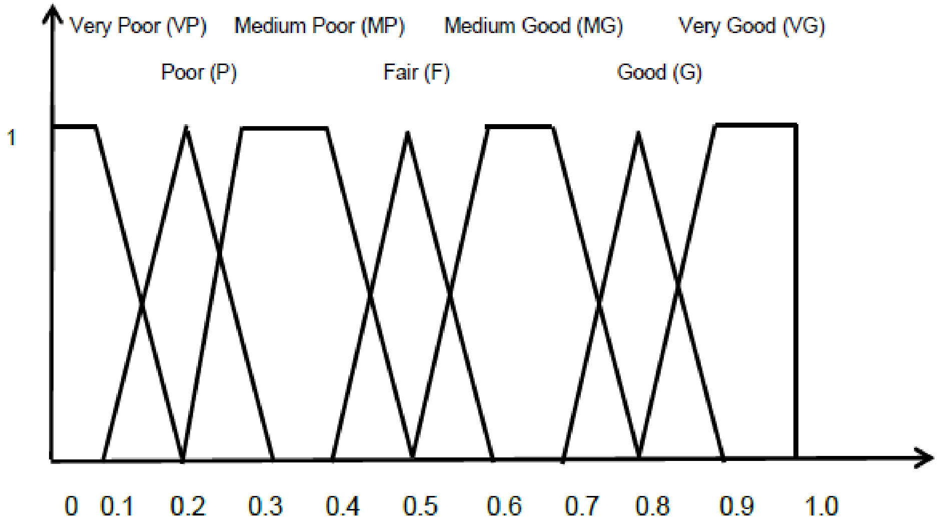


Figure 2.6: Linguistic variables for ratings.

The decision-makers' linguistic variables for evaluating the importance of criteria and ratings of alternatives on qualitative criteria are shown in Table 2.4 and Table 2.5. In Step 3, the linguistic assessments of alternatives were converted into trapezoidal fuzzy numbers in Table 2.6. In Step 4 and Step 5, following the adaptation of the fuzzy decision matrix, the adapted fuzzy decision matrix and weighted adapted fuzzy decision matrix were constructed in Table 2.7 and Table 2.8.

Table 2.4: Importance of weight criteria from the decision makers.

Criteria	Decision makers		
	D_1	D_2	D_3
Core Competency (C_1)	VH	VH	VH
Quality (C_2)	H	H	H
Process improvement (C_3)	H	VH	H
Technical capability and capacity (C_4)	H	H	H
Production facilities and capacity (C_5)	H	MH	M
Management and Organization (C_6)	VH	VH	H
Financial Capacity (C_7)	H	MH	H
Performance History (C_8)	VH	VH	H

Very Low (VL), Low (L), Medium Low (ML), Medium (M), Medium-High (MH), High (H), Very High (VH)

Table 2.5: Ratings of the five suppliers by decision makers under various criteria.

Criteria	Suppliers	Decision Makers		
		D_1	D_2	D_3
C_1	A_1	G	G	G
	A_2	VG	VG	VG
	A_3	G	VG	G
	A_4	G	G	VG
	A_5	G	VG	VG
C_2	A_1	G	MG	G
	A_2	G	VG	VG
	A_3	VG	VG	G
	A_4	G	G	MG
	A_5	G	MG	G
C_3	A_1	G	G	G
	A_2	VG	VG	VG
	A_3	VG	VG	G
	A_4	MG	G	G
	A_5	G	VG	MG
C_4	A_1	MG	G	G
	A_2	VG	VG	G
	A_3	MG	G	G
	A_4	VG	G	G
	A_5	G	G	MG
C_5	A_1	G	VG	G
	A_2	VG	VG	VG
	A_3	G	VG	G
	A_4	G	G	VG
	A_5	MG	MG	MG
C_6	A_1	G	MG	G
	A_2	G	VG	VG
	A_3	VG	VG	G
	A_4	G	G	MG
	A_5	G	MG	G

(table continues)

Criteria	Suppliers	Decision Makers		
		D_1	D_2	D_3
C_7	A_1	G	G	G
	A_2	VG	VG	VG
	A_3	VG	VG	G
	A_4	MG	G	G
	A_5	G	VG	VG
C_8	A_1	G	MG	G
	A_2	G	VG	VG
	A_3	VG	VG	G
	A_4	G	G	MG
	A_5	G	MG	G

Very Poor (VP), Poor (P), Medium Poor (MP), Fair (F), Medium Good (MG), Good (G), Very Good (VG)

Table 2.6: Fuzzy decision matrix and fuzzy weights of alternatives.

	A_1	A_2	A_3	A_4	A_5	Weight
C_1	(7,8,8,9)	(8,9,10,10)	(7,8.3,8.7,10)	(7,8.3,8.7,10)	(7,8.7,9.3,10)	(0.8,0.9,1.0,1.0)
C_2	(5,7.3,7.7,9)	(8,8.7,9.3,10)	(8,8.7,9.3,10)	(5,7.3,7.7,9)	(5,7.3,7.7,9)	(0.7,0.8,0.8,0.9)
C_3	(7,8,8,9)	(8,9,10,10)	(7,8.7,9.3,10)	(5,7.3,7.7,9)	(5,7.7,8.3,10)	(0.7,0.83,0.87,1.0)
C_4	(5,7.3,7.7,9)	(7,8.7,9.3,10)	(5,7.3,7.7,9)	(7,8.3,8.7,10)	(5,7.3,7.7,9)	(0.7,0.8,0.8,0.9)
C_5	(7,8.3,8.7,10)	(8,9,10,10)	(7,8.3,8.7,10)	(7,8.3,8.7,10)	(5,6,7,8)	(0.4,0.63,0.67,0.9)
C_6	(5,7.3,7.7,9)	(7,8.7,9.3,10)	(7,8.7,9.3,10)	(5,7.3,7.7,9)	(5,7.3,7.7,9)	(0.7,0.87,0.93,1.0)
C_7	(7,8,8,9)	(8,9,10,10)	(7,8.7,9.3,10)	(5,7.3,7.7,9)	(7,8.7,9.3,10)	(0.5,0.73,0.77,0.9)
C_8	(5,7.3,7.7,9)	(7,8.7,9.3,10)	(7,8.7,9.3,10)	(5,7.3,7.7,9)	(5,7.3,7.7,9)	(0.7,0.87,0.93,1.0)

Table 2.7: Adapted fuzzy decision matrix.

	A_1	A_2	A_3	A_4	A_5
C_1	(0.7,0.8,0.8,0.9)	(0.8,0.9,1,1)	(0.7,0.83,0.87,1)	(0.7,0.83,0.87,1)	(0.7,0.87,0.93,1)
C_2	(0.5,0.73,0.77,0.9)	(0.8,0.87,0.93,1)	(0.8,0.87,0.93,1)	(0.5,0.73,0.77,0.9)	(0.5,0.73,0.77,0.9)
C_3	(0.7,0.8,0.8,0.9)	(0.8,0.9,1,1)	(0.7,0.87,0.93,1)	(0.5,0.73,0.77,0.9)	(0.5,0.77,0.83,1)
C_4	(0.5,0.73,0.77,0.9)	(0.7,0.87,0.93,1)	(0.5,0.73,0.77,0.9)	(0.7,0.83,0.87,1)	(0.5,0.73,0.77,0.9)
C_5	(0.7,0.83,0.87,1)	(0.8,0.9,1,1)	(0.7,0.83,0.87,1)	(0.7,0.83,0.87,1)	(0.7,0.8,0.8,0.9)

(table continues)

	A_1	A_2	A_3	A_4	A_5
C_6	(0.5,0.73,0.77,0.9)	(0.7,0.87,0.93,1)	(0.7,0.87,0.93,1)	(0.5,0.73,0.77,0.9)	(0.5,0.73,0.77,0.9)
C_7	(0.7,0.8,0.8,0.9)	(0.8,0.9,1,1)	(0.7,0.87,0.93,1)	(0.5,0.73,0.77,0.9)	(0.7,0.87,0.93,1)
C_8	(0.5,0.73,0.77,0.9)	(0.7,0.87,0.93,1)	(0.7,0.87,0.93,1)	(0.5,0.73,0.77,0.9)	(0.5,0.73,0.77,0.9)

Table 2.8: Weighted adapted fuzzy decision matrix.

	A_1	A_2	A_3	A_4	A_5
C_1	(0.56,0.72,0.8,0.9)	(0.64,0.81,1,1)	(0.56,0.75,0.87,1)	(0.56,0.75,0.87,1)	(0.56,0.78,0.93,1)
C_2	(0.35,0.58,0.62,0.81)	(0.56,0.69,0.74,0.9)	(0.56,0.69,0.74,0.9)	(0.35,0.58,0.62,0.81)	(0.35,0.58,0.62,0.81)
C_3	(0.49,0.66,0.69,0.9)	(0.56,0.75,0.87,1)	(0.49,0.72,0.81,1)	(0.35,0.61,0.67,0.9)	(0.35,0.64,0.72,1)
C_4	(0.35,0.58,0.62,0.81)	(0.49,0.69,0.74,0.9)	(0.35,0.58,0.62,0.81)	(0.49,0.69,0.74,0.9)	(0.35,0.58,0.62,0.81)
C_5	(0.28,0.52,0.58,0.9)	(0.32,0.57,0.67,0.9)	(0.28,0.52,0.58,0.9)	(0.28,0.52,0.58,0.9)	(0.28,0.5,0.54,0.81)
C_6	(0.35,0.64,0.72,0.9)	(0.49,0.76,0.86,1)	(0.49,0.76,0.86,1)	(0.35,0.64,0.72,0.9)	(0.35,0.64,0.72,0.9)
C_7	(0.35,0.58,0.62,0.81)	(0.4,0.66,0.77,0.9)	(0.35,0.64,0.72,0.9)	(0.25,0.53,0.59,0.81)	(0.35,0.64,0.72,0.9)
C_8	(0.35,0.64,0.72,0.9)	(0.49,0.76,0.86,1)	(0.49,0.76,0.86,1)	(0.35,0.64,0.72,0.9)	(0.35,0.64,0.72,0.9)

In Step 6, the fuzzy positive ideal solution (FPIS, A^*) and fuzzy negative ideal solution (FNIS, A^-) of alternatives will be decided (Chen, Lin, & Huang, 2006). In Step 7, the computation of distance from FPIS and FNIS for each supplier is shown in Table 2.9 and Table 2.10. In Step 8, we compute the closeness coefficient (CC_i) of each supplier (shown in Table 2.11).

$$A^* = \begin{bmatrix} (1,1,1,1),(0.9.0.9,0.9,0.9),(1,1,1,1),(0.9,0.9,0.9,0.9),(0.9,0.9,0.9,0.9),(1,1,1,1), \\ (0.9,0.9,0.9,0.9),(1,1,1,1) \end{bmatrix},$$

$$A^- = \begin{bmatrix} (0.56,0.56,0.56,0.56),(0.35,0.35,0.35,0.35),(0.35,0.35,0.35,0.35),(0.35,0.35,0.35,0.35), \\ (0.28,0.28,0.28,0.28),(0.35,0.35,0.35,0.35),(0.25,0.25,0.25,0.25),(0.35,0.35,0.35,0.35) \end{bmatrix}$$

Table 2.9: Distances between A_i $(i = 1,2,\ldots.,5)$ and A^* with respect to each criterion.

	C1	C2	C3	C4	C5	C6	C7	C8
$d\ (A_1, A^*)$	0.29	0.35	0.35	0.35	0.40	0.39	0.35	0.39
$d\ (A_2, A^*)$	0.20	0.21	0.26	0.34	0.35	0.29	0.29	0.29
$d\ (A_3, A^*)$	0.26	0.21	0.31	0.35	0.40	0.29	0.32	0.29
$d\ (A_4, A^*)$	0.26	0.32	0.42	0.34	0.40	0.37	0.41	0.37
$d\ (A_5, A^*)$	0.25	0.28	0.40	0.35	0.37	0.37	0.32	0.37

Table 2.10: Distances between A_i $(i = 1,2,\ldots.,5)$ and A^- with respect to each criterion.

	C1	C2	C3	C4	C5	C6	C7	C8
$d\ (A_1, A^-)$	0.27	0.29	0.37	0.29	0.37	0.36	0.37	0.36
$d\ (A_2, A^-)$	0.34	0.39	0.38	0.38	0.39	0.47	0.47	0.47
$d\ (A_3, A^-)$	0.24	0.39	0.44	0.29	0.37	0.47	0.45	0.47
$d\ (A_4, A^-)$	0.24	0.29	0.34	0.38	0.37	0.36	0.36	0.36
$d\ (A_5, A^-)$	0.31	0.29	0.40	0.29	0.29	0.36	0.45	0.36

Table 2.11: Computations of d_i^*, d_i^- and CC_i.

	d_i^*	d_i^-	$d_i^* + d_i^-$	CC_i
A1	2.87	2.68	5.55	0.483
A2	2.23	3.29	5.52	0.596
A3	2.43	3.12	5.55	0.562
A4	2.89	2.78	5.67	0.490
A5	2.71	2.75	5.46	0.504

In Step 9, the assessment status of each supplier was made based on the closeness coefficient of each alternative. The closeness of the coefficient represents the ranking order of all suppliers, and we can decide the best alternative from among a set of feasible suppliers. According to the closeness coefficient of suppliers: $CC_2 > CC_3 > CC_5 > CC_4 > CC_1$. Therefore, we can determine the ranking order that indicates the appropriateness of all suppliers, A2 – A3 – A5 – A4 – A1, respectively.

General Discussion and Implications

The paradigm shift from the transaction-based approach to the performance-based approach has introduced some critical issues related to suppliers. The determination of suppliers in pre-contractual terms should be carefully considered by decision makers, because of the “adverse selection” problem caused by “hidden information.” While responsibilities and the freedom to act transfer from buyer to supplier in PBCs, this approach creates an uncertain relationship of dependency on the supplier. Because of the strategic importance of selecting the accurate supplier, this study investigates selection criteria in PBCs and presents implementation in a decision support model (TOPSIS) for assessing alternatives for decision makers.

Grounded theory methodology was used to explore selection criteria in PBCs since it creates a holistic approach for research and for linking findings when there is little knowledge to understand the phenomena in question (Charmaz, 2006). As a primary data source for exploring essential criteria for suppliers, this study builds upon findings from the literature review of PBCs and supplier selection criteria, PBCs awarded in the defense industry, and secondary data for leading companies in PBCs in the U.S. defense industry. We also drew on the literature review of PBCs, the bulk of which is presented in Essay 1 and in the findings of the first essay, “The Effects of Supply Chain Collaboration in PBCs.”

Supplier selection is not only crucial for buyers but is also significant for the contractor who is responsible for integrating upstream suppliers. In PBCs, supplier assessment needs to be structured according to the supplier partnerships’ ability to create new solutions for existing problems that result in cost-efficient performance outcomes. Since choosing appropriate performance metrics is significant for the selection of the best supplier and the alignment of the supplier's goals (Randall et al., 2010), before determining selection criteria for the assessment of suppliers in PBCs, performance metrics were identified. Then, we looked into the main common features of suppliers from the defense industry, based on the number of PBCs awarded by the Department of Defense, and four awarded contracts were analyzed to explore critical criteria. These criteria were considered based on their strength to deliver desired outcomes on performance metrics in the defense industry. Based on the findings, this research highlights eight essential criteria that should be considered to assess suppliers under performance-based arrangements. Unlike supplier selection criteria for TBCs, this study reveals the importance of a "core competency" and "process improvement capability" as new supplier selection criteria in PBCs and highlighted six more critical criteria that should be considered a priority by the buyer. The other six criteria are: quality improvement capability; technical capability and capacity; production facilities and capacity; management and organization; financial capacity; and performance history (see Figure 2.2). Additionally, in this study, after showing the possible methods of MCGDM problems, the usage of TOPSIS fuzzy approach was presented in a case to demonstrate how to determine the best accurate supplier.

Exploration of those supplier selection criteria in PBC context will help to reduce the risks in agency problem in the pre-contractual term that arise from "hidden information" of the supplier to distort his potential or ability to gain a contract (Bergen et al. 1992). So, buyers can avoid "adverse selection" issue in agency problem by usage of those appropriate selection criteria. Utilization of those criteria n decision mechanisms will reduce uncertainties and threats about the potential of the supplier to be unsuccessful while providing a performance.

Considering the specialties of each PBC, these criteria can be investigated based on the contracts' requirements. For successful implementation of PBCs, decision-makers must decide on these criteria or build a team to determine criteria for suppliers. In future studies, these criteria can be extended with face-to-face interviews with PBC managers and buyers. Also, a survey with PBC managers can be conducted to validate these selection criteria.

This study highlights the significant characteristics of suppliers for effective PBCs. It also reveals new essential criteria that extend supplier selection criteria in the literature. Considering the high dependence on suppliers in PBCs and the shift in responsibility to providers, using the criteria presented in this study will mitigate risks for decision makers regarding wrong supplier selection in performance-based arrangements. Additionally, better assessment and evaluation of suppliers will lead to effective and efficient PBCs.

References

Administration for Children & Families (2011). National Quality Improvement Center on the Privatization of Child Welfare Service, DHHS, Washington, DC.

Banaeian, N., Mobli, H., Fahimnia, B., Nielsen, I. E., & Omid, M. (2018). Green supplier selection using fuzzy group decision making methods: A case study from the agri-food industry. Computers & Operations Research, 89, 337-347.

