A 4-STEP PROCESS EVALUATION MODEL TO ASSESS THE SUCCESS OF PERFORMANCE BASED LOGISTICS CONTRACTS

THESIS

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AFIT/GLM/ENS/09-2

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THESIS

Presented to the Faculty

Department of Logistics Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

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March 2009

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Abstract

Performance-Based Logistics (PBL) is DoD' s preferred product support approach in order to satisfy vitally-important war fighter needs. The elasticity of these needs makes it impossible to build a one-fits-all template PBL contract with the contractors. Thus, both economic metrics such as Cost per Unit Usage and non-economic metrics such as Availability, Reliability, Logistics Foot Print and Logistics Response Time can be defined and tailored according to each individual program.

However, evaluation of the success of a PBL contract gets harder proportional to the increased number of different types of metrics. This research suggests an integrated model approach for combining multiple criteria when assessing the success of a PBL contract.

This approach may be used in operational-level decisions such as reward and penalty decisions within a contract, or strategic-level decisions such as extending the contract with the same contractor, terminating the contract and negotiating with other contractors.

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To my Wife and Son

Acknowledgments

I would like to express my sincere appreciation to my faculty advisor, Dr. Martha Cooper, for her guidance and support throughout the course of this thesis effort. The insight and experience was certainly appreciated. I would, also, like to thank to Dr. Jeffrey Ogden, Dr. Dursun Bulutoglu, Dr. William Cunningham, Dr. Alan Johnson and Dr Matthew Fickus for both the support and latitude provided to me in this endeavor.

I am, also, indebted to the many acquisition professionals who spent their valuable time explaining the processes and procedures they used in the Performance Based Logistics contracts. Special thanks go to my comrades in arms 1st Lt. Fatih Cebeci, 1st Lt. Caglar Utku Guler, and 1st Lt. Omer Saglam who shared this experience with me.

Ferit BUYUKGURAL

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A 4-STEP PROCESS EVALUATION MODEL TO ASSESS THE SUCCESS OF PERFORMANCE BASED LOGISTICS CONTRACTS

I. Introduction

Chapter Overview

This thesis investigates and proposes an alternative approach to monitor the Performance Based Logistics (PBL) supported systems both at the individual metrics level and at the whole system level. For this reason, the defined metrics of the PBL contracts are integrated in a mathematical model and that model is integrated into the current evaluation processes in order to build a theoretical model that would fill the defined gaps of the PBL evaluation processes. In addition to that, opening a discussion among the academics and the acquisition professionals is intended.

First of all, the current study starts with reviewing the published sources and the experts' opinions in order to build our foundation of PBL. Then, the gaps of the PBL literature are defined and the focus of the current study is stated. The focus of this study is to investigate and propose a reasonable approach for the evaluation process in PBL.

According to the knowledge that has been gained until that point, the scope and the assumptions of the study are defined and the investigative questions are determined. Next the methodology is described accordingly and the proposed model is built. Then the

model is evaluated, verified and validated. Next the model is applied to two real-life cases and the applicability and the usefulness is assessed.

Finally, the gathered results are analyzed and the core investigative questions answered with the relevant findings. Additionally, the experienced limitations and possible future studies are addressed.

This chapter includes the background, problem statement, research objectives, investigative questions, research focus, methodology, assumptions / limitations and research implications.

Background

Beyond any question the most remarkable global developments of the end of the 20th Century and the beginning of the 21st Century were: the ending of the Cold War which resulted in the dissolution of the Union of Soviet Socialist Republics (USSR) and the Warsaw Treaty and the 9/11 attacks, that initiated the beginning of the "Global War on Terrorism" (GWOT). The necessities of the new era mandated every country to allocate their resources relative to the new war concepts that are evolved from the previous ones. Under these circumstances, PBL is defined as: "Department of Defense (DoD)'s preferred product support approach." (DoD Directive 5000.1, 2003) Basically, PBL may be defined as buying the performance instead of buying the materials (Mahon, 2007). It may seem an easy explanation but has created a lot of confusion in the minds of many acquisition professionals from both the Government's side and the contractors' side. First of all, PBL was born under the highly elastic conditions described above,

which means it must be highly elastic also. That's why the vision of PBL can be translated as answering intensively-elastic needs of the war fighter instantly with a reasonable cost for the nation. So there's no magic template for implementing a PBL program and every program is unique according to the defined needs of the war fighter. If there's no template, how should it be implemented correctly? How can anybody be sure about earning the best results via using PBL? At what extent can we trust a contractor and give him authority over our weapon system? Although the Government has implemented a series of publications to clarify the confusions mentioned above since the first introduction of the PBL, there's still some gaps that are creating difficulties for the stakeholders of the PBL programs.

Besides the Government officials, the academics also contributed to the efforts of defining the best way to implement PBL programs, meanwhile putting together the lessons learned from the previous experiences and offering some general solutions to the problems that occurred then. However, it is very constrained for the academics to do their research comprehensively because of some difficulties such as: reaching the real data of the PBL programs, differences of the military system from the commercial system, diversity of the PBL programs and the privacy necessities of the contractors in order to keep their competitive advantages in the market. According to a study, seven key barriers and seven enablers are defined as depicted in Table 1 (Devries, 2004).

While there's an increased effort to implement PBL for the Government's product support, it hasn't been achieved yet. According to the latest report of the Government Accountability Office (US GAO) depending on a research that compares the decision-making via using performance measures between 1997 and 2007

However, despite having more performance measures available, federal managers' reported use of performance information in management decision-making has not changed significantly. (US GAO July 2008, Highlights)

Table 1. The Barriers and the Enablers of PBL Implementation
(Adapted from Devries, 2004)

BARRIERS OF PBL IMPLEMENTATION	ENABLERS OF PBL IMPLEMENTATION
Funding restrictions /inflexibility (e.g., Working Capital Fund, various appropriations /transfer and expiring funds rules, limited Program Manager [PM]	Supply Chain Management (e.g., end-to-end customer support, enterprise integration).
Statutory /regulatory requirements (e.g., Title 10, service policies).	Strategic alliances /partnerships (e.g., depot partnering, joint ventures)
Old paradigms /culture (e.g., organic versus commercial, parts management versus performance management, minimize contractors on the battlefield).	Performance- based contracting (e.g., incentivizing performance)
Existing infrastructure /bureaucracy (e.g., PM office structure, stovepiping, short PM tours).	Performance-based metrics
Technical data Rights issues.	Total Life Cycle Systems Management (TLCSM) perspective
Lack of PBL awareness /training	Adoption of Commercial Off-the-Shelf (COTS) /Best Commercial Practices
Inability to incentivize organic providers.	Reduction in Total Ownership Cost (RTOC) initiative

Problem Statement

According to the research findings of Devries (2004) performance metrics play the most important role in the process of PBL implementation (See Figure 1).

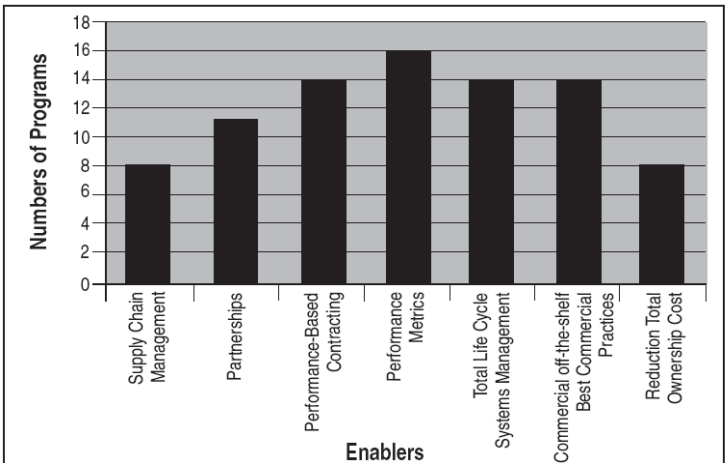

Figure 1. The Enablers of PBL implementation
(Gathered from Devries, 2004)

This research, which depends on both the published literature and face- to-face meetings with the experts, also supported that there are many issues from defining the metrics to evaluation of them in the PBL implementation process.

By definition, PBL aims at reaching the desired outcomes via the capabilities of contractors without mandating how to achieve those goals. Basically, the desired outcomes and the relevant metrics should be defined by the customer for the first step. Then, an agreement with the contractor should be achieved with the contractor.
Next, the data of the defined metrics should be collected. Finally, the collected data of assessed values of the metrics should be evaluated. Otherwise, the performance of the system may not be monitored and managed in a healthy manner.

Therefore, an acceptable, general and easy-to-understand approach which may be used to evaluate the defined metrics in order to monitor the system is investigated in this study.

Research Objectives

First of all, the basic aim of any system is achieving some targeted goals. For this reason, the metrics should be defined according to the targeted goals, data must be collected and a systematic and reasonable approach should be chosen in order to evaluate the system. Without a doubt, PBL-supported systems are not exempted from these fundamental processes. There may not be a template to implement the PBL contracts, so a common systematic approach should be built.

In conclusion, in this study a reasonable model for evaluation of the defined metrics to monitor the system is proposed to make healthy decisions. As a result, the following investigative questions have to be answered.

Investigative Questions

1) What are the general metrics defined in the contracts?

Actually, there's neither a standard template for PBL contracts, nor standardized metrics. However, relevant to their knowledge about PBL, the Defense Acquisition University (DAU) mentioned some useful metrics as: Operational Availability (Ao), Operational Reliability (R), Cost per Unit Usage (CUU), Logistics Footprint (LF) and Logistics Response Time (LRT) in their published book of "Performance Based Logistics: A Program Manager's Product Support Guide", also known as PBL Guide. (DAU, 2005)

However, some academics mentioned that these metrics are high level composite metrics (Kumar et al., 2007). So in each PBL contract, some or all of these metrics should be tailored according to the desired goals and would be negotiated with the contractor/s.

2) What is the general current evaluation method of the metrics?

According to the experts' opinions, in most of the PBL contracts, the metrics are evaluated by a two step process that is:

a) Collecting assessed values of the metrics within the contractually-defined terms. (ex: average monthly values)
b) Comparing assessed values of the metrics with the contractually targeted numbers of each metric individually.[1]

3) What are the gaps of the current evaluation method?

a) According to the laws of statistics, each one of the pair wise comparisons includes risks of making type 1 and type 2 errors, which are the probabilities of making misjudgment depending on a statistical comparison. The probability of making a mistake in comparisons increases as the number of pairs compared increases.
b) According to the Theory of Constraints; local improvements do not necessarily mean that the whole system improved (Goldratt and Cox, 1992). By monitoring each metric individually, we may not visualize the big picture and make healthy decisions at a strategic level.
c) The current evaluation method may be useful in order to understand if the assessed values of the individual metrics satisfied the contractual agreements.

[1] In addition to these two processes, some experts mentioned that in some cases a process of weighing the parameters and calculating a sole number to use for strategic decisions is also used. According to our research, we will mention this additional step to the current evaluation method under the subject heading of "The Issues about the Evaluation Process of the PBL Systems" at the end of "Literature Review".