Barbarosoglu, G., & Yazgac, T. (1997). An application of the analytic hierarchy process to the supplier selection problem. Production and inventory management journal, 38(1), 14.

Bayazit, O. (2006). Use of analytic network process in vendor selection decisions. Benchmarking: An International Journal, 13(5), 566-579.

Berkowitz, D., Gupta, J. N. D., Simpson, J. T., & McWilliams, J. B. (2005). Defining and implementing Performance-based logistics in government. Defense Acquisition Review Journal, 77(3), 255-268.

Bergen, M., Dutta, S., & Walker Jr, O. C. (1992). Agency relationships in marketing: A review of the implications and applications of agency and related theories. Journal of Marketing, 56(3), 1-24.

Birgun Barla, S. (2003). A case study of supplier selection for lean supply by using a mathematical model. Logistics Information Management, 16(6), 451-459.

Boran, F. E., Genç, S., Kurt, M., & Akay, D. (2009). A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method. Expert Systems with Applications, 36(8), 11363-11368.

Bottani, E., & Rizzi, A. (2006). A fuzzy TOPSIS methodology to support outsourcing of logistics services. Supply Chain Management: An International Journal, 11(4), 294-308.

Boudreau, M. W., & Naegle, B. R. (2003). Reduction of total ownership cost (Doctoral dissertation, Naval Postgraduate School). Retrieved from http://stinet.dtic.mil/cgibin/GetTRDoc?AD=A419826&Location=U2&doc=GetTRDoc.pdf

Boyce, J., & Banghart, A. (2012). Performance-based logistics and project proof point. Defense AT&L, 41(2), 26-30.

Chai, J., Liu, J.N.K., & Ngai, E.W.T. (2013). Application of decision-making techniques in supplier selection: a systematic review of literature. Expert Systems Applications 40 (10), 3872-3885.

Chan, F. S. (2003). Interactive selection model for supplier selection process: an analytical hierarchy process approach. International Journal of Production Research, 41(15), 3549-3579.

Chan, F. T., & Kumar, N. (2007). Global supplier development considering risk factors using fuzzy extended AHP-based approach. Omega, 35(4), 417-431.

Chan, F. T., Kumar, N., Tiwari, M. K., Lau, H. C. W., & Choy, K. L. (2008). Global supplier selection: a fuzzy-AHP approach. International Journal of Production Research, 46(14), 3825-3857.

Charmaz, K. (2006). Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis, Sage, Thousand Oaks, CA.

Chen, C.-T., Lin, C.-T., & Huang, S.-F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. International Journal of Production Economics, 102(2), 289-301.

Cheraghi, S. H., Dadashzadeh, M., & Subramanian, M. (2004). Critical success factors for supplier selection: an update. Journal of Applied Business Research, 20(2), 91-108.

Chou, S.-Y. & Y.-H. Chang (2008). A decision support system for supplier selection based on a strategy-aligned fuzzy SMART approach. Expert Systems with Applications 34(4): 2241-2253.

Defense Acquisition University (DAU) (2005a). Defense Acquisition Guidebook, http://akss.dau.mil/dag.

Department of Defense (DoD) (2008). PBL Award 2008 Sub-system ARL 67 Radar Warning System, 3-11. Retrieved from https://www.dau.mil/cop/pbl/_layouts/15/WopiFrame.aspx?sourcedoc=/cop/pbl/DAU%20Sponsored%20Documents/PBL%20Award%20Pkg%202008%20Sub%20system%20ARL%2067%20Radar%20Warning%20System.pdf&action=default.

Department of Defense (DoD) (2007). PBL Award 2007 System FA-18 FIRST, 1-9. Retrieved fromhttps://www.dau.mil/cop/pbl/_layouts/15/WopiFrame.aspx?sourcedoc=/cop/pbl/DAU%20Sponsored%20Documents/PBL%20Award%20Pkg%202007%20System%20FA%2018%20FIRST.pdf&action=default.

Department of Defense (DoD) (2008). PBL Award 2008 System F-22, 4-14. Retrieved from https://www.dau.mil/cop/pbl/_layouts/15/WopiFrame.aspx?sourcedoc=/cop/pbl/DAU%20Sponsored%20Documents/PBL%20Award%20Pkg%202008%20System%20F%2022.pdf&action=default.

Department of Defense (DoD) (2008). PBL Award 2008 Sub-system ARL 67 Radar Warning System, 3-11. Retrieved from https://www.dau.mil/cop/pbl/_layouts/15/WopiFrame.aspx?sourcedoc=/cop/pbl/DAU%20Sponsored%20Documents/PBL%20Award%20Pkg%202008%20Sub%20system%20ARL%2067%20Radar%20Warning%20System.pdf&action=default.

Department of Defense (DoD) (2014). Performance Based Logistics (PBL) Guidebook. Retrieved from https://acc.dau.mil/psa.

De Boer, L., van der Wegen, L., & Telgen, J. (1998). Outranking methods in support of supplier selection. European Journal of Purchasing & Supply Management, 4(2-3), 109-118.

De Boer, L., Labro, E., & Morlacchi, P. (2001). A review of methods supporting supplier selection. European journal of purchasing & supply management, 7(2), 75-89.

Dickson, G. W. (1996). An analysis of vendor selection systems and decisions. Journal of Purchasing, 2(1), 5-17.

Ding, H., Benyoucef, L., & Xie, X. (2005). A simulation optimization methodology for supplier selection problem. International Journal of Computer Integrated Manufacturing, 18(2-3), 210-224.

Eisenhardt, K. M. (1989). Agency theory: An assessment and review. Academy of Management Review, 14(1), 57-74.

Gardner, C., P. (2008). Balancing the Government Risks with Contractor Incentives in Performance-Based Logistics Contracts. Master’s Thesis, Air Force Institute of Technology.

Geary, S., & Vitasek, K. (2005). It’s a war of ideas. Aviation Week & Space Technology, *163*(17), 57.

Gencer, C., & Gurpinar, D. (2007). Analytic network process in supplier selection: A case study in an electronic firm. Applied Mathematical Modeling, 31(11), 2475-2486.

Girubha, J., Vinodh, S., KEK, V., Moutinho, L., & Weaver, W., (2016). Application of interpretative structural modeling integrated multi-criteria decision-making methods for sustainable supplier selection. Journal of Modelling in Management, 11 (2), 358-388.

Goulding, C. (1998). Grounded theory: the missing methodology on the interpretivist agenda. Qualitative Market Research: An International Journal, 1(1), 50-57.

Griffin, W. (2008). The future of integrated supply chain management utilizing performance based logistics. NATO Supreme Allied Command Transformation Norfolk VA.

Guajardo, J. A., Cohen, M. A., Kim, S. H., & Netessine, S. (2012). Impact of performance-based contracting on product reliability: An empirical analysis. Management Science, 58(5), 961-979.

Herrera, F., & Herrera-Viedma, E. (2000). Linguistic decision analysis: steps for solving decision problems under linguistic information. Fuzzy sets and systems, 115(1), 67-82.

Ho, W., Xu, X., & Dey, P. K. (2010). Multi-criteria decision making approaches for supplier evaluation and selection: A literature review. European Journal of Operational Research, 202(1), 16-24.

Hong, G. H., Park, S. C., Jang, D. S., & Rho, H. M. (2005). An effective supplier selection method for constructing a competitive supply-relationship. Expert Systems with Applications, 28(4), 629-639.

Huang, S. H., & Keskar, H. (2007). Comprehensive and configurable metrics for supplier selection. International Journal of Production Economics, 105(2), 510-523.

Hypko, P., Tilebein, M., & Gleich, R. (2010a). Clarifying the concept of performance-based contracting in manufacturing industries: A research synthesis. Journal of Service Management, 21(5), 625-655.

Jin, T., Tian Z., & Xie M., (2014). A Game-Theoretical Approach For Optimizing Maintenance, Spares And Service Capacity In Performance Contracting. International Journal of Production Economics, 31-43.

Kar K., A., & Pani, A. K. (2014). Exploring the importance of different supplier selection criteria. Management Research Review, 37 (1), 89-105.

Karpak, B., Kumcu, E., & Kasuganti, R. R. (2001). Purchasing materials in the supply chain: managing a multi-objective task. European Journal of Purchasing & Supply Management, 7(3), 209-216.

Kilincci, O., & Onal, S. A. (2011). Fuzzy AHP approach for supplier selection in a washing machine company. Expert Systems with Applications, 38(8), 9656-9664.

Kim, S.H., Cohen, M.A., & Netessine, S., (2007). Performance contracting in after-sales service supply chains. Management Science, 53 (12), 1843–1858.

Kim, S.-H., Cohen, M. A., Netessine, S., & Veeraraghavan, S. (2010). Contracting for Infrequent Restoration and Recovery of Mission-Critical Systems. Management Science, 56(9), 1551-1567.

Kobren, B. (2009). What Performance-based logistics is and what it is not - and what it can and cannot do. Defense Acquisition Review Journal, 16(3), 254-267.

Kornov, L., & Thissen, W. A. (2000). Rationality in decision-and policy-making: implications for strategic environmental assessment. Impact Assessment and Project Appraisal, 18 (3), 191-200.

Kratz, L. (2003). Designing and Assessing Supportability in DOD Weapon Systems: A Guide to Increased Reliability and Reduced Logistics Footprint. Office of the Secretary of Defense Washington DC.

Kumar Kar, A., & K. Pani, A. (2014). Exploring the importance of different supplier selection criteria. Management Research Review, 37(1), 89-105.

Labib, A. W. (2011). A supplier selection model: a comparison of fuzzy logic and the analytic hierarchy process. International Journal of Production Research, 49(21), 6287-6299.

Lima, Osiro, & Carpinetti (2014). A comparison between Fuzzy AHP and Fuzzy TOPSIS methods to supplier selection. Applied Soft Computing, 202 (1), 16-24.

Locke, E. A. (2007). The case for inductive theory building. Journal of Management, 33(6), 867-890.

Mahon, D. (2007). Performance-based logistics: Transforming sustainment. Journal of Contract Management, 5, 53-71.

Manuj, I., & Mentzer, J. T. (2008). Global supply chain risk management strategies. International Journal of Physical Distribution & Logistics Management, 38(3), 192-223.

Merriam, S. B. (1998). Qualitative research and case study applications in education. San Francisco, CA: Jossey-Bass.

Miller, A. (2008). Performance-based logistics works. Aviation Week & Space Technology, 169(17), 78.

Moore Nancy Y., & Loredo Elvira N. (2013). Identifying and Managing Air Force Sustainment Supply Chain Risks, RAND Corporation, 41-44.

Narasimhan, R., Talluri, S., & Mendez, D. (2001). Supplier evaluation and rationalization via data envelopment analysis: an empirical examination. Journal of Supply Chain Management, 37(2), 28-37.

Narasimhan, R., Talluri, S., & Mahapatra, S. K. (2006). Multiproduct, multicriteria model for supplier selection with product life-cycle considerations. Decision Sciences, 37(4), 577-603.

Nowicki, D., Kumar, U. D., Steudel, H. J., & Verma, D. (2008). Spares provisioning under performance-based logistics contract: profit-centric approach. Journal of the Operational Research Society, 59(3), 342-352.

Ng, W. L. (2008). An efficient and simple model for multiple criteria supplier selection problem. European Journal of Operational Research, 186(3), 1059-1067.

Ordoobadi, S. M. (2009). Development of a supplier selection model using fuzzy logic. Supply Chain Management: An International Journal, 14(4), 314-327.

Randall, W. S., Pohlen, T. L., & Hanna, J. B. (2010). Evolving a theory of Performance-based Logistics using insights from service-dominant logic. Journal of Business Logistics, 31(2), 35-61.

Randall, W. S., Nowicki, D. R., & Hawkins, T. G. (2011). Explaining the effectiveness of performance-based logistics: a quantitative examination. International Journal of Logistics Management, 22(3), 324-348.

Randall, W. S., & Mello, J. E. (2012). Grounded theory: an inductive method for supply chain research. International Journal of Physical Distribution & Logistics Management, 42(8/9), 863-880.

Randall, W. S., Nowicki, D. R., Deshpande, G., & F. Lusch, R. (2014). Converting knowledge into value: gaining insights from service-dominant logic and neuroeconomics. International Journal of Physical Distribution & Logistics Management, 44(8/9), 655-670.

Randall, W. S., Hawkins, T. G., Haynie, J. J., Nowicki, D. R., Armenakis, A. A., & Geary, S. R. (2015). Performance-Based Logistics and Interfirm Team Processes: An Empirical Investigation. Journal of Business Logistics, 36(2), 212-230.

Rezaei, J., Nispeling, T., Sarkis, J., & Tavasszy, L. (2016). A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method. Journal of Cleaner Production, 135, 577-588.

Sammarco, P. W., Kolian, S. R., Warby, R. A., Bouldin, J. L., Subra, W. A., & Porter, S. A. (2013). Distribution and concentrations of petroleum hydrocarbons associated with the BP/Deepwater Horizon Oil Spill, Gulf of Mexico. Marine pollution bulletin, 73(1), 129-143.

Sarkis, J., & Talluri, S. (2002). A model for strategic supplier selection. Journal of supply chain management, 38(4), 18-28.

Secretary of Defense (2016). Performance Based Logistics (PBL) Awards Selection. https://dap.dau.mil/career/log/blogs/archive/2016/11/22/dod-announces-the-winners-of-the-2016-secretary-of-defense-performance-based-logistics-pbl-awards.aspx

Selviaridis, K. & F. Wynstra (2015). Performance-based contracting: a literature review and future research directions. International Journal of Production Research, 53(12), 3505-3542.

Seydel, J. (2005). Supporting the paradigm shift in vendor selection: Multicriteria Methods for sole-sourcing. Managerial Finance, 31(3), 49-66.

Simon, H. A. (1982). Models of bounded rationality: Empirically grounded economic reason (Vol. 3): MIT press.

Simon, H. A. (1991). Bounded rationality and organizational learning. *Organization Science, 2*(1), 125-134.

Singh, P., & Sandborn, P. (2006). Obsolescence driven design refresh planning for sustainment-dominated systems. The Engineering Economist, 51(2), 115-139.

Smith, L., Smith, M., & Ashcroft, P. (2011). Analysis of environmental and economic damages from British Petroleum’s Deepwater Horizon oil spill.

Spring, B. (2010). Performance-Based Logistics: Making the Military More Efficient. Heritage Foundation Backgrounder, 1-9.

Sols, A. & Johannesen, L. H. (2013). The role of transition contracts in performance-based logistics initiatives. Systems Engineering, 16(4), 453-463.

Straub, A. (2009). Cost savings from performance-based maintenance contracting. International Journal of Strategic Property Management, 13(3), 205-217.

Talluri, S., & Narasimhan, R. (2005). A note on "A methodology for supply base optimization". IEEE Transactions on Engineering Management, 52(1), 130-139.

Talluri, S., Narasimhan, R., & Nair, A. (2006). Vendor performance with supply risk: A chance-constrained DEA approach. International Journal of Production Economics, 100(2), 212-222.

Thiruchelvam, S., & Tookey, J.E., (2011). Evolving trends of supplier selection criteria and methods. International Journal Automotive Mechanical Engineering, 4, 437-454.

Transportation Research Board (2009). Cooperative Highway Research Program Synthesis 389: Performance-based Contracting for Maintenance, Edited by Transportation Research Board of the National Academies, Transportation Research Board, Washington, DC.

Vargo, S. L., & Lusch, R. F. (2004). Evolving to a new dominant logic for marketing. Journal of Marketing, 68(1), 1-17.

Xiang, Y., Zhu, Z., Coit, D. W., & Feng, Q. (2017). Condition-based maintenance under performance-based contracting. Computers & Industrial Engineering, 111(Supplement C), 391-402. doi:https://doi.org/10.1016/j.cie.2017.07.035

Wadhwa, V., & Ravindran, A. R. (2007). Vendor selection in outsourcing.Computers & operations research, 34(12), 3725-3737.

Wang, J. W., Cheng, C. H., & Huang, K. C. (2009). Fuzzy hierarchical TOPSIS for supplier selection. Applied Soft Computing, 9(1), 377-386.

Wang, Y. M., Chin, K. S., & Leung, J. P. F. (2009). A note on the application of the data envelopment analytic hierarchy process for supplier selection.International Journal of Production Research, 47(11), 3121-3138.

Weber, C. A., Current, J. R., & Benton, W. C. (1991). Vendor selection criteria and methods. European Journal of Operational Research, 50(1), 2-18.

Wittmann, C. M., Nowicki, D. R., Pohlen, T. L., & Randall, W. S. (2014). Service-dominant logic and supply chain management: are we there yet?. International Journal of Physical Distribution & Logistics Management, 44(1/2), 113-131.

Wu, T., Shunk, D., Blackhurst, J., & Appalla, R. (2007). AIDEA: A methodology for supplier evaluation and selection in a supplier-based manufacturing environment. International Journal of Manufacturing Technology and Management, 11(2), 174-192.

Ziegenbein, A., & Nienhaus, J. (2004). Coping with supply chain risks on strategic, tactical and operational level. In Global project and manufacturing management: the symposium proceedings, May, 163-177.

Zouggari, A., & Benyoucef, L. (2012). Simulation based fuzzy TOPSIS approach for group multi-criteria supplier selection problem. Engineering Applications of Artificial Intelligence, 25(3), 507-519.