However, as some academics mentioned, there may be conflicts between the metrics such as: “some metrics may be over performing while the others are underperforming” (Sols et al., 2007).

d) “The scarcest resource in an organization is a manager’s time.” (Kaplan and Cooper,. 1997, p.144) The evaluation of the metrics individually may consume more time than necessary especially for the senior executives for two reasons. First, there may be an excessive amount of defined parameters and the decision maker may need time to understand the impact of each one of them on the system. Second, there may be conflicts between parameters. Although the decision maker may spend much time and effort, s/he may not use the performance data appropriately in the decision-making process. (US GAO July 2008, Highlights)

Furthermore; the core investigative questions that will shape and guide this study are determined as;

4) *How should the metrics be evaluated to improve decision making?*
5) *What should be the core objectives of an evaluation model?*
6) *Can the proposed model in this thesis be used for forecasting, or building new PBL contracts?*
7) *At which decision level may the proposed model be used?*

These questions will be answered at Chapter V according to the results gathered throughout this study.

Research Focus

The reviewed literature and the knowledge gathered from the experts suggest that PBL may be divided into three parts in a time scale (See Figure 2). This research is focused on the post- contract period. Second, an alternative approach to monitor the Performance Based Logistics (PBL) supported systems both at the individual metrics level and at the system level is sought, so the evaluation processes and approaches are concentrated on. Finally, a model is built in order to fulfill the aim of proposing an alternative approach in this area.

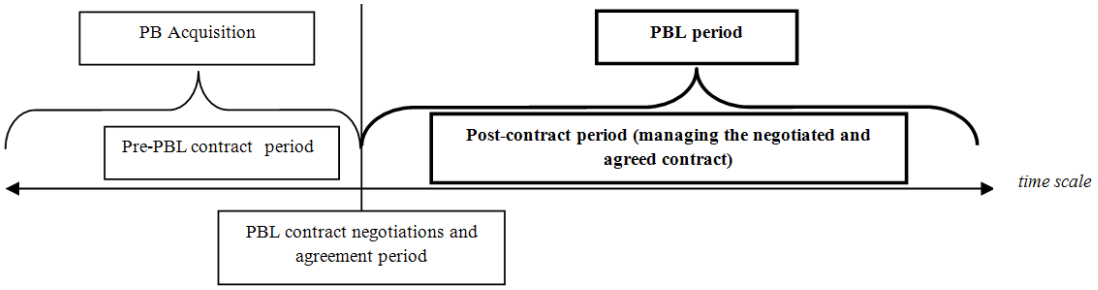

Figure 2. The time scale of PBL applications

Methodology

First of all, the PBL concept was studied according to the published literature and experts' opinions. Second, gaps in the PBL literature were defined in order to make a contribution in one of those directions. Third, the investigative questions were created. Then the data were collected, according to the scope of this study. Next, the laws of statistics, calculus and geometry were used to process the gathered data and built an

integrated model to evaluate the success of PBL contracts. Finally, the published literature and/or the experts' opinions were referenced in order to validate the model.

Assumptions / Limitations

First of all, the research is concerned with the post- contract period; thus, all the parameters were defined, negotiated and agreed to by the relevant sides.

Second, all the performance standards relating to the metrics (both qualitative and quantitative) were mandated with the time frames in the contract, such as: 80 % of availability at the end of every operation day, reduction of logistic footprint at the end of every 3 months, or 85 % user satisfaction at the end of every month.

Third, all the assessed numbers of the metrics must satisfy the targeted contractual numbers or in other words the bottom-line constraints individually for each time period. If not than the overall performance of the contractor must satisfy the overall contractual requirement for the next term.

Organization of the Thesis

This thesis consists of five chapters. In Chapter I, first the basic problem was defined along with the background and the problem statement. Second, the research objectives were set and the investigative questions created. Third, the research focus was designated. Then, the methodology was explained with the relevant assumptions / limitations, and, finally, with the organization of the thesis, the map of the thesis was

revealed. The following Chapters both extend and offer a more detailed study about the research.

Chapter II presents a Literature Review about the PBL concept, including its birth, evolution and the current gaps of the literature. Chapter III describes the research methodology of this thesis, while introducing a new mathematical model about the evaluation of the metrics. Chapter IV presents the results and checks applicability and the usefulness of the proposed evaluation process model.

Finally, Chapter V presents the findings and recommendations, as well as concluding the thesis and suggesting future studies to extend the research.

II. Literature Review

Introduction

In any kind of war, the participation and cooperation of the whole nation is the most important aspect of success. The reliance on contractors increased over time and the ratio of the number of contractors over the number of troops was nearly 1:10 in the Gulf War and dramatically increased to 4:3 in the Balkans between 1995 and 2000 (Vernon, 2003). Most of the times, the contractors seemed to operate as a support unit, generally in the logistics area, for the armed forces. Although these are not the clear borders in a time scale, military logistics can be separated into three eras for the United States (US).[2]

The Traditional Logistics Era continued its evolution from the foundation of the US to the end of the Cold War. The traditional logistics concepts yield predictive, optimized, linear supply chains that operated in hierarchical command and control structures (Griffin, 2008).

The Transition Logistics Era is the overlapping part which started since the end of the Cold War. Supply Chain Management (SCM), Sense and Respond Logistics (S&RL)[3], Performance Based Logistics (PBL)[4] and Enterprise Resource Planning (ERP)[5] systems and networks are introduced in the Department of Defense (DoD). New ways of

[2] The separation of logistics into three areas for the US is constructed by the researcher of this study.
[3] The S&RL framework exploits advanced technologies through highly adaptive, self-synchronizing functional processes designed to drive shorter decision cycles and faster responses.
[4] PBL is the core of this study and will be defined clearly in the next chapters.
[5] The ERP systems and networks are being applied to DoD logistics in an effort to create a connected environmentin which near real-time data can be exchanged and response time shortened.

thinking such as: Total Quality Management (TQM), Lean, the Balanced Score Card (BSC), Activity Based Costing (ABC) have been introduced.

The Integrated Logistics Era is the future goal of DoD. This era defines a highly competitive environment between the contractors and a highly collaborative environment between the contractors and the Government. The main expectation is answering the intensively-elastic needs of the war fighter instantly with a reasonable cost for the nation.

The History of PBL

First of all, it may be proposed that the PBL concept is related to the level of the technology in the system. The US The Government's first aircraft contract with the Wright brothers in 1909 may be a good example for this proposal as depicted in Figure 3.

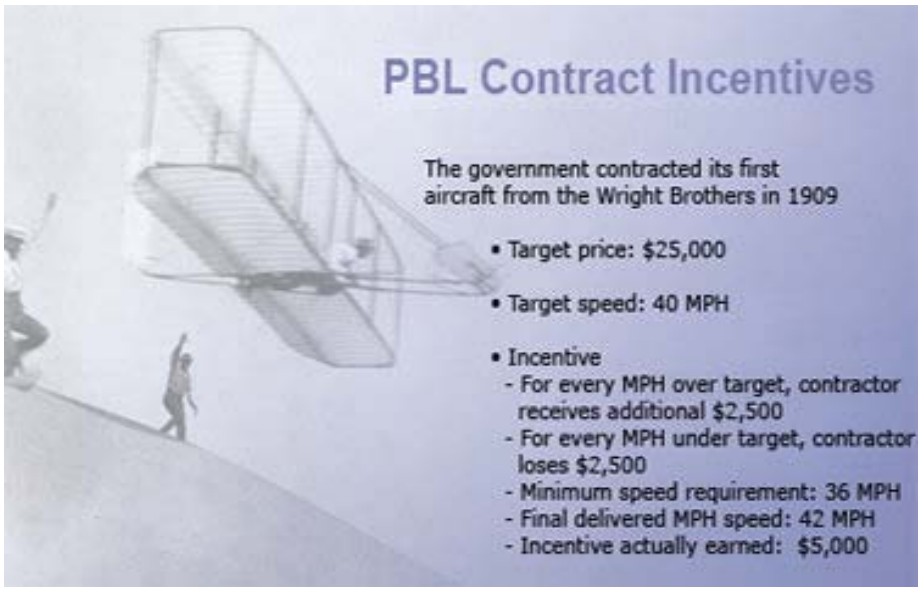

Figure 3. The First PBL application of DoD
(Gathered from DAU, 2008)

The idea behind PBL is that if the contractors could produce a highly technological product or service, then they should know how to improve it by means of reliability and cost aspects. So limiting them by mandating how to produce their product or service under non-PBL contracts may result in losing an opportunity of benefitting from their innovative approaches and cumulated experience (Rievley, 2001).

After the Cold War period, an urgent need for change occurred in every aspect of the armed forces. This urgency forced the DoD to transform their approach. First of all, a main cause of the collapse of the Union of Soviet Socialist Republics (USSR) was the misallocation of their resources and inefficiencies of their system. Although there was one enemy, it was spread out geographically, making it hard for the USSR to carry the heavy burden of logistics support for its system. History clarifies that, using a large conventional army makes war very expensive and requires a large support system to maintain effectiveness. By observing the enemy well, the US has taken the necessary precautions since 1987. The Depot Maintenance seemed to be a good area to start, because it is the key to the total DoD logistics process that supports millions of equipment items, including 52,000 combat vehicles, 350 ships and 17,000 aircraft (Griffin, 2008). For the US DoD, it's estimated that; 80% of the budget is used for sustaining the defense systems. (Sols et al., 2007) As it is mentioned in the Government Accountability Office (US GAO) report in 2001, the DoD defined three series of actions primarily to shape the depot Maintenance environment. The actions taken and the results that have been achieved since 2001 are described below.

1) The base realignment and closure (BRAC) process, which was designed to reduce DOD's infrastructure; has reduced DOD's cold-war--oriented infrastructure from 38 military depots to 19 (See Figure 4).
2) The increased reliance on the private sector for depot maintenance support resulted in the contractors' share of depot maintenance funding increasing by 90 percent while the military depots' share of funding has declined by 6 percent (See Table 2).
3) The major downsizing of depot maintenance personnel amounted to 59 percent, which was the third highest percent of any category of DOD civilian personnel (US GAO, March 2001, p.2).

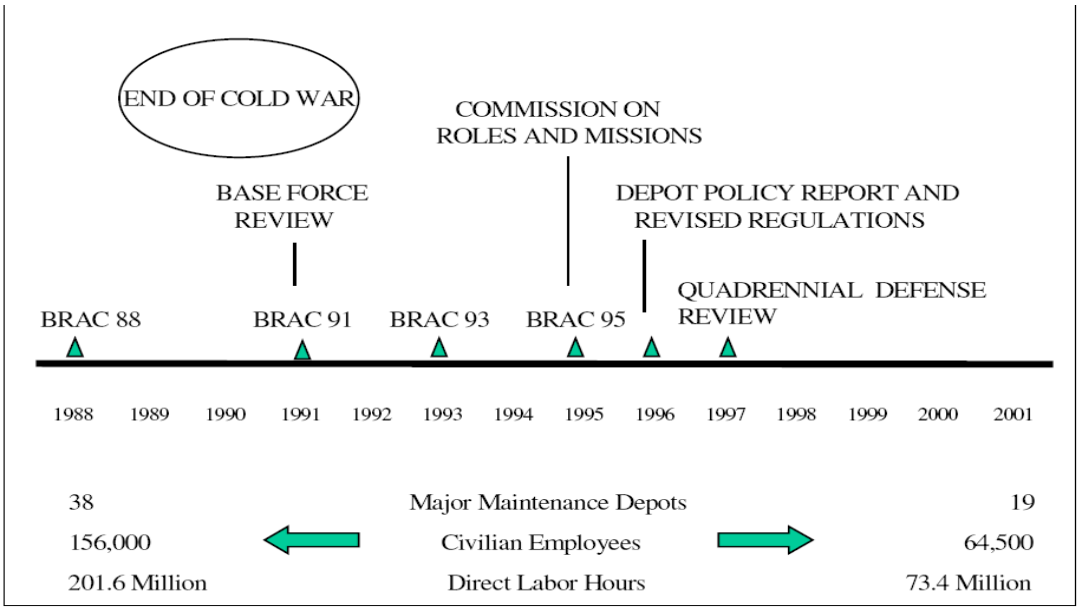

Figure 4. Key Events Influencing the Reshaping of the Military Depot System
(Gathered from US GAO, March 2001)

Table 2. Public and Private Sector Change in Depot Maintenance Funds
(Gathered from US GAO, March 2001)

Sector	**Fiscal year 1987** (dollars in billions)	**Fiscal year 2000** (dollars in billions)	**Change in dollar amount** (dollars in billions)	**Percent change**
Public	$ 8.7	$ 8.2	$- .5	-6%
Private	$ 4.0	$ 7.6	$+ 3.6	+90%
Total	**$12.7**	**$15.8**	**+$3.1**	**+24%**

By the terrorist attacks of September 11, 2001 (9/11), the US was faced with a very difficult situation of shifting from traditional army warfare to asymmetric warfare. Actually, the concept of the Global War on Terrorism (GWOT) defined by the US is harder than what the USSR experienced in the Cold War. Briefly, there's no enemy country but there's an enemy, there are no borders of the conflict zone, but everywhere is potentially a conflict zone and showing a presence of big conventional armed forces in an area is no more a show of superiority, but becoming a bigger target for the shadow enemy. "The new threats are broader and include global, regional and local elements. International organizations, allied nation states, rogue nations, hostile states and terrorist groups all contend within this environment" (Griffin, 2008).

Dealing with terror is similar with the children's Marco Polo game. It gets the signals of the presence of the targets. The prevented visibility and increased mobility of the targets makes the efforts to reach them meaningless unless any of the targets are caught at the very first moment with a reasonable amount of effort. The aim of the targets is taking as much energy as possible to make the enemy exhausted. As seen from a very simple child game, allocation of resources and/or directing the opponent to misallocate its resources is the key to success for everyone.

The budget dynamics of the terrorist organizations are much different than the Governments, which make them more resilient and harder to deal with. An example can be given of one income item, the drug trafficking, for a terrorist organization that the US deals with. According to the recently published two reports of the United Nations (UN), 92% of the global opium production is at the southern regions of Afghanistan in the year 2006. This raw material for heroin soared in 2007, rising 34 percent from the already record levels of 2006, under the control of the Taliban insurgency (UN DRUG REPORT, 2007; UN DRUG REPORT, 2008).

Not only the production, but also the transportation and the distribution activities are governed by a network of terrorist organizations. In 2007, Afghanistan either processed and exported or stored for future export some 660 tons of heroin and morphine. Because of the risks associated with smuggling, opium gains value at every border it crosses. By the time heroin reaches its final destination, its price may have gone up 100 times and the reports found indications that the Taliban may have started to use drug profits to purchase arms, pay militia forces and finance logistics (UN DRUG REPORT, 2008).

Because of some reasons explained above, GWOT most recently referred to as the long war, has stimulated all US federal agencies to review their ongoing operations and budget to concentrate on cost savings.

However, concentrating on cost savings without understanding the demanding nature of asymmetric warfare includes a big risk. According to the Mid- Session Review

of the US Budget[6] 2009, the President is mentioned as "committed to restrain Federal spending for the purpose of balancing the budget by 2012" (EOP US Mid-Session Report, July 2008, p 3). However, in the same document, the 2008 Supplemental Appropriations Act is mentioned. According to that act, U.S. troops in Iraq and Afghanistan will be provided with the resources they need to fight the Global War on Terror and the cost savings are targeted on non-security discretionary spending. The objectives are mentioned as;

> elimination or reducement of 151 unnecessary or duplicative programs totaling $18 billion and holding the growth in non-security spending to below one percent for 2009 (EOP US Mid-Session Report, July 2008, p 3).

In addition to the President's targets, the cost saving opportunities via the improvements of Supply Chain Management (SCM) activities may also be mentioned. According to the revised budget of the US for fiscal year 2009, the share of the total Defense sector is requested as $515.4 billion and the requested DoD Budget is $17.647 billion. (EOP US Mid-Session Report, July 2008, p 23) Assuming a very conservative target of 1% of cost savings via improvements in SCM activities throughout the Defense sector, this would create an extra resource of $5.154 billion.

Just 3 weeks after 9/11, the 2001 Quadrennial Defense Review[7] (OSD QDR) was published and compressing the supply chain via modernizing business processes and using Performance Base Logistics (PBL) are mentioned as logistics transformations

[6] The Mid-Session Review is the supplemental updated form of the US budget by the President. It contains revised estimates of receipts, outlays, budget authority and the budget deficit or the surplus for fiscal years 2008 through 2013.

[7] QDRs are conducted every four years to ascertain what the military will need in manpower and materiel to address anticipated missions envisioned 20 years in the future.

initiatives in the report (Mahon, 2007). Basically, the OSD QDR was declaring the fundamentals of the new era of logistics as:

> To ensure the Department transforms its logistics capabilities, DoD will pursue actions to sustain the force more effectively and efficiently. Specific areas will include a dramatically improved deployment process and accelerated implementation of logistics decision support tools. DoD must also accelerate logistics enterprise integration, reduce logistics demand and reduce the cost of logistics. In addition, conducting industrial vulnerability assessments and developing sustainment plans for the most critical weapons systems and preferred munitions will help ensure effective sustainment. (OSD QDR, 2001, p 35)

In addition, the Chairman of the Joint Chiefs of Staff mentioned the need of an integrated system in his statement by:

> If truly dramatic improvement in future joint operational effectiveness is to be achieved, however, more is required. First, a DOD-wide transformation strategy, a joint organizing vision and a joint transformation roadmap are essential to guide, integrate and synchronize the efforts of the Services. Second, we need DOD-wide reform of key institutional planning, programming, budgeting and acquisition processes. These two requirements are interdependent; no real progress will be made in one without the other. (OSD QDR, 2001, p.68)

Meanwhile it was projected for 2001 that protecting and advancing US interests around the world involve over $1 trillion in assets, about 3 million military and civilian employees and about an annual budget of $310 billion then (US GAO., January 2001, p 6).

In 2002, the Under Secretary of Defense for Acquisition, Technology and Logistics (USD AT&L) mandated the services to develop and implement a schedule to aggressively apply Performance Based Logistics (PBL) to all new weapons systems, as well as all Acquisition Category (ACAT) I and II legacy systems before May 1, 2002 (Mahon, 2007).

In 2003 the DoD Directive 5000.1 which is also known as the Defense Acquisition System (DAS) was implemented and performance-based strategies for procurement and sustainment of the products and services were mentioned as "to do whenever feasible" (DoD Directive 5000.1, 2003, p 9).

In addition to that, "The Primary Objective of Defense Acquisition" is defined as:

> to acquire quality products that satisfy user needs with measurable improvements to mission capability and operational support, in a timely manner and at a fair and reasonable price. (DoD Directive 5000.1, 2003, p 6)

Although implementation of PBL was pointed as a target, it was not described to Program Managers (PMs) how to implement it. The ambiguity of the changeover period and the unanswered questions in the minds of acquisition professionals cumulatively increased. Then the USD AT&L tried to eliminate the confusion by two publications in 2003. The first one was listing key activities and outputs which PMs should consider when assessing a program for a PBL strategy and the second one was the targets for the percentage of contract dollars awarded using performance-based service activities[8] (Mahon, 2007). The Office of Secretary of the Defense (OSD) joined the description process by publishing the Designing and Assessing Supportability in DoD Weapons Systems: A Guide to Increased Reliability and Reduced Logistics Footprint which is also referred to as the Supportability Guide (SG) in October 2003. The SG tried to address and explain the responsibilities of PMs in the Total Life Cycle Systems Management (TLCSM) concept, which is briefly the responsibility for a system from cradle to grave (OSD, 2003). The SG filled up a big gap about the implementation of PBL in addition to

[8] The targets were set as: **%25** for Fiscal Year (FY) 2003, **%35** for FY 2004, **%50** for FY 2005.

DoD Directive 5000.1, 2003, the Defense Acquisition System (DAS) and DoD Instruction 5000.2, the Operation of the DAS. In the SG the necessity of integration of performance and the other elements of effectiveness is mentioned as:

> Performance cannot be considered separate from the other elements of operational effectiveness – they are inextricably linked. The system capabilities and functions represent the desired mission capabilities as a total package, together with the sustainment objectives and the desired logistics footprint reductions. As discussed in the following paragraph, in the current operational and budgetary context, priorities must be complemented with an emphasis on system availability -- Reliability, Maintainability, Supportability (RMS) and producibility (OSD ,2003, p 11).

Meanwhile new issues arose concerned with the PBL implementations of PMs and the office of the USD AT&L continued their publications in January 2004 and March 2004. This continuation of policy and guidance releases suggests that a major transformation in product support may have been prematurely implemented by DoD (Mahon, 2007)

Finally, the Defense Acquisition University (DAU) explained the DoD policy in their publications; "Performance Based Logistics: A Program Manager's Product Support Guide", which is also referred as the PBL Guide[9], on March 2005 (DAU, 2005). According to that publication:

> Performance Based Logistics (PBL) is the purchase of support as an integrated, affordable, performance package designed to optimize system readiness and meet performance goals for a weapons system through long-term support arrangements with clear lines of authority and responsibility. Simply put, performance based strategies buy outcomes, not products or services (DAU, 2005, p 1-1).

PMs optimize performance and cost objectives by the implementation of PBL in varying degrees of The Government-industry partnerships as depicted in Figure 5.

[9] The DAU's publication "Performance Based Logistics: A Program Manager's Product Support Guide" on March 2005 was referred to as the PBL Guide in the literature then.

Figure 5. The Government-industry partnerships
(Gathered from DAU, 2008)

Before explaining the implementation of PBL, it would be useful to mention some key components of PBL which are: the Integrated Product Teams, PBL metrics, Performance Based Agreements and Business Cases Analyses

Integrated Product Teams

PBL Integrated Product Teams (IPTs) which are also referred to as the main stakeholders of implemented PBL programs, are war fighters, users, developers, acquirers, technologists, testers, budgeters and sustainers experts and war fighter representatives(DoDD 5000.1, 2003, para. E1.1.2.). A sample PBL IPT team depicted in Figure 6.