ESSAY 3

UNDERSTANDING THE IMPACTS OF CONTRACT LENGTH AND FLEET SIZE IN PERFORMANCE-BASED CONTRACTS

Introduction

Performance-based contracting (PBC) offers an approach to binding the supplier's payment based on his ability to obtain desired objectives as specified by buyers. The fundamental structure of the PBC is built upon evaluation of outputs instead of paying for required inputs, activities, or processes (Martin, 2007). Today, this contract type can be seen from manufacturing to service industries, including the private and public sectors (Hypko, Tilebein, & Gleich 2010a; Hooper 2008; Selviaridisa & Wynstra, 2015).

In PBC, the contract identifies what is required, such as availability rates of systems, but the supplier determines how to attain these objectives (Kim, Cohen, & Netessine, 2007). How to arrive at the required outcome depends on the supplier's decisions about investment in quality, logistics processes, or inventory to realize desired objectives such as availability rate. The number of systems and length of the contract are two critical factors that affect the supplier's decision (Straub 2009, Randall et al., 2012, Jin et al., 2012, Jin, Tian, & Xie, 2014). In PBC, while buyers expecthigh product quality, suppliers can be reluctant to make upfront investment to increase reliability, because of uncertain expectations of relationship continuity with customers (Hypko et al., 2010). While suppliers in long-term arrangements are eager to invest in quality, in the short term, they prefer to enhance existing processes, such as inventory management, transportation, and repair services (Randall et al., 2012). On the other hand, the number of systems is another critical point for suppliers' decisions, since it affects suppliers' upfront investments for reliability improvement. Thus, contract length and fleet size become the primary contract features to decide between investment in reliability or processes. The primary purpose of this study is to investigate how suppliers' decisions to invest in quality improvement and inventory level are affected by the incentive structure of PBCs in different terms of contracts and fleet sizes. In addition, we aimed to show the effect of these contract features on supplier profit and the buyer’s annual unit cost. The research question at the center of this study is what are the effects of contract length and fleet size on investments for reliability and spare parts in PBCs? How do these two contract features impact the supplier’s annual profit and the buyer’s annual unit cost?

The remainder of this paper proceeds as follows. After presenting related literature in [Literature review], this study's theoretical paradigms are explained in [Theoretical paradigms]. These are followed by research methodology and methodology of the study in [Methodology and Mathematical Model]. Numerical examples and results presented in [Numerical Examples], before concluding with a general discussion and implications in [General Discussion and Implications].

Literature Review

PBCs have been offered as an exceptional model, a “win-win” solution for both buyers and suppliers (Hypko et al. 2010). All efforts in PBCs, such as maintenance programs and inventory management, are designed to reduce the cost of ownership for sustaining systems (Gansler & Lucyshyn; 2006; Vitasek et al., 2007). PBCs create more high-profit margins for suppliers through additional revenue when they achieve desired objectives such as availability rate (Ong et al., 2005). In addition, suppliers are motivated by incentives to invest in the reliability of systems, which result in high operational readiness (Gansler & Lucyshyn, 2006; Vitasek et al., 2007). This investment in reliability increases the availability of systems while reducing total service costs, spare parts procurement, inventory holding costs, and the logistics footprint (Cohen, M. A., &

Netessine, S., 2007; Devries, 2005; Gansler, 2006).

Many studies have examined optimum solutions, such as the trade-off between inventory and reliability improvement for suppliers in PBC. Kumar et al. (2007) developed a multi-objective optimization model to optimize reliability, maintainability, and supportability criteria that are important in PBCs (Kumar, Nowicki, et al. 2007). Nowicki et al. (2008) created an optimization model for the spare asset allocation problem under three different revenue functions: step, exponential, and linear revenue functions. They found that an optimal spares asset allocation cannot be sustained without considering the associated profit stream. Using a principal-agent contracting framework, Kim et al. (2010) analyzed efficiencies of sample-average and cumulative downtime within two contract types used in the performance-based approach. They found that when a component is highly reliable, implementation of PBCs may create high agency cost. Mirzahosseinian and Piplani (2011) investigated how component reliability, maintenance facility, and inventory management affect the availability of systems under PBCs. They found that the base stock level of spare parts had an insignificant impact on system availability. Thus, to attain a minimum target availability level, the supplier must enhance component reliability and repair time, rather than increase the stock of spares (Mirzahosseinian and Piplani 2011). Jin et al. (2012) investigated how the relationship between system cost, reliability, and spare parts under PBCs affect the operational availability of a system. They found substantial evidence to conclude that these three factors were the primary drivers of system performance. Additionally, they showed that under a more extended service agreement in PBCs, suppliers as original equipment manufacturers are eager to invest in reliability improvement. Also, they revealed that increasing spare parts inventory has less impact on the availability of very reliable systems. Guajardo et al. (2012) showed in his experimental study, based on data from the Rolls-Royce company, that product reliability was impacted by the use of two support strategies: time and material based (T&MC) strategy and performance-based strategy. They found that the reliability of products is much higher (25%–40%) under PBC than under T&MC. Kim et al. (2015) developed a game-theoretical model to investigate the interaction of investment in reliability improvement and spare parts under the traditional resource-based contract and PBC. They found that incentives under PBC motivate suppliers to make the upfront investment in reliability improvement, thus generating savings by reducing acquisition and holding costs in spare assets. On the contrary, under the material-based contracts, the supplier invests more in inventory and less in reliability (Kim, Cohen & Netessine, 2015). Bakshi, Kim, and Savva (2015) developed a principal-agent model to investigate the interaction between reliability signaling and the vendor's unrestricted investment in spare parts inventory. They found that customers are eager to accept PBC when mature technologies are available for acquired products rather than products with newly developed technology.

Although there are many studies that examine the trade-off between spare parts and reliability, there is dearth of research on the impact of different terms of contracts and fleet sizes on the improvement of reliability and spare parts in PBCs. The selection of contract length is critical in PBCs for buyers to shift suppliers' focus on their benefits by aligning goals. Also, unlike previous research, this study investigates how the number of systems in the contract affects suppliers' decisions for reliability investments and spare parts.

Theoretical Background

In PBC, the buyer outsources the task of delivering the system's performance to the supplier (Helander & Moller, 2008). This relationship between supplier (agent) and buyer (principal) creates the agency problem when the preferences and goals of the principal and agent conflict (Eisenhardt, 1989). The main issues in the post-contractual term are “hidden action” and “moral hazard” (Bergen, Dutta & Walker, 1992). The problem of moral hazard in the post-contractual term stems from the buyer’s inability to observe the supplier’s actions in PBC because of imperfect information. The buyer’s inability to observe supplier actions can be mitigated by the performance-based payment (Eisenhardt, 1989). Although buyers may have information about the supplier’s capability, such as service capacity and technological ability, they cannot forecast the supplier’s action in performing the work specified by the contract. Because of imperfect information about the agent’s decisions, difficulties arise when it comes to ascertaining whether the supplier is performing in the buyer’s best interests (Eisenhardt, 1989; Bergen et al., 1992). The performance-based payment, tied to the achievement of outcomes, enables the alignment of the buyer’s goals with the supplier’s preferences and transfers risks from the principal (buyer) to the agent (supplier) (Eisenhardt, 1989; Firchau, 1987). However, even the incentive structure of performance-based payment in PBC does not alleviate the buyer’s burden of assuming responsibility for the system’s operational performance. Also, to mitigate risks that emerge from agency problems, buyers can conduct outcome-based incentives in various contract types in a different revenue models (Sols, Nowicki, & Verma, 2007). With the incentivizing structure of PBC, buyers can motivate suppliers to act in agreement with their own interests. Thus, in PBC context, the moral hazard problem in the post-contractual term can be handled by reducing the information asymmetry by understanding the effects of each contractual feature.

Methodology and Mathematical Model

In this study, we conducted an analytical model through Matlab. The effects of each key contract feature (fleet size and contract length) on spare parts and failure rates were investigated under the step revenue model, which is adapted from Nowicki et al. (2008). Because there are more than two decision variables, a genetic algorithm was used to examine the impact of each key contract feature on availability rates in PBC. For our research questions, the mathematical model in this study was adapted from the model of Jin et al. (2014).

Genetic Algorithm

As a metaheuristic approach, a genetic algorithm (GA) is an appropriate method to find the optimal solutions for multi-objective optimization problems by using evolutionary techniques (Horn, Nafpliotis, & Goldberg, 1994). Based on Holland (1973, 1992), who developed GA, the algorithm starts from the creation of a random population of solutions that builds search space in optimization. After generating the initial population, the algorithm uses three evaluation operators: selection, crossover, and mutation (Houck, Joines, & Kay, 1995). At first, better solutions are reproduced by the selection of better individuals. In GA, the term of individuals is used to represent possible solutions; and the name of the population is used to describe a set of individuals or solutions (Chiu, Hsu, & Yeh, 2006). Next, in the crossover process, two individuals are exchanged at random and put into the next solution to generate better individuals for optimal solutions. Finally, in the mutation process, individuals are created through random modifications based on the initial parameters of GA that are selected to process the algorithm. So, while the selection process decreases the search space within the initial population by eliminating poorer individuals, crossover and mutation processes search the initial population to find better solutions (Razali & Geraghty, 2011). In each loop, new solutions are used to change the weaker option to find better individuals. The algorithm continues until the termination of chosen criteria. The flowchart of GA algorithm is presented in Figure 3.1.

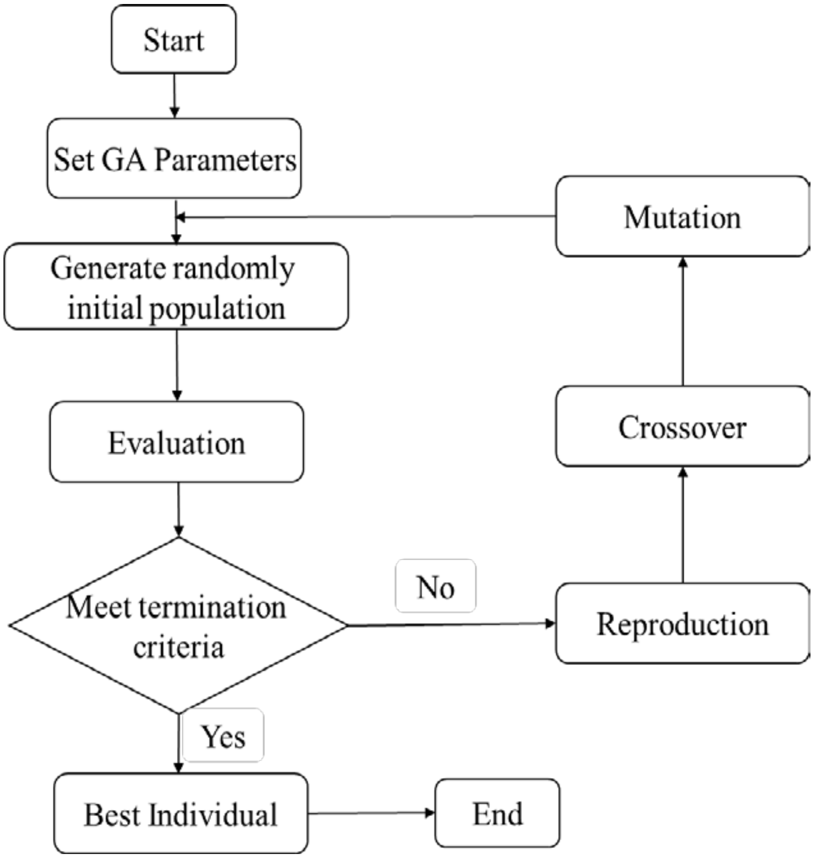


Figure 3.1: Genetic algorithm flowchart.

Mathematical Model

Notations:

A_S	Availability of system
$A_{(i)}$	Availability of subsystem where i=1,2,3.
A_{min1}	Minimum availability of the system for the penalty zone
A_{min2}	Minimum availability of the system for the award zone
n	Number of systems in the contract
λ_{max}	Maximum inherent failure rate (faults/year)
λ_{min}	Minimum inherent failure rate (faults/year)
λ	Failure rate (faults/year), decision variable
s	Base-stock level of spare parts, decision variable
τ	Length of contract (year)
t_r	Turn-around time for fixing the broken item

t_s	Repair-by-replacement time when the spare part is available
Y	Random variable for on-order spare parts
Z	Random variable for backorders for spare parts
H	Random variable for on-hand spare parts
x	Random variable for spare parts demands
φ	Coefficient for design difficulty
B_1	Baseline design cost with the maximum inherent failure rate
B_2	Baseline unit cost with the maximum inherent failure rate
L	Number of subsystem
θ	Interest rate compounded annually
$R(\mathrm{A})$	Revenue function
$c(\lambda)$	Unit production cost
$D(\lambda)$	Design cost
$I(\lambda,s)$	Inventory cost for service logistics
$M(\lambda,n)$	Maintenance/repair cost
$\Pi(\lambda,s,n)$	Lifecycle cost
a	Fixed price
$\mathrm{b}_{(\mathrm{i})}$	Reward where i=1,2.
$P(\lambda,s,n)$	Profit function

In this model, the supplier who is an original equipment manufacturer in PBCs provides the maintenance and repair logistics of n systems. Also, as an original equipment manufacturer, the supplier provides system design improvements and owns the inventory (see Figure 3.2). In this study, spare parts in inventory are considered at one location within the buyer site. This inventory for spare parts is managed by the one-for-one replacement policy during system failures. Also, the repairable inventory model is used for controlling expensive critical parts that are replaced correctively (Driessen et al., 2010; Sherbrooke, 1968). The goal of this repair depot is to minimize inventory investment and to diminish holding or backorder costs (Jin, Tian, & Xie, 2014). After the replacement of a faulty item in the failed system with a spare part in inventory, the defective part will be sent to the repair depot. Working under the assumption that there are sufficient repair servers in the repair deport, the M/G/∞ queue system was considered for this flow (Sherbrooke, 1992). Thus, all maintenance times are uniformly distributed with the mean value of repair time (t_r). This average turnaround repair time includes forward-and-return transportation times (Jin, Tian, & Xie, 2014). When spare parts are available in inventory, the broken item is replaced by the spare part in inventory, which is located on the buyer's site within the average of replacement time (t_s).

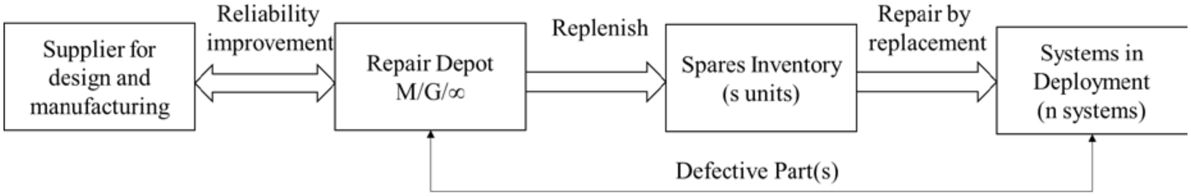


Figure 3.2: Manufacturing and service supply flow.

Operational availability is considered one of the most significant criteria for repairable systems and is defined as the percentage of time that a system is ready for a mission (DAU, 2005a, Mahon 2007, Nowicki, Kumar, Steudel, & Verma, 2008). This primary performance metric, operational availability, is operationalized in Equation 1. It can be characterized as the percentage of system uptime over the total of system uptime and downtime (Wang, Loman, & Vassilou, 2004).

$$A = \frac{(uptime)}{(uptime)+(downtime)} = \frac{MTBF}{MTBF+MDT} \tag{1}$$

$$MDT = MTTR + MLDT \tag{2}$$

System uptime is represented by the meantime between failures (MTBF), which is the operating time between two successive failures. On the other hand, system downtime is represented by the mean downtime (MDT), which is the sum of meantime to replacement (MTTR) of a part and mean logistics delay time (MLDT). Thus, MDT is affected by the inventory level of spare parts and waiting time for logistic services such as labor and transportation.

Based on the assumption of an exponential distribution of system lifetime, the relationship between MTBF and the failure rate, λ, can be estimated as:

$$\text{MTBF} = 1/\,\lambda \tag{3}$$

$$\lambda = 1/MTBF \tag{4}$$

MDT is affected by the spare parts inventory level. If the spare parts are in stock, when the system fails, a defective part is replaced with a new part with an average time of t_s. Otherwise, an order is placed for the broken part and replacement time is lengthened until the spare part arrives (Jin et al. 2014). To model these two cases, two random variables were used for spare parts availability in inventory. These are on-hand inventory (*H)* and backorder (*Z)*. On-hand inventory (*H*) and *s* are related to each other through *H=max{0,s-Y},* where *Y* is a random variable representing the inventory level on order. Also, backorder and s are related to each other through *Z=max{0,Y-s}.* A random variable for on-order spare parts (*Y*) can be modeled as a Poisson distribution with mean $\mu_0 = n\lambda t_r$ where $n\lambda$ represents the fleet failure rate, and t_r represents the repair time when spare part is not available (Jin et al. 2014).

$$MDT = t_s Pr\{0 \le s\} + (t_s + t_r)(1 - Pr\{0 \le s\}) \text{ where} \tag{5}$$

$$Pr\{0 \le s\} = \sum_{x=0}^{s} \frac{\mu_0^x e^{\mu_0}}{x!}, and\ \mu_0 = n\lambda t_r \tag{6}$$

Here x is the number of spare parts in demand. The expected value for on-hand quantities (*H*) and the backorder quantities (*Z*) can be predicted as follows:

$$E|H| = \sum_{x=0}^{s} \left((s - x) \frac{\mu_0^x e^{\mu_0}}{x!} \right) \tag{7}$$

$$E|Z| = \mu_0 - s - \sum_{x=0}^{s} \left((x - s) \frac{\mu_0^x e^{\mu_0}}{x!} \right) = n\lambda t_r - s - \sum_{x=0}^{s} \left((x - s) \frac{(nt_r\lambda)^x e^{-nt_r\lambda}}{x!} \right) \tag{8}$$

Finally, by exchanging Equations (5), (6), (7), and (8) into Equation (1), operational availability can be presented as:

$$A(\lambda, s, n, t_r) = \frac{1}{1 + \lambda t_s + \lambda t_r (1 - \sum_{x=0}^{s} \frac{(nt_r\lambda)^x e^{-nt_r\lambda}}{x!})} \tag{9}$$

This equation combines the inherent failure rate, spare parts, fleet size, and repair time in one analytical formula.