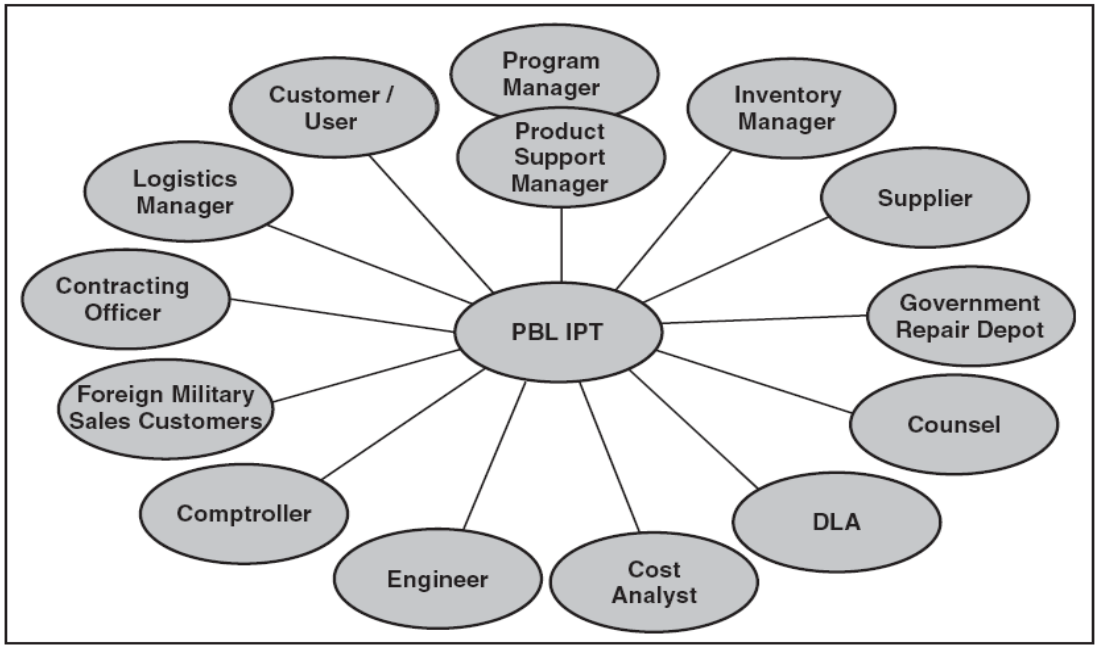

Figure 6. A Sample PBL IPT
(Gathered from DAU, 2005)

This team should work together from the beginning of the program and it is essential for the success of any program that members are able to work across organizational boundaries.

PBL Metrics

An effective PBL implementation depends on metrics that accurately reflect the user's needs and can be effective measures of the support provider's performance. The PBL Top-Level Metrics are defined in the DAU (2005) as:

1) "Operational Availability (Ao) is the percent of time that a system is available for a mission or the ability to sustain operations tempo" (DAU, 2005, p. 2-5).

2) "Operational Reliability (R) is the measure of a system in meeting mission success objectives (percent of objectives met, by system)" (DAU, 2005, p. 2-5).
3) Cost per Unit Usage (CUU) is the total operating cost divided by the appropriate unit of measurement for a given system" (DAU, 2005, p. 2-5).
4) Logistics Footprint (LF) is the Government/contractor size or "presence" of deployed logistics support required to deploy, sustain and move a system. Measurable elements include inventory/equipment, personnel, facilities, transportation assets and real estate" (DAU, 2005, p. 2-5).
5) Logistics Response Time (LRT) is the period of time from logistics demand signal sent to satisfaction of that logistics demand. "Logistics demand" refers to systems, components, or resources (including labor) required for system logistics support" (DAU, 2005, p. 2-6).

However, these five metrics defined by the PBL Guide may not be appropriate to use raw for every PBL contract. First of all, these metrics are general and composite, for example: Operational Availability (Ao), may be defined as the ratio of mean time between maintenance (MTBM)[10] to total system time (Kumar et al., 2007).

Thus, each program should consider and tailor some or all of these metrics, as well as define new metrics for their program. Ledyard and Vitasek (2004) offered five rules that may be used for the measurement process as depicted in Figure 7.

[10] According to our literature review, Mean Time Between Failure (MTBF) is also used instead of MTBM.

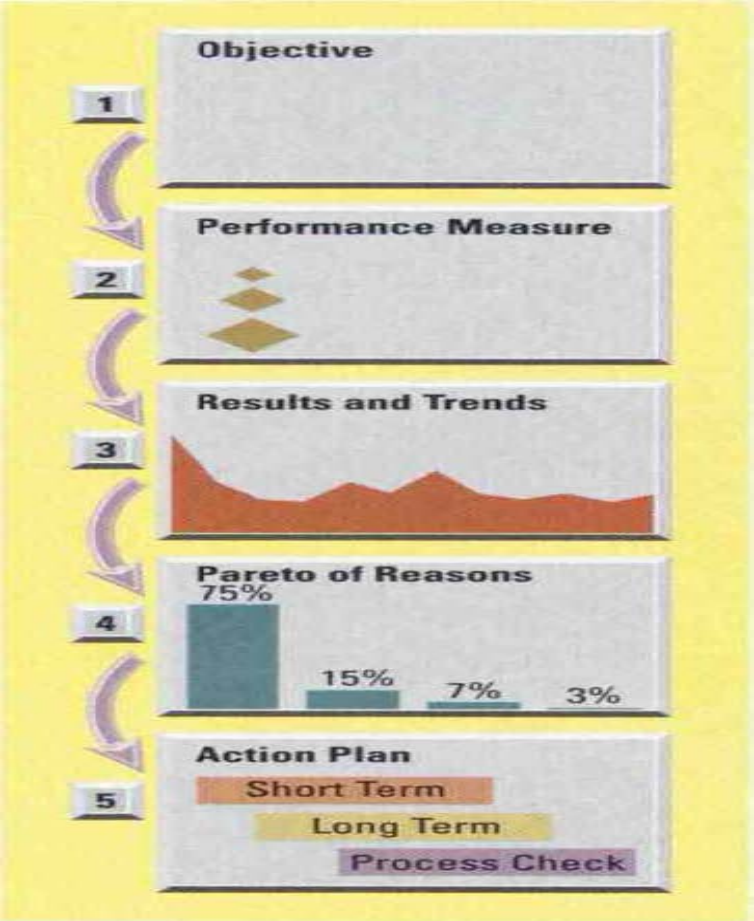

Figure 7. Five Rules Approach for Good Measurement
(Gathered from Ledyard and Vitasek, 2004)

Performance Based Agreements and Business Case Analyses

Before discussing Performance Based Logistics (PBL) implementation, it is important to mention two key PBL implementation issues, which are Performance Based Agreements (PBAs) and PBL Business Case Analyses (PBL BCAs).

PBAs are one of the key components of an effective product support strategy. (DoDD 5000.1, 2003, para E1.1.16.) They establish the negotiated baseline of

performance and corresponding support necessary to achieve that performance, whether provided by commercial or organic support providers.

According to the PBL Guide BCAs should consider:

- The relative cost versus benefits of different support strategies
- The methods and rationale used to quantify benefits and costs
- The impact and value of performance/cost/schedule/sustainment trade-offs
- Data required to support and justify the PBL strategy
- Sensitivity of the data to change
- Analysis and classification of risks
- A recommendation and summary of the implementation plan for proceeding with the best value alternative (DAU, 2005, p 3-28).

Implementation of PBL

The PBL implementation process is flexible and PBLs differ in scale, covering a broad range from component level up to system platform level. On one hand, DAU academics proposed in the PBL Guide, that the 12-step process to implement a PBL program into consideration be tailored appropriately to the level of the system. (See Figure 8)

Figure 8. PBL Implementation steps
(Gathered from DAU, 2005)

On the other hand Berkowitz et al. (2005) offered six guidelines briefly explained below:

1) "Assign responsibilities clearly throughout the firm— Blanket statements about policy changes that imply that 'PBL is everyone's responsibility' are typically ineffective" (Berkowitz et al., 2005, pp 263-264).
2) "Design metrics to motivate the right behavior— Metrics designed to motivate the right behavior must be carefully crafted and applicable across the entire organization" (Berkowitz et al., 2005, pp 263-264).
3) **"**Manage failures to limit disincentives for risk-taking**—** Failure is part of the learning process" (Berkowitz et al., 2005, pp 263-264).
4) "Develop a supportive organizational context for tools**—** These tools include middleware to standardize decision-making based on legacy system output and tracking systems to document performance improvements and lessons learned across the organization" (Berkowitz et al., 2005, pp 263-264).
5) "Manage relationships with stakeholders**—** Continuing communication with stakeholders is one way to gain their support" (Berkowitz et al., 2005, pp 263-264).
6) **"**Benchmark to promote continuous improvement**—** In order to find how well initiatives are working, compare results through the benchmarking process (Berkowitz et al., 2005, pp 263-264).

Risk vs. Contract Types in PBL

Buying performance instead of materials and/or services includes risk implications both for the contractor and the Government. Sols et al. (2007) proposed a reasonable relationship between risk and contract types as depicted in Figure 9.

General contract types of PBL mentioned in Sols et al. (2007) are described in the Federal Acquisition Regulations (FAR) as:

1) "Firm Fixed Price (FFP): A firm-fixed-price contract provides for a price that is not subject to any adjustment on the basis of the contractor's cost experience in performing the contract" (GSA, 2005, p 16.2-1).
2) "Cost Plus Fixed Fee (CPFF): A cost-plus-fixed-fee contract is a cost reimbursement contract that provides for payment to the contractor of a negotiated fee that is fixed at the inception of the contract" (GSA, 2005, p 16.3-1).
3) "Fixed Price Incentive (FPI): A fixed-price incentive (firm target) contract specifies a target cost, a target profit, a price ceiling (but not a profit ceiling or floor) and a profit adjustment formula" (GSA, 2005, p 16.4-2).
4) "Cost Plus Incentive Fee (CPIF): The cost-plus-incentive-fee contract is a cost-reimbursement contract that provides for the initially negotiated fee to be adjusted later by a formula based on the relationship of total allowable costs to total target costs" (GSA, 2005, p 16.4-3).

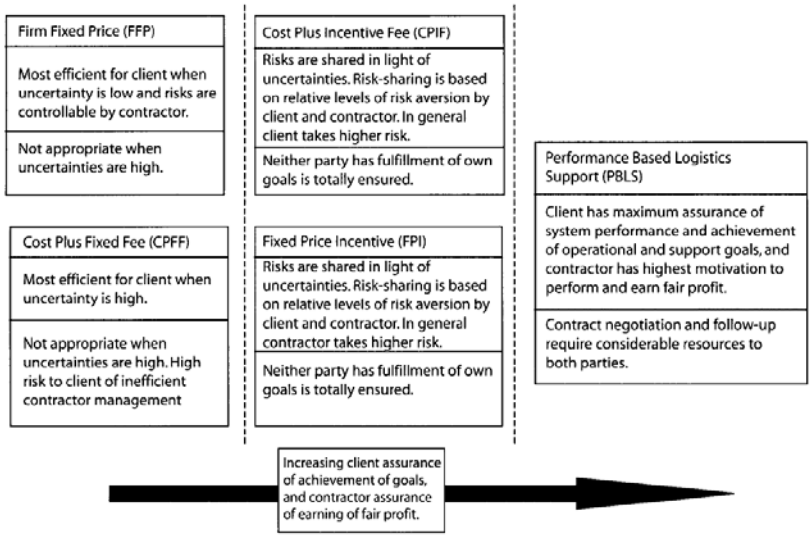

Figure 9. Contract Types vs Risk
(Gathered from Sols et al., 2007)

The Gaps in the PBL Literature

PBL is a relatively new concept and there are still some important issues that should be addressed. According to the reviewed literature, the main issues about PBL may be grouped under three main headings which are: the Ethical Issues of Reliance of Contractors in Battlefields, the Issues about Contract Length, and the Measurement Issues of the PBL Systems.

The Ethical Issues of Reliance of Contractors in the Battlefield

Openshaw (2006) addressed some important ethical issues related to contractor reliance in his study. Briefly, the contractors are not military members, so basically do not have the same status as a military soldier. Under the international agreements between the Governments, military members are mentioned; however the contractors are exempted in many cases. Because of this reason, in the chaotic atmosphere of the conflict

zones, actions and the contingencies related with the actions of the contractors may cause more damage than the benefit for the Governments. For a worst case scenario, contractors may resign at any time and leave the combat zone, which would paralyze the capability of the troops almost immediately (Openshaw, 2006).

Issues about Contract Length

Generally, PBL contracts create a necessity for contractors to make upfront investments. That's why longer contract terms allow contractors to spread the investment costs over a larger base and this may create a long-term relationship between the Government and the contractor (Griffin, 2008). On the other hand, this approach includes some risks for the Government. Gardner (2008) defines some of the potential risks as: "supplier opportunism, selection of the wrong supplier, supplier volume uncertainty, foregoing to other businesses of suppliers and unreasonableness of buyers" (Gardner, 2008).

Measurement Issues of the PBL Systems

The PBL concept was created to achieve a higher level of outcome by using the capabilities of the contractors such as business experience, innovation and technical background (Rievley, 2001). However, before giving a complete authority to the contractor (supplier) about how they would do something, the Government (customer) should be sure of what it would get. Thus, the desired outcomes would be defined and then appropriate performance metrics would be developed for being sure of the desired outcomes. However, there are gaps between the war fighter -oriented The Government metrics and the profit -oriented contractor metrics and how the services provided by the contractors would be measured by means of The Government objectives. For example,

reducing the logistics foot-print (LFP) may be a desired outcome for the Government, but it is hard to translate, quantify and measure. The contractors may not perceive it the same way as the Government and higher transaction costs could be the result (Doerr et al., 2005).

According to some academics, the PM's approach should be pragmatic while establishing the metrics (Ledyard and Vitasek 2004). However, some earlier academics called attention to the trap of "if you can't measure what you want, want what you can measure" (Kaplan and Cooper, 1996, p 100). Instead, they insisted on searching new approaches in order to develop new metrics and new measurement approaches to achieve the desired outcomes (Kaplan and Cooper, 1996, p 100) .The National Aeronautics and Space Administration (NASA) Headquarters Performance Based Contracting Assessment of 1999 confirms this by mentioning the difficulties in developing appropriate and meaningful performance standards for advanced Research and Development (R&D) activities (Rievley, 2001). Besides, this doesn't mean that they should give up searching to develop new metrics and demanding performance outcomes that are vitally important for critical mission accomplishments.

Generally achieving the desired levels of reliability and availability at a reasonable cost is a common expectation from the contractor (Smith, 2004). But this expectation covers a wide range. Three main measurement issues related with PBL within the scope of this research are:

1) Defining desired levels of performance: Kaplan and Norton (1996) offered an integrated approach from defining the mission of the company to constructing an entire organization around that mission statement in the Balanced Score Card (BSC).

Basically, the aim of the BSC is deriving the mission of the company and achieving the strategy that would lead the company to reach that goal and then deriving the strategy in order to build relevant metrics that would translate "the mission and strategy into action" (Kaplan and Cooper, 1996). They defined four sets of performance metrics perspectives that are: financial, customers, internal business processes and learning and growth (Kaplan and Cooper, 1996). Three important aspects of the BSC for the current study are:

a) The performance metrics are mentioned and developed according to the defined mission and strategy by four main dimensions and many sub-dimensions.
b) All the defined metrics should have cause and effect relationships by means of whether or not serving to the strategy. These cause and effect relationships define the hypothesized correlations among the metrics.
c) "Causal paths that form all the measures on a score card should be linked to financial objectives" (Kaplan and Cooper, 1996, p 151). On the Government side financial measures are cost savings and budget constraints.

Two important issues of the BSC are relevant to the current study. First, their opening argument in the BSC criticizes the usage of a single metric in order to monitor the system via an airplane-pilot example that mentions the existence of many different flight instruments (Kaplan and Cooper, 1996, pp 1-2). Although accepting this idea, we also may call attention to the cockpit windows, or canopies of the aircrafts in addition to many other instruments. By the existence of the windows, the

pilot can evaluate the current overall position of the aircraft in a short time frame and then may check the relevant instruments in order to take the necessary steps.

Second, linking of all the measures to the financial outcomes in BSC may be appropriate for commercial organizations; however, financial outcomes may not be the only desired outcomes in PBL-governed weapon systems for the Government. In other words, the desired outcomes for the Government may include some additional areas and the metrics that are related to different specific areas may conflict with each other. Therefore, a higher level sight may be needed to govern the system.

In conclusion, the BSC is a necessary mindset while building the metrics and the measurement and/or management system. Although constructing a BSC takes time and effort, a strategic-level BSC should be built for the organization and the relevant metrics should be set before starting to negotiate the PBL contract for a weapon system.

2) Cost Management: Achievable cost reductions are expected from PBL-governed systems and Business Case Analyses (BCAs)[11] are very important in the PBL implementation process. However, in some situations, cost data neither exists nor is accurately allocated (Rievley, 2001; US GAO, 2005, p 7; Mahon, 2007). According to the reviewed literature, Activity Based Costing (ABC) may be the right choice for PBL-governed systems. In addition to that, Traditional Cost Accounting (TCA) systems are not appropriate, but mandated because of financial reporting purposes: especially for tax issues for the commercial companies (Kaplan and Cooper, 1997, p 13). The Government also relies on TCA systems for funding and spending issues.

[11] See pp 21-22 in this study for a more detailed description of BCAs.

Activity Based Costing (ABC) is an approach especially for the service industries in order to link the costs of the resources they supply to the outcomes gathered by the service provided (Kaplan and Cooper, 1997, p 228). The most important aspects of ABC related with the current study may be mentioned as:

a) It is an integrated approach similar to the BSC, which concentrates on linking the cost of supplies used with the outcomes gathered. Allocating the costs according to the cause and effect relationships among the different levels of the system makes ABC potentially more accurate than TCA systems.
b) Parallel to the usage of ABC systems, accurate cost data may be gathered in order to build a BCA.
c) Some important cost metrics may be developed via the usage of ABC.

Evaluation Processes of PBL

Each system has some inputs and some outcomes. The objective of the PBL is minimizing the committed resources (inputs) while maximizing the achieved levels of performance outcomes and the mission of the evaluation processes is to ensure that the system is serving the objective. Generally problems occur because of either the inappropriately mandated performance goals, or misunderstood metrics (Sols et al., 2007).

Kumar et al (2007) offered an optimization model to both The Government and the contractor sides. In their study, it's proposed that the contractors would optimize multiple performance measures of their product by choosing the optimum sub-units at the design level and the Government officials would choose the best design between competing firms via the usage of their model (Kumar et al., 2007). Despite being out of

the scope of the current study[12], it is important to mention some gaps of their model. First, the model is a descriptive one and some elements such as annual failure rate of the parts, stock levels of parts, annual repair rates are assumed to be known between alternatives before the design stage. However, these elements may only be estimated with related variances in the best case. Second, the logistics footprint is defined as a decision parameter for their model, even though it was not explained how it was calculated as a sole number[13]. Third, as they mentioned in their study, the increase of the number of components and the subsystems would make it impossible to solve with an exact algorithm.

The common sense in implementing a PBL contract is to incentivize the contractor to achieve the desired levels of performance. Some academics suggested defining dead (neither penalty nor reward), penalty and bonus zones for each one of the figures of merits (FOMs)[14], compensation between pairs of metrics, and proposed a multi-dimensional dead, penalty, and reward zones approach (Sols et al., 2007). These concepts are depicted in Figures 10, 11 and 12.

[12] The optimization model mentioned in the study of Kumar et al., (2007), is mainly concerned with the Pre- PBL period. (See Figure 3)
[13]The Logistic Footprint includes inventory/equipment, personnel, facilities, transportation assets and real estate by definition, assuming it as a sole number without showing how it was calculated in a model may be an over assumption.
[14] The word Figure of Merit (FOM) is used instead of metrics in Sols et al., (2007)

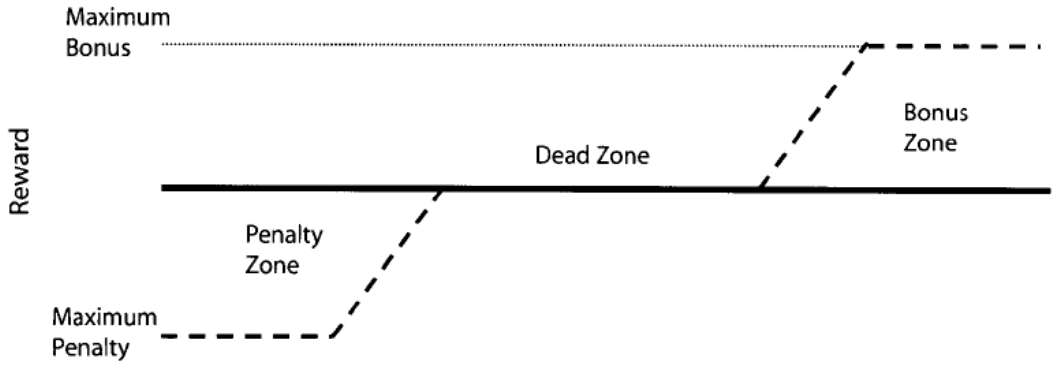

Figure 10. Dead, Bonus and Penalty Zones Concept
(Gathered from Sols et al., 2007)

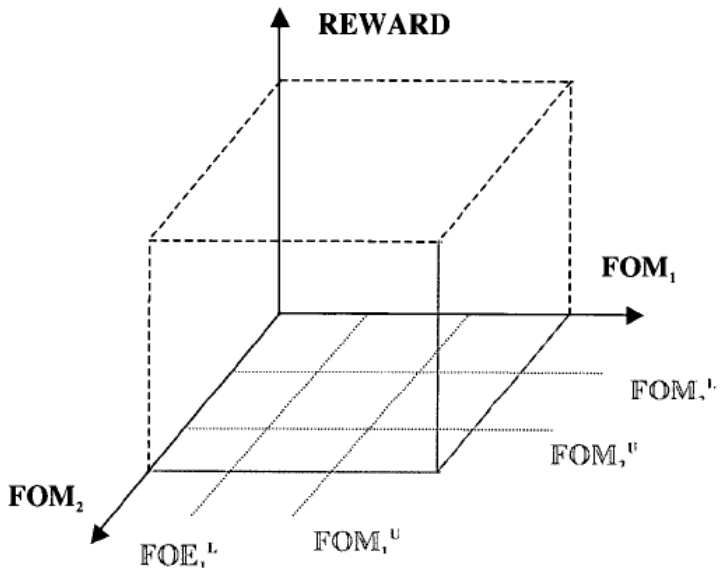

Figure 11. 3-Dimensional Dead, Penalty and Reward Zones
(Gathered from Sols et al., 2007)