Life cycle cost: The primary advantage of PBC contracts is managed by suppliers, only if they can come up with future cost avoidance solutions to support systems. Therefore, it is significant to consider all possible solutions and their interaction effects at the same time. For instance, improvement of the reliability of the system not only will affect the design cost of the system but also will affect inventory costs of spare parts. In the next models, we show how improvement in reliability impacts design and manufacturing cost.

The design cost of the system is adapted from Jin et al., (2012, 2014) and Mettas A., (2000). Design cost increases exponentially with reliability growth (Jin et al., 2012). So, in the exponential cost model, the design cost for a subsystem can be expressed as:

$$D(\lambda) = B_1 exp(\varphi \frac{\lambda_{max}-\lambda}{\lambda-\lambda_{min}}), \text{ for } \lambda_{min} \leq \lambda \leq \lambda_{max} \tag{10}$$

where λ_{max} is the maximum acceptable failure rate specified by the customer, and λ_{min} is the best feasible rate by the supplier. In particular, B_1 is the baseline design cost with λ_{max}. The difficulties of increasing the reliability of subsystem or component (i) are represented by φ and take a values between 0 and 1. This value represents challenges, such as design complexity and technological limitations, that increase the subsystem/component's reliability relative to others. The large design difficulty rate indicates that the reliability growths of the subsystems or components are difficult to improve. Additionally, this large design difficulty rate (φ) results in a high design cost in order to increase the reliability of the subsystems or components (Mettas A., 2000).

Inventory cost and the repair cost are the primary two expenses in post-production support costs. Inventory cost is related to a number of spare parts that is affected by the reliability of systems. The inventory cost can be expressed as:

$$I(\lambda, s) = \mathrm{sc}(\lambda) \tag{11}$$

On the other hand, transportation cost, labor cost, and repair facilities are the main dimensions of repair costs. The total repair cost during the length of the contract (τ) can be expressed as:

$$M(\lambda, n) = c_r n \lambda \varphi(\theta, \tau) \tag{12}$$

where

$$\vartheta(\theta, \tau) = \frac{(1+\theta)^{\tau} - 1}{\theta(1+\theta)^{\tau}} \tag{13}$$

Failure rate (λ) is defined as yearly. Repair cost (c_r) per fault item includes labor costs, facility costs for repair, and transportation costs. $\vartheta(\theta, \tau)$ calculated for the present value of an annuity with interest rate (θ).

Life cycle cost consists of design cost of reliability improvement, fleet cost of systems, inventory cost of subsystems, and maintenance costs. So, the life cycle cost for the supplier can expressed as:

$$\pi(\lambda, s, n) = D(\lambda) + nc(\lambda) + I(\lambda, s) + M(\lambda, n) \tag{14}$$

Revenue Function: Unlike traditional material contracting, suppliers are rewarded based on their achievement of targeted outcomes in PBCs. In calculating the supplier's revenue, Nowicki et al. (2008) devised three different revenue functions: step, exponential, and linear revenue functions. We adopted Nowicki et al.’s (2008) step revenue function, which is consistent with Sols, Nowicki, and Verma (2007)’s reward scheme for PBCs. This revenue model, which is shown in Equation (15), consists of three bands. When the system’s availability reaches minimum availability of the system for the award zone ($A_{\min 2}$), the supplier receives minimum revenue, the intercept (a), and based on the incremental difference in availability, $\left(A_S - A_{\min(i)}\right)$, the supplier gets the additional award or penalty, which is described by the slope (b_i) (see Figure 3.3).

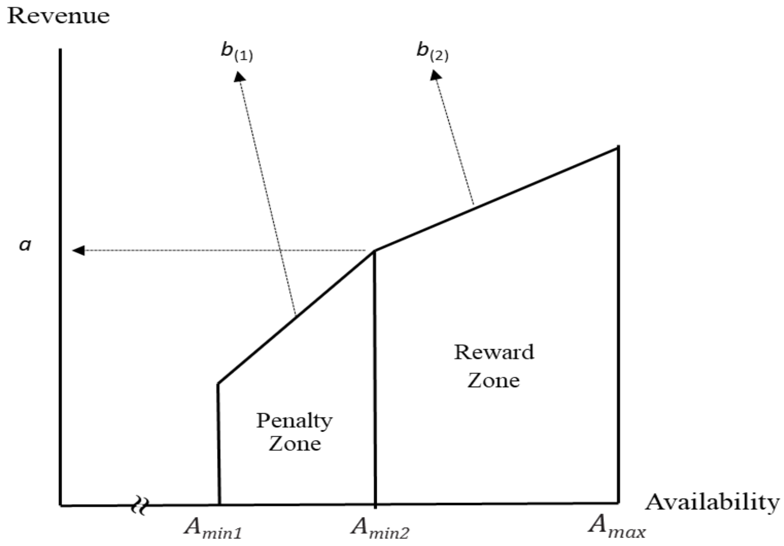


Figure 3.3: Revenue model (revenue and availability bands).

$$R\big(A_s(\lambda,s;n)\big) = \begin{cases} 0 & if\ A_s < A_{min1} \\ a - b_1 * (A_{min2} - A_s) & if\ A_{min1} \le A_s < A_{min2} \\ a + b_2 * (A_s - A_{min2}) & if\ A_{min2} \le A_s < A_{max} \end{cases} \tag{15}$$

Revenue of Supplier: Supplier's expected profit modeled in Equation (16) and subject to target availability rates in revenue function and minimum-maximum failure rates of the each component. The number of subsytems is represented by L.

$$Max\ E[P(\lambda,s)] = R\left(A_s(\lambda,s)\right) - \sum_{i=1}^{L}\big(D_i(\lambda_i) - B_{1,i}\big) - n\sum_{i=1}^{L}\big(c_i(\lambda_i)\big) - \sum_{i=1}^{L}\big(I_i(\lambda_i,s_i)\big) - \sum_{i=1}^{L}\big(M_i(\lambda_i,n)\big) \tag{16}$$

Subject to

$$A_s(\lambda,s) \ge \prod_{i=1}^{L} A_i(\lambda_i,s_i) \ge A_{min1} \tag{17}$$

$$\lambda_{min,i} \le \lambda_i \le \lambda_{max,i} \text{ for } i = 1,2,\dots.,L \tag{18}$$

Here, the maximum profit of supplier is formulated for sustaining the entire system fleet by determining optimal failure rates and spare parts for each subsystem in the range of minimum and maximum failure rates. Considering the two decision variables within each of the four subsystems, a genetic algorithm through MATLAB was used to find the impact of each key contract feature for optimal failure rates and spare parts in PBC.

Numerical Examples

In this study's numerical example, the supplier is contracted to design and supply four major components of the system, which has different reliability and feasibility rates. In this model, each of the *n* systems consists of four sub-systems connected in a series configuration in which the system will fail if any of its subsystems collapse (Figure 3.4).

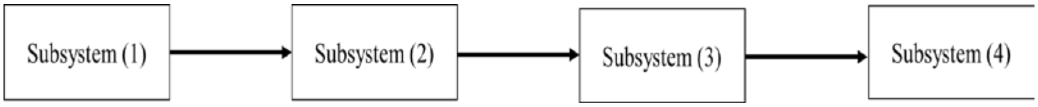


Figure 3.4: Serial system diagram.

For the numerical experiment, we created the data for this study. Since PBCs have been widely used in the defense industry since 2003 (Sols et al., 2007, Mahon, 2007), and considering that approximately 40% of the defense budget is consumed by operation and maintenance costs, we used similar relativity in our data for repair and attained costs of subsystems. In this example, the supplier's objective is to maximize his profit margin by taking account of design cost, maintenance, and spare parts, while meeting the customer's availability target under the step revenue function. The essential information about each subsystem, e.g., the baseline manufacturing cost, the acceptable maximum, and the best achievable failure rate (faults/year) are presented in Table 3.1.

Table 3.1: Reliability and cost parameters for the system.

Parameter Subsystem category	Subsystem 1 i=1	Subsystem 2 i=2	Subsystem 3 i=3	Subsystem 4 i=4
λ_{max} (faults/year)	0.4	0.4	0.4	0.4
λ_{min} (faults/year)	0.08	0.16	0.08	0.08
Φ	0.1	0.15	0.1	0.1
t_s (days)	10	10	5	7
t_r (days)	100	100	51	68
θ	0.05	0.05	0.05	0.05
c_r (dolar/repair)	55,000	55,000	24,000	32,000
B_1(dolar)	1,600,000	1,600,000	800,000	800,000
B_2(dolar)	160,000	160,000	80,000	80,000

In this study, the system consists of four subsystems. Subsystem 1 and Subsystem 2 have the same values, except for coefficient of design difficulty. Subsystem 3 and Subsystem 4 have the same values, with the exception of repair cost. With this modification, we also aimed to observe the effects of difficulty rates and repair cost in the subsystems on reliability improvement and spare parts inventory.

The genetic algorithm is used through MATLAB to maximize supplier profit for the fleet and to find the optimal or close to optimal values for failure rates and spare parts. The model was conducted with a different length of contract and fleet size under the two revenue models with different availability rates. In the first numerical example, revenue built upon for the availability rates of 0.95 and 0.97 for A_{min1} and A_{min2}, respectively. The second numerical example is based on the availability rates of 0.90 and 0.95 for A_{min1} and A_{min2}, respectively (see Figure 3.3). To understand the impact of the fleet size in each numerical example, we used eight fleet sizes with 5, 10, 20, 30, 40, 50, 60, and 70. In addition, to investigate the effect of the length of the contract in each example, we conducted ten lengths of contract: 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 years.

For the fixed price (a) in the contract, the value of \$2.53 x 10^7 was used for 30 units and five-year contracts. To be able to make a comparison of the profit with different values, based on the increase or decrease in fleet size and the length of the contract, award rates are increased or decreased related to this change. For the parameters of penalty and reward slopes, b_1 and b_2 , 5a and 4a are used in revenue function, respectively, in each model. In the step revenue model, the supplier will decide λ and s, subject to availability rates in revenue function to maximize his profit.

The First Numerical Example ($A_{min1} = 0.95$ and $A_{min2} = 0.97$)

The base contract features for the length of contract and fleet size, which presents base value in this study, are 5 years and 30 units, respectively.

Fleet Size

Based on the values presented in Table 3.1, the optimal solution was found in GA for failure rate (λ) and spare parts (s) within a five-year agreement for the eight different fleet sizes with 5, 10, 20, 30, 40, 50, 60, and 70 unit of systems presented in Table 3.2 and Figure 3.5.

The results indicate that the supplier's yearly profit grows when fleet size in the contract increases. However, in the lowest two fleet sizes with five and ten units, this increase is much smaller. The low profit in these fleet sizes is caused by the inability of suppliers to compensate for the design cost for reliability improvement. Therefore, in these two levels, failure rates are also much higher than in the other level fleet sizes. This result in the supplier decision to stay in the first zone of revenue function, which represents between two minimum availability rates (between 0.95 and 0.97) (see Figure 3.3). Therefore, based on the step revenue model, for these two lowest levels of fleet size, the supplier brought in greater profits in this penalty zone. The availability rates of the systems decrease for buyers for these two smaller fleet sizes. Except for these two smaller fleet sizes, based on Figure 3.5, we can conclude that there is linear growth in the supplier's profit alongside an increase in fleet size.

Also, as seen in Table 3.2 and Figure 3.5, except with the highest level of fleet size with 70 units, for the buyer, this yearly unit cost of each system exponentially decreases with an increase in fleet size. For the lowest two fleet sizes, with 5 and 10 units, while suppliers earn less profit, the buyer must make much larger payments for each system in the fleet.

Based on the results, we can conclude that increasing spare parts under the PBC doesn't profoundly affect availability rates. A close look at each subsystem, with an increase in fleet size, for Subsystem 1 and 2, shows that growth in spare parts is much higher, since they have a higher unit cost than Subsystems 3 and 4, resulting in high design cost. The Subsystem 1 and the Subsystem 2 have the same values, except for the coefficient of design difficulty. A close look at the first two subsystem shows that an increase in spare parts for Subsystem 2 is higher than the first one, because of the high coefficient of design difficulty (50%) and design cost for improvement in reliability. Subsystem 3 and Subsystem 4 have the same values, with the exception of repair cost. The increase in spare parts for Subsystem 4, which has a higher repair cost (50%), results in many more spare parts in inventory in more than thirty-unit fleets.

Generally, we see in Table 3.2 and Figure 3.5 that suppliers are much more eager to invest in reliability under the PBC. And this investment shows exponential increases with the increase in fleet size. On the other hand, a close look at the subsystems reveals that the improvement in failure rates is lower for Subsystems 1 and 2, which have two times higher unit cost than Subsystems 3 and 4. Given that the calculation of the design cost is dependent on the base unit cost, an increase in reliability is a much more affordable solution when design cost is lower than the holding costs of the units. Also, when we compare Subsystems 1 and 2, we can see that the improvement in reliability for the first subsystem is higher than the second, which has a more difficult design rate.

We can conclude that more systems in the fleet are much more profitable for suppliers under the performance-based contract. From the perspective of the buyer, not only does the yearly unit cost of the system decrease, but also the buyer will get more reliable systems, which increases the readiness of the system.

The length of the contract: Optimal values were found in GA for failure rate (λ) and spare parts (s) for the thirty-unit fleet for the ten different lengths of the contract with 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 years presented in Table 3.3 and Figure 3.6.

As seen in Figure 3.6, under the longer term of contracts, the supplier's yearly profit grows exponentially. However, for the one-year and two-year contracts, the supplier's annual profit is under $50,000, which is close to zero in the graph. Considering that the PBC is implemented in the defense industry under a 3-5-year term with an extension option (DoD, 2014), this result confirms the disadvantages of contracts less than three years. Also, at these two levels, failure rates are much higher than at the other level of the term of contracts. Therefore, results show that under one and two-year contracts, the buyer must pay much more for each unit of the system with lower availability rates. Based on the step revenue model, for these two lowest levels of contract length, the supplier reaps greater profit in this penalty zone. So, the availability rates of the systems decrease for buyers for these two smaller fleet sizes.

As seen in Table 3.3 and Figure 3.6, the yearly unit cost of each system exponentially decreases for the buyer with the increase in contract length. Also, based on the results, we can conclude that the supplier is far more eager to invest in the reliability of the system than to increase spare parts under the PBC. On the other hand, failure rates show an exponential decrease with the increase in contract length. On the other hand, after a close look at the subsystems, we can conclude with the same results for the increase in fleet size that are stated above.

We can conclude that longer contract length is far more profitable for suppliers and buyers under the performance-based contract. From the perspective of the buyer, not only does the yearly unit cost of the system decrease, but also the buyer attains more reliable systems, which increase system readiness.