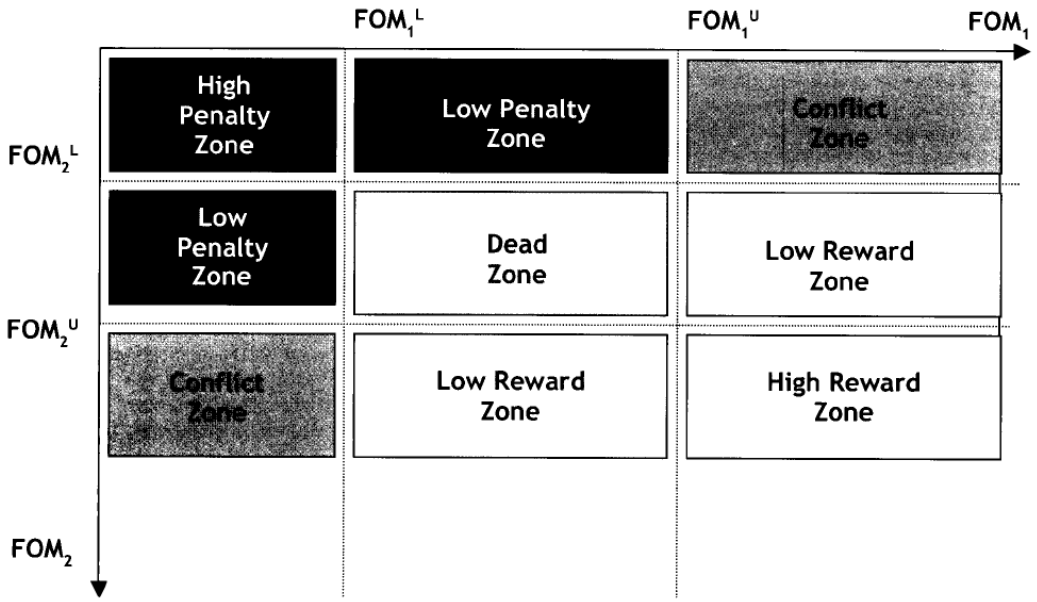

Figure 12. 3-Dimensional Dead, Penalty and Reward Zones[15]
(Gathered from Sols et al., 2007)

The multi-dimensional dead (neither penalty nor reward), penalty and reward zones approach includes some important aspects for the current study. First, the idea of linking two metrics in a 3-dimensional shape and defining 9 possible zones for the two metrics reveals the difficulty of integrating metrics in a model. Second, each one of the metrics is defined with a variance, so the model is prescriptive. Third, compensation between pairs of metrics is introduced. This idea with the usage of weighted average evaluation considers inter-relationships between the metrics. There are some issues with this approach. First, a requirement of (n+1) dimensional space is mentioned for (n) number of different metrics as depicted in Figure 11. For each pair of metrics, there would be 9 different possibilities, as depicted in Figure 12 as dead, penalty and reward zones. However, in this model, only two metrics' axes were presented with the reward axis in order to define the zones within. So basically, as the authors point out, using the

[15] The word Figure of Merit (FOM) is used instead of metrics, the super-indices L and U denote the lower and the upper thresholds (Sols et al., 2007).

five key parameters as DAU introduced: availability, reliability, logistics foot print, logistics response time and cost per unit usage, would result in a 6-dimensional space. This implies 90 different zones[16] with related compensation, penalty and reward amounts. As the number of defined metrics increases in a PBL contract, the number of zones would disproportionally increase. In addition to being hard to implement, the Government should also consider the risk of still paying some amount to the contractor because of the existence of some high reward zones. A similar approach is used by some academics to suggest possible improvements to the maintenance contracting process currently utilized by the South Carolina Department of Transportation (SCDOT) (Bell and Berkland, 2007). According to the defined 8 key parameters and 44 derived sub-parameters, they defined a weighted evaluation process with a partial payment method that includes incentives. Although the parameters were defined in a systematic way, the evaluation process might not be appropriate. For example, SCDOT accepted to pay some amount of money to the contractor because of satisfying some parameters at certain levels; however, the assessed values of the other parameters are evaluated as unacceptable and penalties assessed. (See Table 3)

[16]For 5 parameters; first we need to select 2 from 5 and then we need to define 9 zones for each pair. So the total number of the zones would be: $C\begin{pmatrix}5\\2\end{pmatrix}\times 9 = 90$

Table 3. Evaluation Process of SCDOT
(Gathered from Bell and Berkland, 2007)

EXAMPLE OF CONTRACTOR PAYMENT
$ 100,000.00 MONTHLY UNIT BID AMOUNT

Element Value equals Element Weight X Unit Price Bid (Monthly Bid Amount)
Ex. Asphalt Pavement Repair
Element Weight = .09
Unit Price Bid = $100,000.00
Element Value = $9,000.00

If the contractor performance rating meets the performance target then the contractor receives total payment for the element value. If the performance rating is 1 to 5 points below the performance target then the contract payment for that element is 75% of the element value. If the performance rating is 6 to 10 points below the performance target then the contract payment for that element is 50% of the element value. If the performance rating is over 10 points below the performance target then the contractor does not receive payment for the element.

	ELEMENT	ELEMENT WEIGHT	TARGET	TARGET ELEMENT POINTS	RATING	RATING ELEMENT POINTS	VALUE BELOW TARGET	ELEMENT VALUE	PAYMENT
BRIDGES	Bridge Decks	0.0225	80	1.8	59.7	1.34325	-20.3	$ 2,250.00	$ -
	Superstructure	0.045	80	3.6	58.21	2.61945	-21.79	$ 4,500.00	$ -
	Substructure	0.045	80	3.6	74.63	3.35835	-5.37	$ 4,500.00	$ 2,250.00
	Pipes & Culverts	0.0225	90	2.025	47.19	1.061775	-42.81	$ 2,250.00	$ -
	Retaining Walls	0.0075	90	0.675	99.87	0.675	0	$ 750.00	$ 750.00
	Channel & Slope Protection	0.0075	90	0.675	62.69	0.470175	-27.31	$ 750.00	$ -
		0.15	90	12.375		9.528			
PVMT	Asphalt Pavement Repair	0.09	95	8.55	87.69	7.8921	-7.31	$ 9,000.00	$ 4,500.00
	Concrete Pavement Repair	0.09	95	8.55	88.89	8.0001	-6.11	$ 9,000.00	$ 4,500.00
	Pvm't Shoulder Condition	0.02	90	1.8	98.65	1.8	0	$ 2,000.00	$ 2,000.00
		0.2	94.5	18.9		17.6922			
SHLD & DITCH	Low Shoulder	0.04	85	3.4	91.28	3.4	0	$ 4,000.00	$ 4,000.00
	High Shoulder	0.03					0	$ 3,000.00	$ 3,000.00
	Lateral Ditches	0.03					0	$ 3,000.00	$ 3,000.00
		0.1							
DRAINAGE	Crossline Pipe (Blocked)	0.03					0	$ 3,000.00	$ 3,000.00
	Crossline Pipe (Damaged)	0.02					0	$ 2,000.00	$ 2,000.00
	Curb & Gutter (Blocked)	0.01					0	$ 1,000.00	$ 1,000.00
	Curb & Gutter (Damaged)	0.01	85	0.85	99.94	0.85	0	$ 1,000.00	$ 1,000.00
	Drop Inlets, CB's, etc (Blocked)	0.02	85	1.7	89.68	1.7	0	$ 2,000.00	$ 2,000.00
	Drop inlets, CB's, etc (Damaged)	0.01	85	0.85	96.61	0.85	0	$ 1,000.00	$ 1,000.00
		0.1	85	8.5		8.5			
ROADSIDE APPURT	Guardrail/Cablerail	0.09	95	8.55	98.81	8.55	0	$ 9,000.00	$ 9,000.00
	Concrete Median Barrier	0.015	95	1.425	99.92	1.425	0	$ 1,500.00	$ 1,500.00
	Noise Walls	0.015	95	1.425	80.84	1.2126	-14.16	$ 1,500.00	$ -
	Impact Attenuators	0.03	95	2.9	84.21	2.5263	-10.79	$ 3,000.00	$ -
		0.15	95	14.25		13.7139			
ROADSIDE	Mowing	0.03	90	2.7	22.86	0.6858	-67.14	$ 3,000.00	$ -
	Brush & Tree Control	0.0225	85	1.9125	70.64	1.5894	-14.36	$ 2,250.00	$ -
	Turf Condition	0.015	80	1.2	82.32	1.2	0	$ 1,500.00	$ 1,500.00
	Uncontrolled Growth	0.015	70	1.05	76.22	1.05	0	$ 1,500.00	$ 1,500.00
	Litter & Debris Control	0.0375	90	3.375	5.71	0.214125	-84.29	$ 3,750.00	$ -
	Landscape Beds	0.0225	70	1.575	63.64	1.4319	-6.36	$ 2,250.00	$ 1,125.00
	Slope	0.0075	95	0.7125	99.26	0.7125	0	$ 750.00	$ 750.00
		0.15	84.75	12.525		6.883725			
TRAFFIC/ITS	Pavement Markings	0.03	85	2.55	97.28	2.55	0	$ 3,000.00	$ 3,000.00
	Pavement Markers	0.015	85	1.275	97.31	1.275	0	$ 1,500.00	$ 1,500.00
	Ground Signs	0.0195	92	1.794	85.84	1.67388	-6.16	$ 1,950.00	$ 975.00
	Overhead Signs	0.0375	92	3.45	91.75	3.440625	-0.25	$ 3,750.00	$ 2,812.50
	Roadway lighting	0.03	90	2.7	47.19	1.4157	-42.81	$ 3,000.00	$ -
	Words % Symbols	0.0075	85	0.6375	69.19	0.518925	-15.81	$ 750.00	$ -
	Sign Lighting	0.0075	90	0.675	41.45	0.310875	-48.55	$ 750.00	$ -
	Delineators	0.003	90	0.27	89.31	0.26793	-0.69	$ 300.00	$ 225.00
		0.15	89.01	13.3515		11.452935			

The Element Target for Asphalt Pavement Repair is 95, the Contractor Rating is 87.69. Therefore, the Contractor receives payment in the amount of 50% of the element value of $9,000.00, which is $4,500.00

2007 OVERALL TARGET	88.40	76.27076	
OVERALL CONTRACTOR PERFORMANCE	76.27	AVAILABLE MONTHLY PAYMENT	$100,000.00
VALUE BELOW PERFORMANCE TARGET	12.13	PERFORMANCE PAYMENT	$57,887.50

Building the trust and partnerships between parties is an important aspect of PBL; however, the Government side must consider the necessary precautions in order to

guarantee the desired performance outcomes. One of the most effective tools for the Government is using incentives and disincentives.

Sols et al. (2008) offered an n-dimensional compensated effectiveness metric approach with a reward scheme model, which proposes to calculate a single number as the "compensated system effectiveness metric" and build a reward scheme accordingly (Sols et al. 2008). Defining a model in which a calculated single metric for the evaluation process proposed can be useful. Some issues should be considered. The metrics mentioned are composite and multiple tiered with weights assigned at each tier to sub-components of the effectiveness measure. Normalization for the metrics to fit in [0,1] interval permits aggregation. The responsibility to define and calculate the metrics is given to the customer; this may include some degree of risk because of the subjectivity. In addition, compensating between pairs of metrics is complicated when some are over-performing and some are under-performing especially if the number of defined metrics increases. For example, a real life example of an SCDOT contract which was described by Bell and Berkland, (2007), includes 44 sub-metrics; therefore SCDOT could consider 946 alternatives before implementing the compensation between metrics. [17]

Finally, the historical or the predicted value of the calculated system effectiveness metric indicated the process for defining the baseline, minimum acceptable and target values. Both historical and predicted values may be either very low or infeasible. Instead, the upper and the lower limits of the values should be defined by the team of operational units, according to their needs for fulfilling the mission. Then the contractors should

[17] $C\binom{44}{2} = 946$

search the feasibility of satisfying those needs with a budget constraint via their expertise and innovative approaches.

The Core Objectives of an Evaluation Model

The reviewed literature revealed that some models were introduced for the evaluation processes in PBL and some of the models are mentioned in the current study. According to the cumulated knowledge, the objectives of a model which would be used in evaluation processes may be proposed as:

1) Simplicity : The model must be easy-to-understand and apply by the decision makers.
2) Reasonability: The assumptions and the results of a model must make sense to the decision maker.
3) Elasticity : A model should be dynamic and can be applied in many kinds of PBL contracts.
4) Precision : The results should be precise to guide the decision maker.
5) Capability : A model should be capable of processing any number of metrics within many time periods.
6) Integrality : A model should be capable of integrating all metrics and calculate a sole metric as the overall performance measure.
7) Objectivity : The data processing and the outcomes of a model should be the same, no matter who performs them. Therefore, the model should be quantitative and closed to subjective comments as much as possible.

Conclusion

First of all, PBL was born from the necessities of the new era of war, just after the 9/11 terrorist attacks with the implementation of global war on terrorism (GWOT). It represents the preferred approach for all procurements by DoD and can be defined as: the transformation from acquiring materials to acquiring performance outcomes. Although relying on the knowledge and the innovation of the contractor for their product and/or service may be reasonable, the benefits of PBL have not been experienced yet, because of the ineffective implementation for this long-term support strategy (US GAO, 2005).

Second, the reviewed literature pointed out three main problem areas of PBL as: The Ethical Issues of Reliance of Contractors in the Battlefields, Issues About Contract Length, and Measurement Issues of the PBL Systems. Although some studies have been done in order to fill the gaps in these areas, there are still some issues especially for the evaluation processes and the proposed models. Thus, the current research attempts to contribute to the literature by searching for a systematic approach for evaluation of the defined metrics via a theoretical integrated model to monitor the system and to make healthy decisions about it.

Finally, the core objectives of a model were suggested as: reasonability, elasticity, precision, capability, integrality and objectivity. Achieving these objectives is an aimed of the current study.

III. Methodology

Introduction

First of all, the PBL concept was studied according to the published literature and experts' opinions. Second, the gaps of the PBL literature were searched and defined in order to identify a contribution in one of those directions. This research suggests a systematic approach via an integrated model to combine multiple criteria when assessing the success of a PBL contract.

A 4-Step Process Evaluation Model (the 4SPEM) is proposed in this thesis. First the current evaluation model (CEM) is built. The CEM is used to check the achieved results of individual metrics according to whether or not they are satisfying the contractual requirements. Second, a mathematical model (MM) is built. The MM is used to calculate the overall performance metric (OPM) for each term. Briefly, the OPM is a single, integrated number which represents the overall performance of the system within a defined time period (term). Third, the integrated model (IM) is built. The IM is used to put together the findings of the CEM and MM and the findings of the IM are analyzed and interpreted.

The defined objectives of the 4SPEM are achieving: reasonability, elasticity, precision, capability, integrality and objectivity.The detailed methodology is depicted in Figure 13.

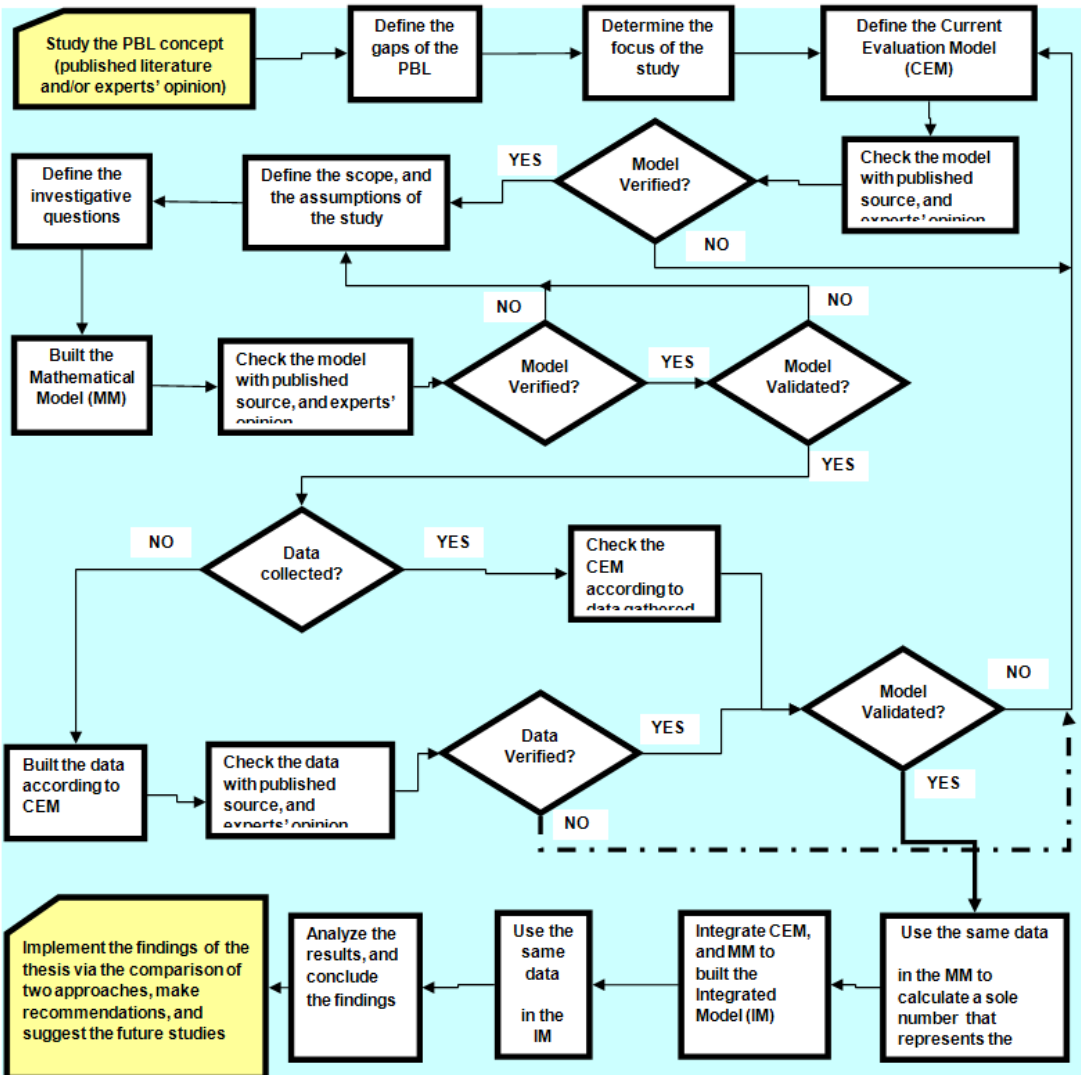

Figure 13. The Methodology Algorithm of the Thesis

4-Step Process Evaluation Model (the 4SPEM)

The 4SPEM is designed to suggest an additional insight to decision makers about the PBL system that is governed by them. The milestones of the 4SPEM are defined as: Building the Current Evaluation Model (CEM), Building the Mathematical Model (MM), Building the Integrated Model (IM) and Analysis and Interpretation of the Findings.

Step 1: Building the Current Evaluation Model (CEM)

The CEM is built according to the current evaluation methods which are used by the acquisition professionals. Although the literature reviewed so far suggests that there's no template for evaluation of the parameters, the evaluation in the CEM is by a 2-step process, as described below:

1) Collecting data of assessed outcome values of defined metrics by time period.
2) Comparison of each calculated metric assessed value with the defined target value of that metric in the contract.

In addition to this 2-step process, some academics mention applying weighting of metrics for the evaluation process (Canada and Sullivan, 1989). Although weights can be applied within the CEM, it would decrease the level of objectivity of the model. In addition to that, favoring one metric over another may lead the contractor in the wrong direction. The viewpoint taken for the current research is that all of the metrics should be perceived as: the defined needs of the war fighter. Thus, none of them should be treated differently than the others.

In conclusion, the CEM will be used for the first step to check whether or not the minimum contractual requirements are satisfied by period/term.

Step 2: Building the Mathematical Model (MM)

First of all, defining a desired metric value within a time frame is the same as defining an outcome of a time function. By definition: "a function is a rule that assigns to each input number exactly one output number." (Haeussler et al., 2007)

Secondly, the importance of PBL is demanding many different performance outcomes simultaneously at the end of certain time periods continuously. It can be illustrated with an explosion of a bomb example. Let's assume that the bomb was triggered at time zero and as the time passes the blast expands in all directions simultaneously and the effect (the overall performance outcome) of the bomb is explained by the multidimensional expansion of the blast in the space.

Every metric in the PBL is a defined dimension in the space and they will expand in different directions following the triggering of the system. The periods of time at which we calculate the assessed values of the metrics are the snap shots of this continuous process. So in addition to calculating the assessed values of the metrics individually, we can also calculate the overall performance outcome (the expansion) of the system.

The MM proposes to calculate and analyze a sole number, the overall performance metric (OPM), for both the overall contractual expectation and the assessed overall performance of the system. These calculated numbers will be used to evaluate whether or not the overall expectation from the relevant metrics at defined times was addressed. Briefly, by defining the requirements for satisfying each parameter within a time frame, a multi-dimensional shape in the space is defined upfront in the contract. For example, if three parameters were defined in a PBL contract, then a four- dimensional volume is defined and the volume of the shape is the OPM of contract. The fourth dimension is time.

The MM model depends on a 4-step process. The first step is building the customized integration formula (CIF) of the relevant metrics defined in the contract. The

important point of building the integration formula is defining the effect of each metric to the system. If it has a positive effect, then the time function representing that metric will be used in the numerator for its part in the formulation; otherwise it will be used in the denominator. For example, A_0 (t) and R (t) are desired to be as much as possible (positive effect), but LRT (t) is desired to be as low as possible (negative effect). So A_0 (t) and R (t) will be used in the numerator, but LRT (t) will be used in denominator. Equation (1) illustrates an example formulation of a customized integration formula to calculate the overall performance metric.

$$OPM = \int_g^h A_o(t)d(t) \times \int_g^h R_o(t)d(t) \times \int_g^h \frac{1}{LRT(t)} dt \qquad (1)$$

where

A_0 (t), R_0 (t) and LRT (t) are *relevant time functions* of the defined metrics,

g is *the beginning of the term* and *h* is *the end of the term*.