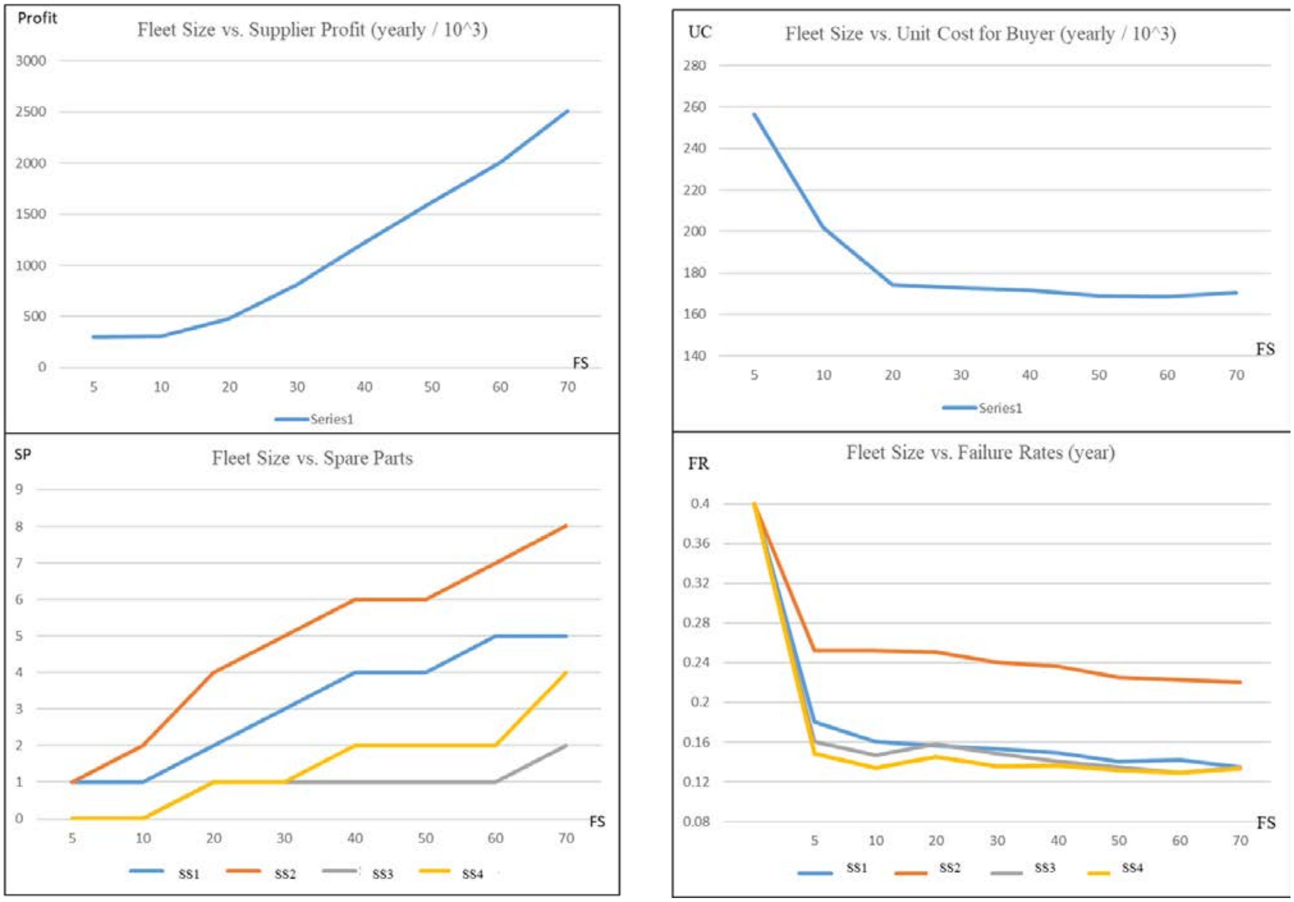


Figure 3.5: Results for the different fleet size within the five-year length of contract (A_{min1} = 0.95, A_{min2} = 0.97, τ=5).

Table 3.2: Results for the different fleet size within the five-year length of contract ($A_{min1} = 0.95$, $A_{min2} = 0.97$, $\tau = 5$).

Fleet Size (n)	5	10	20	30	40	50	60	70
Availability (A_s)	0.9699	0.9695	0.9766	0.9769	0.9763	0.9742	0.9733	0.9781
Supplier Profit (\$/year)(10^3)	299.6	308.52	478.08	811.74	1222.04	1618.54	2002.40	2513.60
Unit cost of Buyer (\$/unit/year)(10^3)	256.68	201.64	174.36	172.88	171.42	168.89	168.56	170.52
Spare parts								
Subsystem 1	1	1	2	3	4	4	5	5
Subsystem 2	1	2	4	5	6	6	7	8
Subsystem 3	0	0	1	1	1	1	1	2
Subsystem 4	0	0	1	1	2	2	2	4
Failure rates								
Subsystem 1	0.1805	0.1600	0.1562	0.1532	0.1488	0.1407	0.1423	0.1349
Subsystem 2	0.2525	0.2523	0.2506	0.2406	0.2365	0.2252	0.2230	0.2204
Subsystem 3	0.1605	0.1467	0.1579	0.1483	0.1407	0.1349	0.1291	0.1346
Subsystem 4	0.1480	0.1338	0.1454	0.1353	0.1367	0.1317	0.291	0.1335

Table 3.3: Results for the different length of contract for thirty-unit fleet size ($A_{min1} = 0.95$, $A_{min2} = 0.97$, $n = 30$)

Length of the contract (τ) (year)	1	2	3	4	5	6	7	8	9	10
Availability (A_s)	0.9699	0.9699	0.9768	0.9777	0.9769	0.9757	0.9759	0.9741	0.9742	0.9746
Supplier Profit (\$/year)(10^3)	35.206	46.160	455.866	703.175	811.740	924.466	1025.757	1070.412	1135.333	1190.300
Unit cost of Buyer (\$/unit/year) (10^3)	621.30	336.50	239.10	199.10	172.88	154.75	144	134.160	127.970	122.070
Spare parts										
Subsystem 1	2	2	3	3	3	3	3	2	2	2
Subsystem 2	5	5	5	5	5	5	5	5	5	5
Subsystem 3	1	1	1	1	1	1	1	1	1	1
Subsystem 4	1	1	2	2	1	1	1	1	1	1

(table continues)

Length of the contract (τ) (year)	1	2	3	4	5	6	7	8	9	10
Failure rates										
Subsystem 1	0.1473	0.1460	0.1584	0.1544	0.1532	0.1496	0.1496	0.1402	0.1390	0.1373
Subsystem 2	0.2523	02493	0.2515	0.2446	0.2406	0.2384	0.2336	0.2340	0.2343	0.2311
Subsystem 3	0.1487	0.1492	0.1490	0.1480	0.1483	0.1469	0.1462	0.1420	0.1405	0.1436
Subsystem 4	0.1359	0.1352	0.1496	0.1457	0.1353	0.1341	0.1341	0.1311	0.1329	0.1305

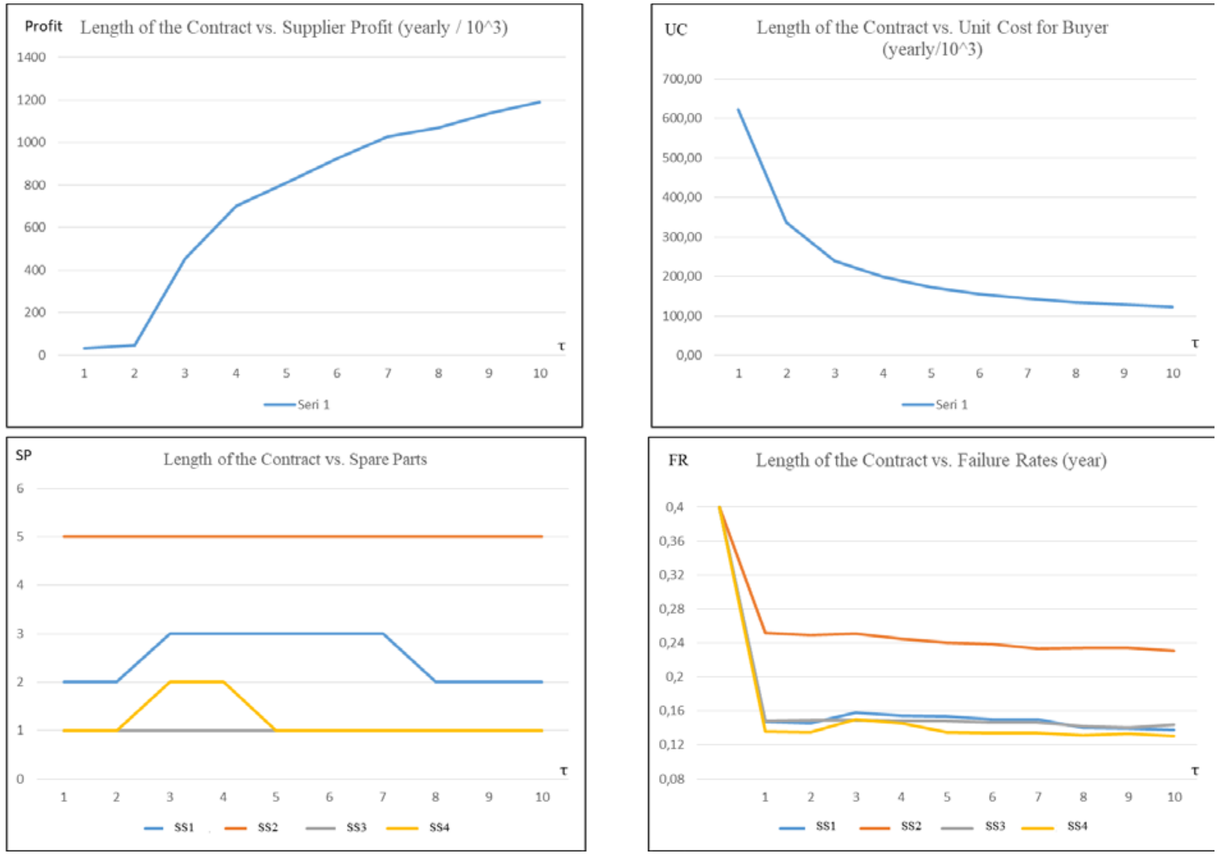


Figure 3.6: Results for the different length of contract for thirty-unit fleet size (A_{min1} = 0.95, A_{min2} = 0.97, τ=5).

The Second Numerical Example (A_{min1} = 0.90 and A_{min2} = 0.95)

In contrast to the first numerical example, we changed the minimum two availability rates from 0.95 and 0.97 to 0.90 and 0.95. All other variables remain the same. In this section, we will only present different findings from the above example.

Fleet Size

Based on the values presented in Table 3.1, optimal solutions were found in GA for failure rate (λ) and spare parts (s) within the five-year length of agreement for the eight different fleet sizes with 5, 10, 20, 30, 40, 50, 60, and 70 unit of systems presented in Table 3.4 and Figure 3.7.

The supplier's yearly profit grows when the fleet size in the contract increases. However, unlike the above example, as seen in Figure 3.7, this increase shows exponential characteristics rather than linear growth.

As seen in Table 3.4 and Figure 3.7, this example also shows that for the buyer, yearly unit cost of each system exponentially decreases with the increase in fleet size. In contrast to the above example, the supplier stays in the penalty zone to maximize profit and provide lower availability rates with the increase in fleet size. The same results for spare parts and failure rates were found in this example.

The length of the contract: Optimal values were found in GA for failure rate (λ) and spare parts (s) for the thirty-unit fleet for the ten different lengths of the contract with 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 years presented in Table 3.5 and Figure 3.8.

In contrast to the above example, the supplier stayed in the first zone for the 3, 4, 5, and 6-year contracts. With contracts longer than six years, suppliers get availability rates between 0.965 and 0.967. Also, this high readiness of the system results in a higher yearly unit cost for the buyer after six-year terms. Although findings for the supplier's annual profit differ from the first example, results indicate similar findings with fleet size. The growth shows exponential characteristics. The same results for spare parts and failure rates were found with an increase in contract length.

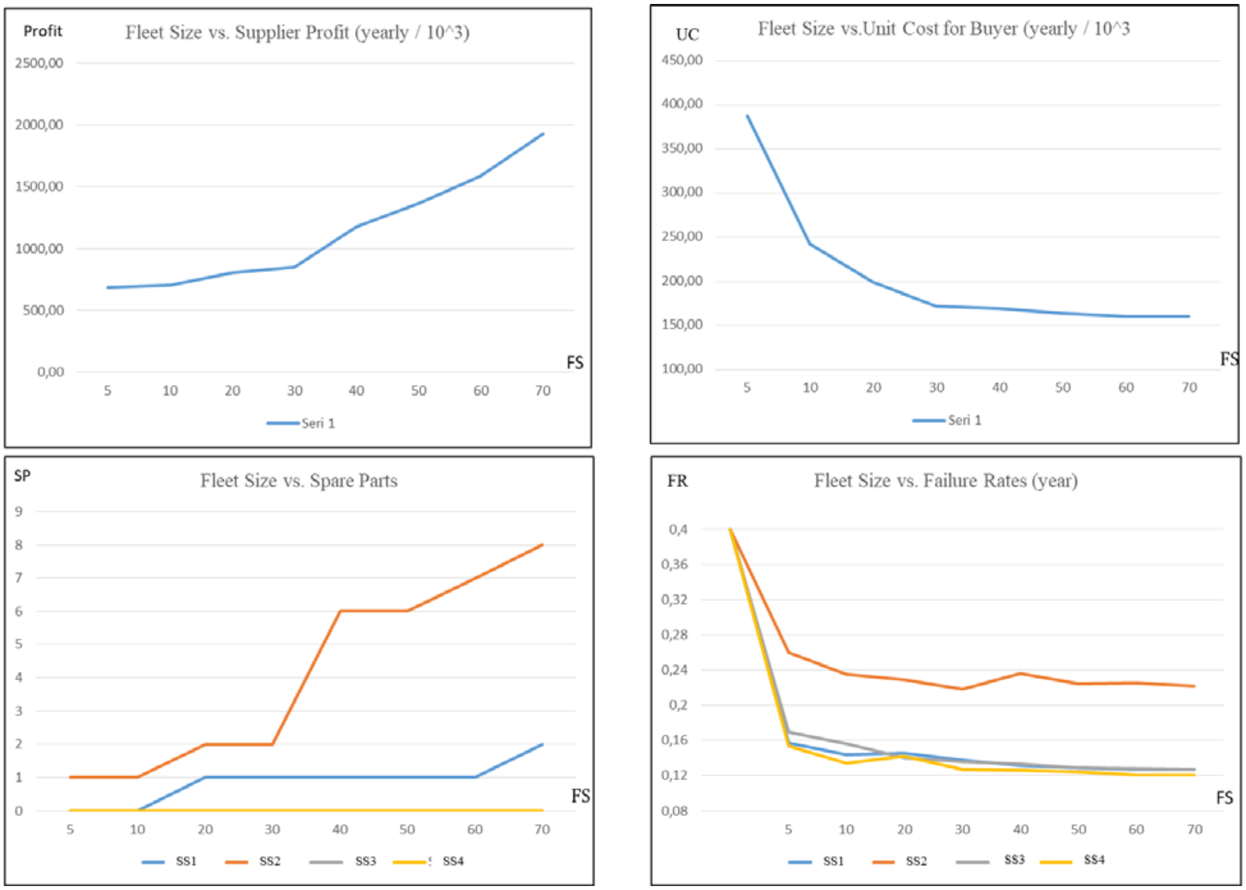


Figure 3.7: Results for the different fleet size within the five-year length of contract (A_{min1} = 0.90, A_{min2} = 0.95, τ=5).

Table 3.4: Results for the different fleet size within the five-year length of contract ($A_{min1} = 0.90$, $A_{min2} = 0.95$, $\tau = 5$).

Fleet Size (n)	5	10	20	30	40	50	60	70
Availability (A_s)	0.9499	0.9499	0.949	0.9405	0.9471	0.9410	0.9367	0.941
Supplier Profit (\$/year)(10^3)	682.40	702.42	805.86	848.26	1177.86	1367.92	1585.98	1926.36
Unit cost of Buyer (\$/unit/year)(10^3)	387.49	242.78	199.50	171.89	169.14	164.43	160.49	160.30
Spare parts								
Subsystem 1	0	0	1	1	1	1	1	2
Subsystem 2	1	1	2	2	6	6	7	8
Subsystem 3	0	0	0	0	0	0	0	0
Subsystem 4	0	0	0	0	0	0	0	0
Failure rates								
Subsystem 1	0.1568	0.1435	0.1456	0.1377	0.1317	0.1287	0.1272	0.1269
Subsystem 2	0.2602	0.2347	0.2291	0.2182	0.2363	0.2244	0.2257	0.2220
Subsystem 3	0.1696	0.1560	0.1406	0.1357	0.1333	0.1290	0.1280	0.1274
Subsystem 4	0.1535	0.1338	0.1420	0.1270	0.1261	0.1245	0.1210	0.1210

Table 3.5: Results for the different length of contract for thirty-unit fleet size ($A_{min1} = 0.90$, $A_{min2} = 0.95$, $n = 30$).

Length of the contract (τ) (year)	3	4	5	6	7	8	9	10
Availability (A_s)	0.9395	0.9398	0.9397	0.9404	0.9651	0.9662	0.9667	0.9668
Supplier Profit (\$/year)(10^3)	846.57	842.80	847.96	856.65	957.40	1202.72	1434.54	1671.72
Unit cost of Buyer (\$/unit/year) (10^3)	250.64	201.58	172.51	151.16	182.79	193.19	207.31	220.10
Spare parts								
Subsystem 1	1	1	1	1	2	2	2	2
Subsystem 2	2	2	2	2	4	4	4	4
Subsystem 3	0	0	0	0	0	0	0	0
Subsystem 4	0	0	0	0	1	1	1	1

(table continues)

Length of the contract (τ) (year)	3	4	5	6	7	8	9	10
Failure Rates								
Subsystem 1	0.1391	0.1353	0.1377	0.1354	0.1453	0.1437	0.1406	0.1403
Subsystem 2	0.2183	0.2213	0.2182	0.2191	0.1329	0.1305	0.2299	0.2282
Subsystem 3	0.1366	0.1370	0.1357	0.1345	0.1393	0.1346	0.1352	0.1336
Subsystem 4	0.1294	0.1282	0.1270	0.1287	0.1370	0.1343	0.1339	0.1356

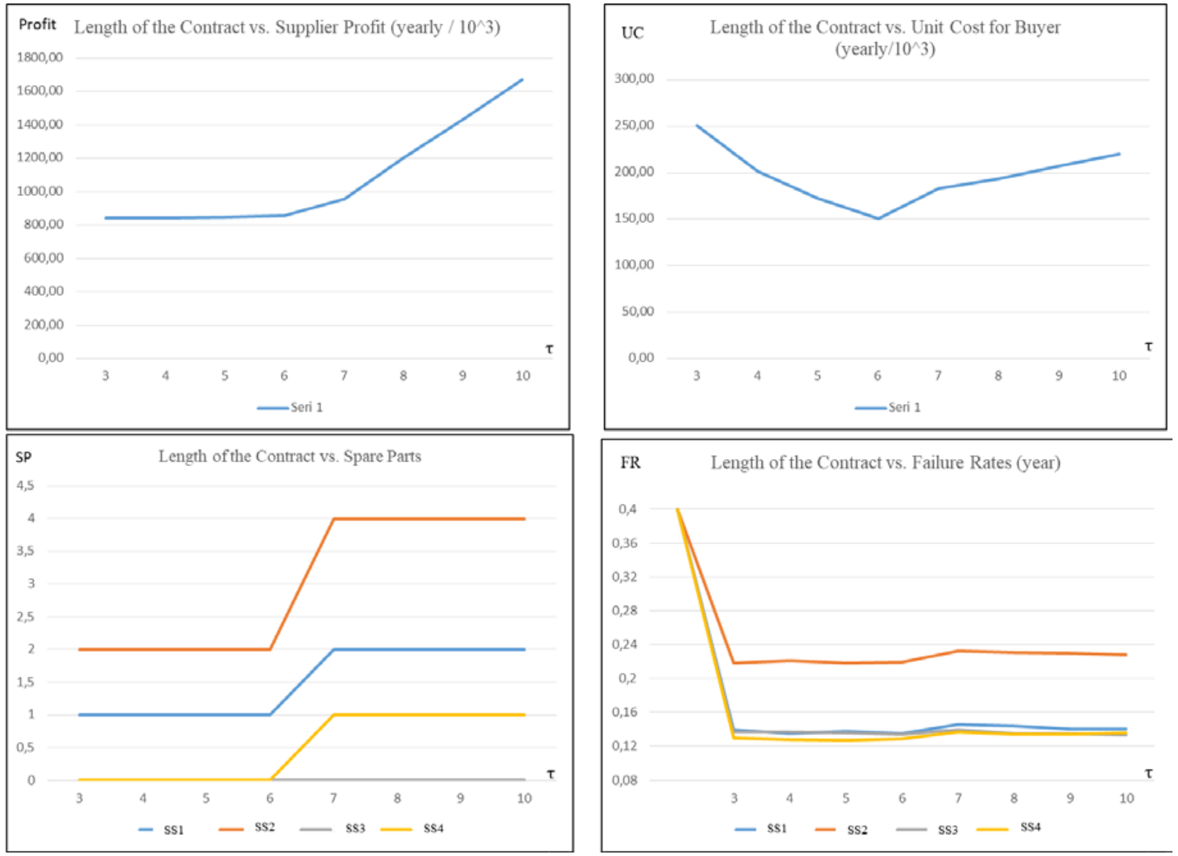


Figure 3.8: Results for the different length of contract for thirty-unit fleet size ($A_{min1} = 0.90$, $A_{min2} = 0.95$, $\tau=5$).

General Discussion and Implications

In this essay, we examined the effects of fleet size and contract length on reliability investment, inventory level, supplier’s profit and annual unit cost of the system for a buyer in PBCs. We analyzed how the supplier’s decision was affected by contract length and fleet size in a mathematical model, adapted from Jin et al. (2012), within the step revenue model, adapted from Nowicki et al. (2008). In PBCs, although suppliers have more freedom to act, they start to shoulder risks based on their decision on how to provide targeted performance rates. Therefore, they have to consider all aspects of contracts’ specialties that affect the outcome. On the other hand, buyers need to forecast the impacts of their decisions about contract length and fleet size. These features will impact the supplier's initiatives for upfront investments. Therefore, the main features of the agreement, which needs to be shaped in pre-contractual terms, should be closely considered and analyzed by both parties so that the supplier chooses the best optimal solutions based on his profit in the step revenue model. In this study, the impacts of the length of the contract and fleet size become possible for suppliers and buyers. So, this predictability helps to reduce information asymmetry and uncertainty that exists in agency problem in the post-contractual problem. From the perspective of buyers, unveil the impacts of these features increase the buyer's non-coercive power to motivate the supplier to act in the best interest of the buyer. On the other hand, this predictability will reduce the uncertainty of supplier’s action and helps to build more efficient PBCs.

We found that there was a substantial relationship between reliability enhancement, spare parts, the length of the contract, and fleet size. A general conclusion is that failure rates and the annual unit cost for the buyer exponentially decrease when fleet size or contract length become larger to meet minimum targeted availability rates and to get maximum profit. This result also confirms previous studies by Jin et al., (2012) and Randal et al., (2010). However, the increase in spare parts is relatively low with an increase in fleet size and the length of the contract. We propose that the impact of inventory investment has little effect on desired availability rates. Additionally, the annual profit of suppliers grows substantially with an increase in fleet size and length of contracts. This growth is sustained by the supplier's ability to absorb the design cost in large fleet size and longer term of agreements. Also, as seen in the examples above, the supplier's annual profit is low and almost stable with smaller fleet size (5 and 10) and short-term contracts (one-year and two-year). These results show that PBC arrangements are far more convenient for longer than three-year contracts and larger fleet sizes.

We can conclude that PBCs for a large number of systems have a positive effect on suppliers' decisions to make an upfront investment to increase the reliability of systems, which benefit from both suppliers and buyers. Considering the supplier's profit increase because of the absorption of the design and manufacturing costs in a more extended period and large fleet size, we can conclude that performance providers will be more motivated to make PBCs for a significant number of systems and the more extended contract term. Also, this results in an advantage for the buyer to acquire more reliable systems that contribute to greater system readiness.

Also, we found that long-term contracts have a positive impact on reliability enhancement. We can conclude that the supplier is much more eager to invest in the reliability of the system than in increasing spare parts under the PBC. Failure rates show an exponential decrease with an increase in the length of contracts. Additionally, considering the rise in the supplier's annual profit and the exponential decrease in the unit cost of the system for the buyer, we can conclude that a longer contract term creates a win-win situation for the buyer and for customers. This finding is consistent when we observed existing PBCs. Notably, in the defense industry, the Department of

Defense defined a 3 to 5-year contract term with an optional extension for their suppliers based on performance (DoD, 2014). We can conclude that an increase in contract lengthis much more profitable for suppliers and buyers under the performance-based contract.

Although we observed that the number of spare parts was slightly increased under the long-term contract, and with larger fleet size, we can conclude that increasing spare parts under the PBC does not profoundly affect availability rates. This slight increase is reasonable because of the number of systems and the longer contract period. On the other hand, we found that the growth rate in spare parts is much higher when design difficulty coefficient and repair cost are high. Therefore, we can conclude that PBCs motivate suppliers to make the upfront investment for reliability improvement with powerful incentives, which make for savings in future costs and result in high readiness of the system.

Although under the PBCs, performance providers have a freedom to how provide desired objectives, buyers can lead suppliers' decisions by using these features in the contract in the pre-contractual term and by the reward scheme. Also, based on our results, we can conclude that PBCs create a win-win situation for both buyers and suppliers. Therefore, from the perspective of principal-agent theory, we can conclude that the moral hazard problem in the post-contractual term can be handled by reducing the information asymmetry by understanding the effects of each contractual feature in PBCs in the pre-contractual term.

In this study, we did not investigate the effects of repair and maintenance enhancement on availability rates. In future studies, the impacts of process improvement to reduce the time required for repair and maintenance services and the logistic delay time in PBCs can be investigated. This study might also be conducted under different reward schemes with various contract types to find the most efficient and effective contract structure.

From the scholarly perspective, we can conclude that the transformation of post-production support from a traditional-based approach, which depends on sales of spare parts and maintenance service to performance-based agreements, must be considered as part of a holistic approach with interdisciplinary studies between engineering and supply chain management. On the other hand, from the managerial perspective, we can say that the PBC approach will transform manufacturing industries, which only produce goods, to provide post-production support for customers in their facilities.

References

Bakshi, N., Kim, S. H., & Savva, N. (2015). Signaling new product reliability with after-sales service contracts. Management Science, 61(8), 1812-1829.

Bergen, M., Dutta, S., & Walker Jr, O. C. (1992). Agency relationships in marketing: A review of the implications and applications of agency and related theories. Journal of Marketing, 56(3), 1-24.

Chiu, C. C., Hsu, C. H., & Yeh, Y. S. (2006). A genetic algorithm for reliability-oriented task assignment with k/spl tilde/duplications in distributed systems. IEEE Transactions on Reliability, 55(1), 105-117.

Cohen, M. A., & Netessine, S. (2007). 'Power by the Hour': Can Paying Only for Performance Redefine How Products Are Sold and Serviced? Knowledge@Wharton.

Defense Acquisition University (DAU) (2005a). Defense Acquisition Guidebook, http://akss.dau.mil/dag.

Department of Defense (DoD) (2014). Performance Based Logistics (PBL) Guidebook. Retrieved from https://acc.dau.mil/psa.

Devries, H. J. (2005). Performance-based logistics: Barriers and enablers to effective implementation. Defense Acquisition Review Journal, 11(3), 241-253.

Driessen M.A., Arts J.J.,.Houtum G.J, Rustenburg W.D., Huisman B., (2010). Maintenance spare parts planning and control: A framework for control and agenda for future research, Beta Working Paper series 325.

Eisenhardt, K. M. (1989). Agency theory: An assessment and review. Academy of management review, 14(1), 57-74.

Firchau, V. (1987). Information systems for principal-agent problems. In Agency Theory, Information, and Incentives (pp. 81-92). Springer Berlin Heidelberg.

Gansler, J. S., & Lucyshyn, W. (2006). Evaluation of performance based logistics. Doctoral dissertation, Naval Postgraduate School. Retrieved from http://www.acquistionresearch.org/ _files/fy2006/umd-lm-06-040.pdf

Guajardo, J. A., Cohen, M. A., Kim, S. H., & Netessine, S. (2012). Impact of performance-based contracting on product reliability: An empirical analysis. Management Science, 58(5), 961-979.

Helander, A., & Möller, K. (2008). How to become solution provider: System supplier's strategic tools. Journal of Business-to-Business Marketing, 15(3), 247-289.

Holland, J. H. (1992). Genetic algorithms. Scientific American, 267(1), 66-73.

Holland, J. H. (1973). Genetic algorithms and the optimal allocation of trials. SIAM Journal on Computing, 2(2), 88-105.

Hooper, L. (2008). Paying for performance: Uncertainty, asymmetric information and the payment model. Research in Transportation Economics, 22(1), 157-163.

Houck, C. R., Joines, J., & Kay, M. G. (1995). A genetic algorithm for function optimization: a Matlab implementation. Ncsu-ie tr, 95(09), 1-10.

Hypko, P., Tilebein, M., & Gleich, R. (2010). Benefits and uncertainties of performance-based contracting in manufacturing industries: An agency theory perspective. Journal of Service Management, 21(4), 460-489.

Hypko, P., Tilebein, M., & Gleich, R. (2010a). Clarifying the Concept of Performance-based Contracting in Manufacturing Industries: A Research Synthesis. Journal of Service Management 21 (5): 625–655.

Jin, T., & Y. Tian (2012). Optimizing reliability and service parts logistics for a time-varying installed base. European Journal of Operational Research, 218(1), 152-162.

Jin, T., & Wang, P. (2012). Planning performance based contracts considering reliability and uncertain system usage. Journal of the Operational Research Society, 63(10), 1467-1478.

Jin, T., Tian Z., Xie M. (2014). A Game-Theoretical Approach For Optimizing Maintenance, Spares And Service Capacity In Performance Contracting Optimizing Maintenance, Spares And Service Capacity In Performance Contracting. International Journal Production Economics, 31-43.

Kim, S.H., Cohen, M.A., & Netessine, S. (2007). Performance contracting in after-sales service supply chains. Management Science 53 (12), 1843–1858.

Kim, S. H., Cohen, M. A., Netessine, S., & Veeraraghavan, S. (2010). Contracting for infrequent restoration and recovery of mission-critical systems. Management Science, 56(9), 1551-1567.

Kim, S. H., Cohen, M. A., & Netessine, S. (2015). Reliability or Inventory? An Analysis of Performance-Based Contracts for Product Support Services. Working Paper.

Kumar, U. D., Nowicki, D., Ramírez-Márquez, J. E., & Verma, D. (2007). A goal programming model for optimizing reliability, maintainability and supportability under performance based logistics. International Journal of Reliability, Quality and Safety Engineering, 14(03), 251-261.

Mahon, D. (2007). Performance-based logistics: Transforming sustainment. Journal of Contract Management, 5, 53-71.

Martin, L. L. (2007). Performance-based contracting for human services: A proposed model. Public Administration Quarterly, 130-158.

Mettas A. (2000), Reliability Allocation and Optimization for Complex Systems, 2000 Proceedings Annual Reliability and Maintainability Symposium, IEEE.

Mirzahosseinian, H. & R. Piplani (2011). A study of repairable parts inventory system operating under performance-based contract. European Journal of Operational Research, 214(2), 256-261.

Nowicki, D., Kumar, U. D., Steudel, H. J., & Verma, D. (2008). Spares provisioning under performance-based logistics contract: profit-centric approach. Journal of the Operational Research Society, 59(3), 342-352.

Ong, M., Ren, X., Allan, G., Kadirkamanathan, V., Thompson, H. A., & Fleming, P. J. (2005). Decision support system on the grid. International Journal of Knowledge-Based and Intelligent Engineering Systems, 9(4), 315-326.

Randall, W. S., Pohlen, T. L., & Hanna, J. B. (2010). Evolving a theory of Performance-based Logistics using insights from service-dominant logic. Journal of Business Logistics, 31(2), 35-61.

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

Razali, N. M., & Geraghty, J. (2011, July). Genetic algorithm performance with different selection strategies in solving TSP. In Proceedings of the world congress on engineering, Hong Kong: International Association of Engineers, Vol. 2, 1134-1139.

Richardson, D., & Jacopino, A. (2006, January). Use of R&M measures in Australian defence aerospace performance based contracts. In Reliability and Maintainability Symposium, 2006. RAMS'06. Annual (pp. 331-336). IEEE.

Selviaridis, K., & Wynstra, F. (2015). Performance-based contracting: a literature review and future research directions. International Journal of Production Research, 53(12), 3505-3540.

Sherbrooke, C. C. (1968). METRIC: A multi-echelon technique for recoverable item control. Operations Research, 16(1), 122-141.

Sherbrooke, C. C. (1992). Multiechelon inventory systems with lateral supply. Naval Research Logistics (NRL), 39(1), 29-40.

Sols, A., Nowicki, D., & Verma, D. (2007). Defining the fundamental framework of an effective Performance-based logistics (PBL) contract. Engineering Management Journal, 19(2), 40-50.

Straub, A. (2009). Cost savings from performance-based maintenance contracting. International Journal of Strategic Property Management, 13(3), 205-217.

Vitasek, K., Cothran, J., & Rutner, S. (2007). Best practices of public private partnering: Developing a win-win strategy for working with depots (White paper). Knoxville, TN: the University of Tennessee and Supply Chain Visions.

Vitasek, K., & Geary, S. (2007). Performance-Based Logistics—Next Big Thing.ProLogis Supply Chain Review, Summer, 1-11.

Wang, W., Loman, J., & Vassiliou, P. (2004). Reliability importance of components in a complex system. In Reliability and Maintainability, 2004 Annual Symposium-RAMS (pp. 6-11). IEEE.

CONCLUSION

Performance-based arrangements have become a prevalent contract type among practitioners seeking to reduce the life cycle cost of systems while increasing their readiness. Therefore, this concept has also become a popular topic among academics seeking to enhance understanding of this phenomenon. Much of the previous research on performance-based contracts has been aimed at showing key features of its design, challenges, incentive structure, and its impact on supplier behavior (Selviaridis & Wynstra, 2015). Still, many more studies are needed to extend its theoretical framework, and empirical research should be conducted to extend understanding of PBC phenomena. The three essays introduced in this dissertation seek to contribute to knowledge of PBC phenomena by expanding understanding of the success factors behind effective performance-based contracts.

In Essay 1, the goal is to investigate how the effects of supply chain collaboration, in conjunction with investments, contribute to the value offerings that are created in performance-based contracts. The empirical findings of this paper show that the significance of collaboration within the supplier and upfront investments consist of quality, process, and knowledge investments that are critical positive enablers of PBC benefits. Also, this study reveals the characteristics of upfront investments that provide future cost avoidance for suppliers in performance-based arrangements and contributes to the existing body of knowledge by providing theoretical insights in the PBC context. The results of this study indicate that supply chain collaboration and investments lead to better PBC benefits. These research results highlight the amplifying function of investment between SCC and effective PBCs. Thus, better collaboration within suppliers is an essential factor to come up with innovative investment solutions to increase the benefits by avoiding future costs in PBCs. These findings are also consistent and provide empirical evidence for the statements of Randall et al. (2011), in which the authors emphasize the importance of this investment climate and relational exchange of suppliers for continuous value creation in PBCs.

Building upon the findings in the PBC literature, which leads to successful performance-based arrangements in Essay 1, Essay 2 explores critical criteria for supplier selection for effective PBCs. Also, using grounded theory exploration technique enables us to investigate links and findings using a holistic approach. In contrast to supplier selection criteria for transaction-based contracts, this study reveals the importance of a “core competency” and “process improvement capability” as new selection criteria in PBCs and highlighted six more selection criteria that should be considered a priority for the buyer. These six criteria are: quality improvement capability; process improvement capability; technical capability; production facilities and capacity; management and organization; financial capacity; and performance history (see Figure 2.2). While highlighting the critical characteristics of suppliers for a performance-based arrangement, this study presented an appropriate multi-criteria group decision making tool for the evaluation of the best supplier for decision makers. The findings of this study reduce the risks of high dependence to suppliers in PBCs by avoiding the selection of the wrong supplier based on critical selection criteria. Better assessment and evaluation of suppliers is a critical factor for the achievement of successful PBCs (Sols & Johannesen 2013; Ziegenbein & Nienhaus, 2004).

Building on the dimensions of “Investment” and “Financial Benefits” from Essay 1, Essay 3 explores the impacts of contract features, such as the contract length and fleet size, on suppliers’ decisions in performance-based arrangements in a mathematical model. The results of this study enhance understanding of the impacts of fleet size and the length of contracts on decision made by suppliers for reliability and inventory investments in PBCs and extend the usage of revenue models in PBC. The results show that there was a considerable relationship between reliability enhancement, spare parts, the length of the contract, and fleet size. A general conclusion is that failure rates and the annual unit cost for the buyer exponentially decrease when fleet size or contract length become larger in order to meet minimum targeted availability rates and to obtain maximum profit. When fleet size or the length of contract becomes larger to meet minimum targeted availability rates and to get maximum profit, suppliers are much more eager to invest in reliability than spare parts. This enables savings in future costs caused by maintenance, and results in high system readiness in the incentive structure of PBCs. These results echos previous studies of Kim et al., (2015) and Jin et al., (2012) and also confirms the propositions of Randal et al. (2010). Understanding of the effects of contractual features in PBCs in the pre-contractual term will mitigate the risks that arise from asymmetric information and the moral hazard problem in the post-contractual term.

Taken together, the essays in this dissertation provide a solid foundation for theoretical and practitioner understanding of the success factors behind effective and efficient PBCs, by contributing to the existing body of knowledge with theoretical insights and empirical findings in the PBC context. Exploring the positive impacts of collaboration and investments in PBC benefits and understanding the impact of contract features will lead practitioners to find better value offerings for both sides. Understanding the success factors of PBCs and essential selection criteria of suppliers by buyers will lead to the greater achievement of desired performance and will reduce the risk of dependence for suppliers. In sum, this dissertation adds valuable knowledge to the context of performance-based contracting for practitioners and academics. The information provided will allow researchers to develop a theoretical framework of PBC and provide managers with the information needed to achieve successful PBCs. Finally, the contributions of each individual essay incrementally contribute to better implementation of PBCs.

COMPREHENSIVE REFERENCE LIST

Administration for Children & Families (2011). National Quality Improvement Center on the Privatization of Child Welfare Service, DHHS, Washington, DC.

Anderson, J. C., & Gerbing, D. W. (1988). Structural equation modeling in practice: A review and recommended two-step approach. Psychological bulletin, 103(3), 411.

Agripino, M., Cathcart, T., & Mathaisel, D. (2002). A lean sustainment enterprise model for military systems. Acquisition Review Quarterly, 9, 274-297.

Bagozzi, R. P., & Yi, Y. (1988). On the evaluation of structural equation models. Journal of the academy of marketing science, 16(1), 74-94.

Banaeian, N., Mobli, H., Fahimnia, B., Nielsen, I. E., & Omid, M. (2018). Green supplier selection using fuzzy group decision making methods: A case study from the agri-food industry. Computers & Operations Research, 89, 337-347.

Barbarosoglu, G., & Yazgac, T. (1997). An application of the analytic hierarchy process to the supplier selection problem. Production and Inventory Management Journal, 38(1), 14.

Barratt, M. (2004). Understanding the meaning of collaboration in the supply chain. Supply Chain Management: An International Journal, 9(1), 30-42.

Bakshi, N., Kim, S. H., & Savva, N. (2015). Signaling new product reliability with after-sales service contracts. Management Science, 61(8), 1812-1829.

Bayazit, O. (2006). Use of analytic network process in vendor selection decisions. Benchmarking: An International Journal, 13(5), 566-579.

Bentler, P. M. (1990). Comparative fit indexes in structural models. Psychological bulletin, 107(2), 238.

Bentler, P. M., & Bonett, D. G. (1980). Significance tests and goodness of fit in the analysis of covariance structures. Psychological bulletin, 88(3), 588.

Berkowitz, D., Gupta, J. N., Simpson, J. T., & McWilliams, J. B. (2005). Defining and implementing performance-based logistics in government. Defense Acquisition Review Journal, 11(3), 255-267.

Bergen, Mark, Shantanu Dutta, & Orville C. Walker, Jr. (1992). Agency Relationships in Marketing: A Review of the Implications and Applications of Agency and Related Theories. Journal of Marketing, 56 (Jul), 1-24.

Bergen, M., Dutta, S., & Walker Jr, O. C. (1992). Agency relationships in marketing: A review of the implications and applications of agency and related theories. Journal of Marketing, 56(3), 1-24.

Birgun Barla, S. (2003). A case study of supplier selection for lean supply by using a mathematical model. Logistics Information Management, 16(6), 451-459.

Boran, F. E., Genç, S., Kurt, M., & Akay, D. (2009). A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method. Expert Systems with Applications, 36(8), 11363-11368.

Boardman, J., & Sauser, B. (2008). Systems thinking: Coping with 21st century problems. CRC Press.

Bottani, E., & Rizzi, A. (2006). A fuzzy TOPSIS methodology to support outsourcing of logistics services. Supply Chain Management: An International Journal, 11(4), 294-308.

Boudreau, M. W., & Naegle, B. R. (2003). Reduction of total ownership cost. Doctoral dissertation, Naval Postgraduate School. Retrieved from http://stinet.dtic.mil/cgibin/GetTRDoc?AD=A419826&Location=U2&doc=GetTRDoc.pdf

Bowersox, D.J., Closs, D.J., & Stank, T.P., (2003). How to master cross-enterprise collaboration. Supply Chain Management Review 7 (4), 18–27.

Boyce, J., & Banghart, A. (2012). Performance based logistics and project proof point. Defense AT&L, 41(2), 26-30.

Byrne, B.M., (1989). A Primer of LISREL: Basic Applications and Programming for Confirmatory Factor Analysis Analytic Models. Springer–Verlog, NY.

Buchanan, N., & Klingner, D. E. (2007). Performance-based contracting: are we following the mandate? Journal of Public Procurement, 7(3), 301.

Buhrmester, M., Kwang, T. & Gosling, S.D. (2011), “Amazon’s Mechanical Turk a new source of inexpensive, yet high-quality, data?”, Perspectives on Psychological Science, Vol. 6 No. 1, pp. 3-5..

Caldwell, N., & Howard, M. (2014). Contracting for complex performance in markets of few buyers and sellers. International Journal of Operations & Production Management, 34(2), 270-294.

Cao, M., Vonderembse, M. A., Zhang, Q., & Ragu-Nathan, T. S. (2010). Supply chain collaboration: conceptualisation and instrument development. International Journal of Production Research, 48(22), 6613-6635.

Cao, M., & Zhang, Q., (2011). Supply chain collaboration: impact on collaborative advantage and firm performance, Journal of Operations Management, 29 (3) (2011), 163-180.

Chai, J., Liu, J.N.K., & Ngai, E.W.T., (2013). Application of decision-making techniques in supplier selection: a systematic review of literature. Expert Systems Applications 40 (10), 3872-3885.

Chan, F. S. (2003). Interactive selection model for supplier selection process: an analytical hierarchy process approach. International Journal of Production Research, 41(15), 3549-3579.

Chan, F. T., & Kumar, N. (2007). Global supplier development considering risk factors using fuzzy extended AHP-based approach. Omega, 35(4), 417-431.

Chan, F. T., Kumar, N., Tiwari, M. K., Lau, H. C. W., & Choy, K. L. (2008). Global supplier selection: a fuzzy-AHP approach. International Journal of Production Research, 46(14), 3825-3857.

Charmaz, K. (2006), Constructing Grounded Theory: A Practical Guide Through Qualitative Analysis, Sage, Thousand Oaks, CA.

Chau, P., (1997). Reexamining a model for evaluating information center success using a structural equation modeling approach. Decision Sciences, 28 (2), 309–334.

Churchill Jr, G. A. (1979). A paradigm for developing better measures of marketing constructs. Journal of Marketing Research, 64-73.

Chen, C.-T., Lin, C.-T., & Huang, S.-F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. International Journal of Production Economics, 102(2), 289-301.

Cheraghi, S. H., Dadashzadeh, M., & Subramanian, M. (2004). Critical success factors for supplier selection: an update. Journal of Applied Business Research, 20(2), 91-108.

Chiu, C. C., Hsu, C. H., & Yeh, Y. S. (2006). A genetic algorithm for reliability-oriented task assignment with k/spl tilde/duplications in distributed systems. IEEE Transactions on Reliability, 55(1), 105-117.

Chou, S.-Y. & Y.-H. Chang (2008). A decision support system for supplier selection based on a strategy-aligned fuzzy SMART approach. Expert Systems with Applications 34(4): 2241-2253.

Cohen, M. A., & Netessine, S. (2007). 'Power by the Hour': Can Paying Only for Performance Redefine How Products Are Sold and Serviced? Knowledge@Wharton.

Creswell, J. W. (2003). Research design qualitative, quantitative, and mixed method approaches (2nd ed.). Thousand Oaks, CA: Sage.

Devries, H. J. (2005). Performance-based logistics: Barriers and enablers to effective implementation. Defense Acquisition Review Journal, 11(3), 241-253.

Defense Acquisition University (DAU) (2005a). Defense Acquisition Guidebook, http://akss.dau.mil/dag.

Department of Defense (DoD) (2007). PBL Award 2007 System FA-18 FIRST, 1-9. Retrieved fromhttps://www.dau.mil/cop/pbl/_layouts/15/WopiFrame.aspx?sourcedoc=/cop/pbl/DAU%20Sponsored%20Documents/PBL%20Award%20Pkg%202007%20System%20FA%2018%20FIRST.pdf&action=default.

Department of Defense (DoD) (2008). PBL Award 2008 System F-22, 4-14. Retrieved from https://www.dau.mil/cop/pbl/_layouts/15/WopiFrame.aspx?sourcedoc=/cop/pbl/DAU%20Sponsored%20Documents/PBL%20Award%20Pkg%202008%20System%20F%2022.pdf&action=default.

Department of Defense (DoD) (2008). PBL Award 2008 Sub-system ARL 67 Radar Warning System, 3-11. Retrieved from https://www.dau.mil/cop/pbl/_layouts/15/WopiFrame.aspx?sourcedoc=/cop/pbl/DAU%20Sponsored%20Documents/PBL%20Award%20Pkg%202020820Sub%20system%20ARL%2067%20Radar%20Warning%20System.pdf&action=default.

Department of Defense (DoD) (2014). Performance Based Logistics (PBL) Guidebook. Retrieved from https://acc.dau.mil/psa.

De Boer, L., van der Wegen, L., & Telgen, J. (1998). Outranking methods in support of supplier selection. European Journal of Purchasing & Supply Management, 4(2-3), 109-118.

De Boer, L., Labro, E., & Morlacchi, P. (2001). A review of methods supporting supplier selection. European journal of purchasing & supply management, 7(2), 75-89.

Dickson, G. W. (1996). An analysis of vendor selection systems and decisions. Journal of Purchasing, 2(1), 5-17.

Ding, H., Benyoucef, L., & Xie, X. (2005). A simulation optimization methodology for supplier selection problem. International Journal of Computer Integrated Manufacturing, 18(2-3), 210-224.

Doerr, K. H., Apte, U., Boudreau, M., & Kang, K. (2010). "Decision support models for valuing improvements in component reliability and maintenance." Military Operations Research, 2010, Volume 15, N4, pp. 55-68.

Doll, W.J., Raghunathan, T., Lim, S.J., & Gupta, Y.P., (1995). A confirmatory factor analysis of the user information satisfaction instrument. Information Systems Research 6 (2), 177–188.

Driessen M.A., Arts J.J.,.Houtum G.J, Rustenburg W.D., Huisman B., (2010). Maintenance spare parts planning and control: A framework for control and agenda for future research, Beta Working Paper series 325.

Eisenhardt, K. M. (1989). Agency theory: An assessment and review. Academy of management review, 14(1), 57-74.

ElMaraghy, A. H., & Majety, R. (2008). Integrated supply chain design using multi-criteria optimization. International Journal of Advance Manufacturing Technology, 37, 371–399.

Emerson, Richard M. (1962). Power-Dependence Relations. American Sociological Review, 27 (Feb), 31-41.

Essig, M., Glas, A. H., Selviaridis, K., & Roehrich, J. K. (2016). Performance-based contracting in business markets. Industrial Marketing Management, 59, 5-11.

Firchau, V. (1987). Information systems for principal-agent problems. In Agency Theory, Information, and Incentives (pp. 81-92). Springer Berlin Heidelberg.

Fornell, C., & Larcker, D. F. (1981). Structural equation models with unobservable variables and measurement error: Algebra and statistics. Journal of marketing research, 382-388.

Fynes, B., De Búrca, S., & Marshall, D. (2004). Environmental uncertainty, supply chain relationship quality and performance. Journal of Purchasing and Supply Management, 10(4-5), 179-190.

Gansler, J. S., & Lucyshyn, W. (2006). Evaluation of performance based logistics. Doctoral dissertation, Naval Postgraduate School. Retrieved from http://www.acquistionresearch.org/ _files/fy2006/umd-lm-06-040.pdf

Gardner, C., P. (2008). Balancing the Government Risks with Contractor Incentives in Performance-Based Logistics Contracts. Master's Thesis, Air Force Institute of Technology.

Gaski, J. F. (1984). The theory of power and conflict in channels of distribution. The Journal of Marketing, 9-29.

Geary, S., & Vitasek, K. (2005). It's a war of ideas. Aviation Week & Space Technology, 163(17), 57.

Gencer, C., & Gurpinar, D. (2007). Analytic network process in supplier selection: A case study in an electronic firm. Applied Mathematical Modeling, 31(11), 2475-2486.

Girubha, J., Vinodh, S., KEK, V., Moutinho, L., & Weaver, W., (2016). Application of interpretative structural modeling integrated multi-criteria decision-making methods for sustainable supplier selection. Journal of Modelling in Management, 11 (2), 358-388.

Goulding, C. (1998). Grounded theory: the missing methodology on the interpretivist agenda. Qualitative Market Research: An International Journal, 1(1), 50-57.

Griffin, J. M. (2005). C-5A galaxy systems engineering case study. AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH CENTER FOR SYSTEMS ENGINEERING.

Griffin, W. (2008). The future of integrated supply chain management utilizing performance based logistics. NATO Supreme Allied Command Transformation Norfolk VA.

Guajardo, J. A., Cohen, M. A., Kim, S. H., & Netessine, S. (2012). Impact of performance-based contracting on product reliability: An empirical analysis. Management Science, 58(5), 961-979.

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). Multivariate Data Analysis (7 ed.). Upper Saddle River, NJ: Prentice Hall.

Helander, A., & Moller, K. (2008). How to become solution provider: System supplier's strategic tools. Journal of Business-to-Business Marketing, 15(3), 247-289.

Heide, Jan B. (1994). Inter-organizational governance in marketing channels. The Journal of Marketing, 71-85.

Herrera, F., & Herrera-Viedma, E. (2000). Linguistic decision analysis: steps for solving decision problems under linguistic information. Fuzzy sets and systems, 115(1), 67-82.

Ho, W., Xu, X., & Dey, P. K. (2010). Multi-criteria decision making approaches for supplier evaluation and selection: A literature review. European Journal of Operational Research, 202(1), 16-24.

Holland, J. H. (1992). Genetic algorithms. Scientific American, 267(1), 66-73.

Holland, J. H. (1973). Genetic algorithms and the optimal allocation of trials. SIAM Journal on Computing, 2(2), 88-105.

Hong, G. H., Park, S. C., Jang, D. S., & Rho, H. M. (2005). An effective supplier selection method for constructing a competitive supply-relationship. Expert Systems with Applications, 28(4), 629-639.

Hooper, D., Coughlan, J., & Mullen, M. (2008). Structural equation modelling: Guidelines for determining model fit. Articles, 2.

Hooper, L. (2008). Paying for performance: Uncertainty, asymmetric information and the payment model. Research in Transportation Economics, 22(1), 157-163.

Houck, C. R., Joines, J., & Kay, M. G. (1995). A genetic algorithm for function optimization: a Matlab implementation. Ncsu-ie tr, 95(09), 1-10.

Huang, S. H., & Keskar, H. (2007). Comprehensive and configurable metrics for supplier selection. International Journal of Production Economics, 105(2), 510-523.

Hunter, C. (2006b). Public and private partnerships and the future of the Army industrial enterprise. Retrieved from http://www.lexingtoninstitute.org/library/resources/documents/ Defense/public privatepartnerships.pdf

Hypko, P., Tilebein, M., & Gleich, R. (2010). Benefits and uncertainties of performance-based contracting in manufacturing industries: An agency theory perspective. Journal of Service Management, 21(4), 460-489.

Hypko, P., Tilebein, M., & Gleich, R. (2010a). Clarifying the Concept of Performance-based Contracting in Manufacturing Industries: A Research Synthesis. Journal of Service Management 21 (5): 625–655.

Jensen, Michael C., & William H. Meckling (1976). Theory of the firm: Managerial behavior, agency costs and ownership structure. Journal of financial economics 3, no. 4, 305-360.

Jin, T., & Y. Tian (2012). Optimizing reliability and service parts logistics for a time-varying installed base. European Journal of Operational Research, 218(1), 152-162.

Jin, T., & Wang, P. (2012). Planning performance based contracts considering reliability and uncertain system usage. Journal of the Operational Research Society, 63(10), 1467-1478.

Jin, T., Tian Z., Xie M. (2014). A Game-Theoretical Approach For Optimizing Maintenance, Spares And Service Capacity In Performance Contracting Optimizing Maintenance, Spares And Service Capacity In Performance Contracting. International Journal Production Economics, 31-43.

Joreskog, K.G, & Sorbom, D., (1986). LISREL VI: Analysis of Linear Structural Relationships by Maximum Likelihood, Instrumental Variables, and Least Squares Methods. Scientific Software, Inc., Moorsville, IN.

Kalwani, M.U., & Narayandas, N., (1995). Long-term manufacturer–supplier relationships: do they pay? Journal of Marketing 59 (1), 1–15.

Kar K., A., & Pani, A. K. (2014). Exploring the importance of different supplier selection criteria. Management Research Review, 37 (1), 89-105.

Karpak, B., Kumcu, E., & Kasuganti, R. R. (2001). Purchasing materials in the supply chain: managing a multi-objective task. European Journal of Purchasing & Supply Management, 7(3), 209-216.

Keating, S., & Huff, K. (2005). Managing in the new risk supply chain. Engineering Management, 15(1), 24-27.

Kilincci, O., & Onal, S. A. (2011). Fuzzy AHP approach for supplier selection in a washing machine company. Expert Systems with Applications, 38(8), 9656-9664.

Kim, S.H., Cohen, M.A., & Netessine, S. (2007). Performance contracting in after-sales service supply chains. Management Science 53 (12), 1843–1858.

Kim, S. H., Cohen, M. A., Netessine, S., & Veeraraghavan, S. (2010). Contracting for infrequent restoration and recovery of mission-critical systems. Management Science, 56(9), 1551-1567.

Kim, S. H., Cohen, M. A., & Netessine, S. (2015). Reliability or Inventory? An Analysis of Performance-Based Contracts for Product Support Services. Working Paper.

Kirk, R. L., & DePalma, T. J. (2005). Performance-based logistics contracts: A basic overview (No. CRM-D0012881. A2-Final). CNA Corporation Alexandria United States.

Kleemann, F. C., & Essig, M. (2013). A providers’ perspective on supplier relationships in performance-based contracting. Journal of purchasing and supply management, 19(3), 185-198.

Knemeyer, A.M. & Naylor, R.W. (2011). Using behavioral experiments to expand our horizons and deepen our understanding of logistics and supply chain decision making. Journal of Business Logistics, Vol. 32 No. 4, pp. 296-302.

Kobren, B. (2009). What Performance-based logistics is and what it is not - and what it can and cannot do. Defense Acquisition Review Journal, 16(3), 254-267.

Kratz, L. & Buckingham, B. A. (2010). Achieving outcomes-based life cycle management. Defense Acquisition Review Journal, 77(1), 45-66.

Kumar, U. D., Nowicki, D., Ramírez-Márquez, J. E., & Verma, D. (2007). A goal programming model for optimizing reliability, maintainability and supportability under performance based logistics. International Journal of Reliability, Quality and Safety Engineering, 14(03), 251-261.

Kumar Kar, A., & K. Pani, A. (2014). Exploring the importance of different supplier selection criteria. Management Research Review, 37(1), 89-105.

Labib, A. W. (2011). A supplier selection model: a comparison of fuzzy logic and the analytic hierarchy process. International Journal of Production Research, 49(21), 6287-6299.

Lavie, D. (2006). The competitive advantage of interconnected firms: an extension of the resource-based view. Academy of Management Review 31 (3), 638–658.

Lima, Osiro, & Carpinetti (2014). A comparison between Fuzzy AHP and Fuzzy TOPSIS methods to supplier selection. Applied Soft Computing, 202 (1), 16-24.

Locke, E. A. (2007). The case for inductive theory building. Journal of Management, 33(6), 867-890.

Mahon, D. (2007). Performance-based logistics: Transforming sustainment. Journal of Contract Management, 5, 53-71.

Manuj, I., & Mentzer, J. T. (2008). Global supply chain risk management strategies. International Journal of Physical Distribution & Logistics Management, 38(3), 192-223.

Marsh, H.W., & Hocevar, D., (1985). Application of confirmatory factor analysis to the study of self-concept: first-and higher-order factor models and their invariance across groups. Psychological Bulletin 97 (3), 562–582.

Martin, L. L. (2007). Performance-based contracting for human services: A proposed model. Public Administration Quarterly, 130-158.

Mentzer, J.T., Foggin, J.H., & Golicic, S.L., (2000). Collaboration: the enablers, impediments, and benefits. Supply Chain Management Review 5 (6), 52–58.

Mentzer, J.T., DeWitt, W., Keebler, J.S., Min, S., Nix, N.W., Smith, C.D., Zacharia, Z.G., (2001). Defining supply chain management. Journal of Business Logistics 22 (2), 1–25.

Merriam, S. B. (1998). Qualitative research and case study applications in education. San Francisco, CA: Jossey-Bass.

Mettas A. (2000), Reliability Allocation and Optimization for Complex Systems, 2000 Proceedings Annual Reliability and Maintainability Symposium, IEEE.

Miller, A. (2008). Performance-based logistics works. Aviation Week & Space Technology, 169(17), 78.

Min, S., Roath, A. S., Daugherty, P. J., Genchev, S. E., Chen, H., Arndt, A. D., & Glenn Richey, R. (2005). Supply chain collaboration: what's happening? The international journal of logistics management, 16(2), 237-256.

Mirzahosseinian, H. & R. Piplani (2011). A study of repairable parts inventory system operating under performance-based contract. European Journal of Operational Research, 214(2), 256-261.

Moore Nancy Y., & Loredo Elvira N. (2013). Identifying and Managing Air Force Sustainment Supply Chain Risks, RAND Corporation, 41-44.

Narasimhan, R., Talluri, S., & Mendez, D. (2001). Supplier evaluation and rationalization via data envelopment analysis: an empirical examination. Journal of Supply Chain Management, 37(2), 28-37.

Narasimhan, R., Talluri, S., & Mahapatra, S. K. (2006). Multiproduct, multicriteria model for supplier selection with product life-cycle considerations. Decision Sciences, 37(4), 577-603.

Ng, I. C., Maull, R., & Yip, N. (2009). Outcome-based contracts as a driver for systems thinking and service-dominant logic in service science: Evidence from the defence industry. European Management Journal, 27(6), 377-387.

Ng, I. L., & Nudurupati, S. S. (2010). Outcome-based service contracts in the defense industry - Mitigating the challenges. Journal of Service Management, 2(5), 656- 674.

Ng, I. C., Ding, D. X., & Yip, N. (2013). Outcome-based contracts as new business model: The role of partnership and value-driven relational assets. Industrial Marketing Management, 42(5), 730-743.

Ng, W. L. (2008). An efficient and simple model for multiple criteria supplier selection problem. European Journal of Operational Research, 186(3), 1059-1067.

Nowicki, D., Kumar, U. D., Steudel, H. J., & Verma, D. (2008). Spares provisioning under performance-based logistics contract: profit-centric approach. Journal of the Operational Research Society, 59(3), 342-352.

Ong, M., Ren, X., Allan, G., Kadirkamanathan, V., Thompson, H. A., & Fleming, P. J. (2005). Decision support system on the grid. International Journal of Knowledge-Based and Intelligent Engineering Systems, 9(4), 315-326.

Ordoobadi, S. M. (2009). Development of a supplier selection model using fuzzy logic. Supply Chain Management: An International Journal, 14(4), 314-327.

Park, N.K., Mezias, J.M., & Song, J., (2004). A resource-based view of strategic alliances and firm value in the electronic marketplace. Journal of Management 30 (1), 7–27.

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. Behavior Research Methods, 40(3), 879-891.

Quick, Robert M. (2011). Performance-Based Logistics: A Military Logistics Model. Doctoral dissertation. Retrieved from ProQuest digital dissertation database. (UMI No. 3467482).

Randall, W. S., Pohlen, T. L., & Hanna, J. B. (2010). Evolving a theory of Performance-based Logistics using insights from service-dominant logic. Journal of Business Logistics, 31(2), 35-61.

Randall, W. S., Nowicki, D. R., & Hawkins, T. G. (2011). Explaining the effectiveness of performance-based logistics: a quantitative examination. The International Journal of Logistics Management, 22(3), 324-348.

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

Randall, W. S., & Mello, J. E. (2012). Grounded theory: an inductive method for supply chain research. International Journal of Physical Distribution & Logistics Management, 42(8/9), 863-880.

Randall, W. S., Nowicki, D. R., Deshpande, G., & Lusch, R. F. (2014). Converting knowledge into value: gaining insights from service dominant logic and neuroeconomics. International Journal of Physical Distribution & Logistics Management, 44(8/9), 655-670.

Randall, W. S., Hawkins, T. G., Haynie, J. J., Nowicki, D. R., Armenakis, A. A., & Geary, S. R. (2015). Performance-Based Logistics and Interfirm Team Processes: An Empirical Investigation. Journal of Business Logistics, 36(2), 212-230.

Razali, N. M., & Geraghty, J. (2011, July). Genetic algorithm performance with different selection strategies in solving TSP. In Proceedings of the world congress on engineering, Hong Kong: International Association of Engineers, Vol. 2, 1134-1139.

Rezaei, J., Nispeling, T., Sarkis, J., & Tavasszy, L. (2016). A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method. Journal of Cleaner Production, 135, 577-588.

Richardson, D., & Jacopino, A. (2006, January). Use of R&M measures in Australian defence aerospace performance based contracts. In Reliability and Maintainability Symposium, 2006. RAMS'06. Annual (pp. 331-336). IEEE.

Salancik, G. R., & Pfeffer, J. (1978). A social information processing approach to job attitudes and task design. Administrative science quarterly, 224-253.

Sammarco, P. W., Kolian, S. R., Warby, R. A., Bouldin, J. L., Subra, W. A., & Porter, S. A. (2013). Distribution and concentrations of petroleum hydrocarbons associated with the BP/Deepwater Horizon Oil Spill, Gulf of Mexico. Marine pollution bulletin, 73(1), 129-143.

Sarkis, J., & Talluri, S. (2002). A model for strategic supplier selection. Journal of supply chain management, 38(4), 18-28.

Schoenherr, T., Ellram, L.M. & Tate, W.L. (2015). A note on the use of survey research firms to enable empirical data collection. Journal of Business Logistics, 36(3), 288-300.

Secretary of Defense (2016). Performance Based Logistics (PBL) Awards Selection. https://dap.dau.mil/career/log/blogs/archive/2016/11/22/dod-announces-the-winners-of-the-2016-secretary-of-defense-performance-based-logistics-pbl-awards.aspx

Segars, A.H., & Grover, V., (1998). Strategic information systems planning success: an investigation of the construct and its measurement. MIS Quarterly 22(2), 139–163.

Selçuk, B., & Agrali, S. (2013). Joint spare parts inventory and reliability decisions under a service constraint. The Journal of the Operational Research Society, 2013-03-01, Volume 64, Issue 3, p. 446.

Selviaridis, K., & Wynstra, F. (2015). Performance-based contracting: a literature review and future research directions. International Journal of Production Research, 53(12), 3505-3540.

Seydel, J. (2005). Supporting the paradigm shift in vendor selection: Multicriteria Methods for sole-sourcing. Managerial Finance, 31(3), 49-66.

Sherbrooke, C. C. (1968). METRIC: A multi-echelon technique for recoverable item control. Operations Research, 16(1), 122-141.

Sherbrooke, C. C. (1992). Multiechelon inventory systems with lateral supply. Naval Research Logistics (NRL), 39(1), 29-40.

Simatupang, T. M., & Sridharan, R. (2002). The collaborative supply chain. The international journal of logistics management, 13(1), 15-30.

Simatupang, T. M., & Sridharan, R. (2005). An integrative framework for supply chain collaboration. The International Journal of Logistics Management, 16(2), 257-274.

Simon, H. A. (1982). Models of bounded rationality: Empirically grounded economic reason (Vol. 3): MIT press.

Simon, H. A. (1991). Bounded rationality and organizational learning. Organization Science, 2(1), 125-134.

Singh, P., & Sandborn, P. (2006). Obsolescence driven design refresh planning for sustainment-dominated systems. The Engineering Economist, 51(2), 115-139.

Smith, L., Smith, M., & Ashcroft, P. (2011). Analysis of environmental and economic damages from British Petroleum’s Deepwater Horizon oil spill.

Spring, B. (2010). Performance-Based Logistics: Making the Military More Efficient. Heritage Foundation Backgrounder, 1-9.

Sols, A., & Johannesen, L. H. (2013). The role of transition contracts in performance-based logistics initiatives. Systems Engineering, 16(4), 453-463.

Sols, A., Nowicki, D., & Verma, D. (2007). Defining the fundamental framework of an effective Performance-based logistics (PBL) contract. Engineering Management Journal, 19(2), 40-50.

Stank, T.P., Keller, S.B., & Daugherty, P.J., (2001). Supply chain collaboration and logistical service performance. Journal of Business Logistics 22 (1), 29–48.

Straub, A. (2009). Cost savings from performance-based maintenance contracting. International Journal of Strategic Property Management, 13(3), 205-217.

Talluri, S., & Narasimhan, R. (2005). A note on "A methodology for supply base optimization". IEEE Transactions on Engineering Management, 52(1), 130-139.

Talluri, S., Narasimhan, R., & Nair, A. (2006). Vendor performance with supply risk: A chance-constrained DEA approach. International Journal of Production Economics, 100(2), 212-222.

Thiruchelvam, S., & Tookey, J.E., (2011). Evolving trends of supplier selection criteria and methods. International Journal Automotive Mechanical Engineering, 4, 437-454.

Transportation Research Board (2009). Cooperative Highway Research Program Synthesis 389: Performance-based Contracting for Maintenance, Edited by Transportation Research Board of the National Academies, Transportation Research Board, Washington, DC.

Vargo, S. L., & Lusch, R. F. (2004). Evolving to a new dominant logic for marketing. Journal of marketing, 68(1), 1-17.

Vitasek, K., Geary, S., & Quick, R. (2006). Performance-based logistics: The basics and beyond. Report presented at The International Logistics Society's 41st Annual International Logistics Conference & Exhibition, Dallas, TX.

Vitasek, K., Cothran, J., & Rutner, S. (2007). Best practices of public private partnering: Developing a win-win strategy for working with depots (White paper). Knoxville, TN: the University of Tennessee and Supply Chain Visions.

Vitasek, K., & Geary, S. (2007). Performance-Based Logistics—Next Big Thing. ProLogis Supply Chain Review, summer, pp. 1-11.

Xiang, Y., Zhu, Z., Coit, D. W., & Feng, Q. (2017). Condition-based maintenance under performance-based contracting. Computers & Industrial Engineering, 111(Supplement C), 391-402. doi:https://doi.org/10.1016/j.cie.2017.07.035

Wadhwa, V., & Ravindran, A. R. (2007). Vendor selection in outsourcing.Computers & operations research, 34(12), 3725-3737.

Wang, J. W., Cheng, C. H., & Huang, K. C. (2009). Fuzzy hierarchical TOPSIS for supplier selection. Applied Soft Computing, 9(1), 377-386.

Wang, W., Loman, J., & Vassiliou, P. (2004). Reliability importance of components in a complex system. In Reliability and Maintainability, 2004 Annual Symposium-RAMS (pp. 6-11). IEEE.

Wang, Y. M., Chin, K. S., & Leung, J. P. F. (2009). A note on the application of the data envelopment analytic hierarchy process for supplier selection.International Journal of Production Research, 47(11), 3121-3138.

Weber, C. A., Current, J. R., & Benton, W. C. (1991). Vendor selection criteria and methods. European Journal of Operational Research, 50(1), 2-18.

Williamson, O. E. (1971). The vertical integration of production: market failure considerations. The American Economic Review, 61(2), 112-123.

Williamson, O. E. (1975). Markets and hierarchies. New York, 2630.

Williamson, O. E. (1979). Transaction-Cost Economics: The Governance of Contractual Relations. Journal of Law and Economics, 22(2), 233-261.

Williamson, O. E. (1981). The Economics of Organization: the Transaction Cost Approach, American Journal of Sociology, (87:3), 548-575.

Williamson, O. E. (1998). The institutions of governance. The American Economic Review, 88(2), 75-79.

Wittmann, C. M., Nowicki, D. R., Pohlen, T. L., & Randall, W. S. (2014). Service-dominant logic and supply chain management: are we there yet?. International Journal of Physical Distribution & Logistics Management, 44(1/2), 113-131.

Wu, T., Shunk, D., Blackhurst, J., & Appalla, R. (2007). AIDEA: A methodology for supplier evaluation and selection in a supplier-based manufacturing environment. International Journal of Manufacturing Technology and Management, 11(2), 174-192.

Ziegenbein, A., & Nienhaus, J. (2004). Coping with supply chain risks on strategic, tactical and operational level. In Global project and manufacturing management: the symposium proceedings, May, 163-177.

Zouggari, A., & Benyoucef, L. (2012). Simulation based fuzzy TOPSIS approach for group multi-criteria supplier selection problem. Engineering Applications of Artificial Intelligence, 25(3), 507-519.