The second step is revealing the time functions of the parameters such as: A_0 (t) , R (t) and LFP (t). Equations (2) to (4) are used to calculate the coefficients of the independent variables. Briefly, Equation (2) is the general exhibition of the time functions of each metric, Equation (3) is the matrix form of the time functions and Equation (4) is the calculation of the coefficients of the relevant time functions.

$$f(t) = \sum_{i=1}^{n} x_i t^{(n-i)} = y_k \qquad (2)$$

where

n = *the number of terms* that performance data is evaluated for individual metrics

x_i = *the coefficients* of independent variables in the function

t = *the independent variables* in the function

y_k = *the dependent variable* in the function

Since we know the values of t, n and y_k , we only need to calculate x_i values in order to reveal the time functions of the relevant metrics. Hence, we will transform the general exhibition of time functions to matrix form as depicted in Equation (3).

$$f(t) = A \times B = C \tag{3}$$

where

A = matrix form of independent variables

B = matrix form of coefficients

C = matrix form of dependent variables

hence

$$A = \begin{pmatrix} t_1^{(n-1)} & \dots & t_1^0 \\ \dots & \dots & \dots \\ t_n^{(n-1)} & \dots & t_n^0 \end{pmatrix}_{nxn} , \quad B = \begin{pmatrix} x_1 \\ \dots \\ x_n \end{pmatrix}_{nx1} , \quad C = \begin{pmatrix} y_1 \\ \dots \\ y_n \end{pmatrix}_{nx1}$$

Then we will use the mathematical approach depicted in Equation (4) to calculate the values of coefficients of the independent variables.

$$A \times A^{-1} \times B = C \times A^{-1} \tag{4}$$

where

A^{-1} = inverse of matrix A

Third, Equations (2), (3), (4) and (1) are used iteratively to calculate the volume of the PBL shape for the relevant terms, in other words, the OPMs for the relevant terms of the PBL contract.

We defined two different ways of finding the time functions of the relevant metrics via Equations (2), (3), (4) and applying them to Equation (1) to calculate OPMs.

The first way may be calculating continuous time functions for each metric from point zero at the time scale to the actual point where the latest term is via Equations (2),

(3) and (4). The time functions are quadratic after the first term in this case and then Equation (1) (CIF) is applied via using the latest term's and the previous term's values of time on the time scale as boundaries of integrals to calculate the OPM of the relevant term. The sum of all terms' OPMs will give us the overall OPM.

The second way may be calculating discrete time functions for each metric from the previous term to the latest term via Equations (2), (3) and (4). The time functions will be linear in this case for all terms. Thus, Equation (1) (CIF) are applied via using only 0 (zero) and 1(one) as boundaries of integrals to calculate OPMs.

Finally, we will try to evaluate both approaches according to the analysis of the data. After that we will analyze each term via comparing the values of contractually-demanded OPMs with assessed values of OPMs and then the findings will be evaluated.

Step 3: Building the Integrated Model (IM)

The IM is built via combining and organizing the findings of the CEM and the MM. A table format is used to exhibit the IM which reveals the current situation of the system and the trend of the system. By this way, the decision makers would gain more insights about the system for which they are responsible. Additionally, the IM would be used as a mediator tool between the contractor and the Government for both negotiations and working on the solutions of the conflicts. Thus, it may be useful to build trust between the partners.

Step 4: Analysis and Interpretation of the Findings

By the highly-elastic nature of the PBL, every IM is unique. However, concluding all of the findings gathered from either the CEM, or the MM, to see the big picture before the decision-making is the general idea of the IM.

Thus, the IM will be analyzed in order to understand both the overall performance and the general trend of the system. Finally, the conclusions depending on the evaluation of results will be interpreted.

Data Sources / Format

First of all, one of the aims of the current study is to test the applicability and the usefulness of the 4SPEM. Thus, PBL data from published sources was used. By doing so; examination of the results would benefit from the insights gathered via the studies of the previous researchers about the PBL contracts that they worked on. Additionally, the model in the current study may be evaluated with real life data.

Data Analysis

Two common technological tools: Microsoft Excel and Mathcad 14 are used to process the data, and perform the relevant analyses. However, the approach is not limited to these two applications. Many kinds of mathematical tools including scientific calculators may be used.

The Example Study

First of all in this example study, the usage of numbers and the mathematical equations are used as little as possible for the sake of simplicity. The aim of this example is to provide a better understanding of this thesis.

Let's assume that the contract is agreed between the two sides and at the end of each year the collected parameters are evaluated according to the CEM and all of them were satisfied according to the defined contract requirements. Can we assume that the contractor is successful and we would continue with that contractor? How about, although some parameters are in an upward trend, the others are declining or may be no different at all? The answers of these questions and the expected comparison between CEM and IM are depicted in Table 4. [18]

[18] Contract metrics are satisfied for all terms. And they are compared with the contract and previous term; and increase is defined as "↗"decrease is defined as "↘" and no difference is defined as "▬" and it's assumed that the overall performance metric is calculated as 1.5 from the contract according to MM.

Table 4. Theoretical Comparison of CEM with IM

1st YEAR with CEM	1st YEAR with IM (individual metrics & overall performance metric)	
Availability ↗	Availability ↗	Overall Performance Metric (OPM)
Reliability ↗	Reliability ↗	
Cost ↙	Cost ↙	1.57
Logistics foot print —	Logistics foot print —	
Logistics response time ↙	Logistics response time ↙	
2nd YEAR with CEM	**2nd YEAR with IM**	
Availability —	Availability —	OPM
Reliability ↗	Reliability ↗	
Cost ↗	Cost ↗	1.59
Logistics foot print ↗	Logistics foot print ↗	
Logistics response time ↗	Logistics response time ↗	
3rd YEAR with CEM	3rd YEAR with IM	
Availability ↗	Availability ↗	OPM
Reliability ↙	Reliability ↙	
Cost ↗	Cost ↗	1.6
Logistics foot print —	Logistics foot print —	
Logistics response time —	Logistics response time —	
END OF 3rd YEAR	**END OF 3rd YEAR**	
How's our system going? (hard to measure) How's our contractor doing? (it depends) Will we continue with him? (subjective)	How's our system going?(easy to measure with additional help of my model) 1.5<1.57<1.59<1.6 How's our contractor doing? (he's doing fine according to my model) 1.5<1.57<1.59<1.6 Will we continue with him?(his performance has an upward trend, so yes) 1.5<1.57<1.59<1.6	

Conclusion

In this chapter, the methodology of the thesis is briefly explained. First, the map of the study is described via the Methodology Algorithm in Figure 13. A holistic approach is adopted and the study is concentrated on the post-PBL period. The aim of the current study is to contribute to the area of evaluation processes and propose a model which should include: reasonability, elasticity, precision, capability, integrality and objectivity.

Second, a 4-Step Process Evaluation Model (the 4SPEM) is defined. It starts with building the Current Evaluation Model (CEM), which has a 2-step sub process. It continues with building the Mathematical Model (MM). A 4-step sub process is defined to realize the MM with the underlying theories. However, we defined two different approaches in building the MM and we will use one of the two approaches after the evaluation process. Next, building the Integrated Model (IM) is defined and the interpretation of the findings explained. Following that the expected data sources are explained with the format of the data and then the planned approach of the data analysis is defined.

Finally, a simple example of the thesis is illustrated in Table 4. The aim of the example is to provide a better understanding of the current study; therefore, the usage of numbers and mathematical formulas were limited.

IV. Analysis

Introduction

First of all, this research chose two real life PBL cases from published sources in order to apply the 4SPEM. Briefly, Case 1 is related to the Navy A-RCI[19] and Virginia S/CC/A[20] Program. The research of Gansler and Lucyshyn (2006) is used for both explaining and gathering the data of performance metrics of the program. Case 2 is related to the C-17 Globemaster Sustainment Program and the research of Mahon (2007), is used as the data source for that case.

Secondly, the 4SPEM[21] is applied to both cases and the applicability and the reliability of the model is checked. Microsoft Excel and Mathcad 14 are used as technical tools; however, other tools may be used according to the familiarity of the researcher.

The analyses and interpretation of the findings are done according to the 4SPEM at the end of each case. The primary concern is investigating whether or not the approach in the current study may reveal additional insights about the relevant PBL contracts.

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[19] "The A-RCI is a four-phase program for transforming submarine sonar systems (AN/BSY-1, AN/BQQ-5 and AN/BQQ-6) from legacy systems to a more capable and flexible COTS/Open System Architecture (OSA) and is designated AN/BQQ-10" (Gansler and Lucyshyn, 2006, pp. 28)

[20] Virginia Class sonar,combat control and architecture (S/CC/A)

[21] the 4SPEM includes; Building the CEM, Building the MM, Building the IM ,Analyzing and Implementing the Findings

Case 1

The Navy A-RCI[22] and Virginia S/CC/A[23] Program;

This PBL program is responsible for managing the entire Acoustic Rapid Commercial off the Shelf Insertion (A-RCI), and Sonar Combat Control and Architecture (S/CC/A) supply chain process, from processing the requisition through the transportation to the fleet or the point of debarkation (for overseas delivery). The inventory is stored and repaired at the contractor's Manassas facility (Gansler, 2006, p 31).

1. The desired performance outcomes are mentioned in the PBL contract as:

   a. "Supply Material Availability (SMA): The contractual requirement for SMA is mentioned as 85 percent" (Gansler, 2006, p 31).

   b. "Average Customer Wait Time (ACWT): ACWT requirement for issue priority group (IPG) I items for continental U.S. (CONUS) is 2 days.

      ACWT for IPG I items for outside the continental U.S. (OCONUS) is 3 days.

      ACWT requirements for IPG II items for CONUS and OCONUS are mentioned as within the required delivery date" (Gansler, 2006, p 31).

The contractual requirements are depicted in Table 5.

Table 5. Contractual Requirements for Case 1
(Gathered from Gansler and Lucyshyn, 2006)

Monthly Terms	S-04 1	O-04 2	N-04 3	D-04 4	J-05 5	F-05 6	M-05 7	A-05 8
SMA	85%	85%	85%	85%	85%	85%	85%	85%
ACWT (CONUS)	2 days	2 days	2 days	2 days	2 days	2 days	2 days	2 days
ACWT (OCONUS)	3 days	3 days	3 days	3 days	3 days	3 days	3 days	3 days

[22] The A-RCI is a four-phase program for transforming submarine sonar systems (AN/BSY-1, AN/BQQ-5 and AN/BQQ-6) from legacy systems to a more capable and flexible COTS/Open System Architecture (OSA) and is designated AN/BQQ-10. (Gansler and Lucyshyn, 2006)

[23] Virginia Class sonar,combat control and architecture (S/CC/A)

2. The achieved performance of the related metrics for the first eight months were as depicted in Table 6;

Table 6. Achieved Average Performance Results for Case 1
(Gathered from Gansler, 2006)

Monthly Periods	S-04 1	O-04 2	N-04 3	D-04 4	J-05 5	F-05 6	M-05 7	A-05 8
SMA	92.1%	89.5%	91.1%	86.4%	100.0%	97.5%	97.6%	96.4%
ACWT (CONUS)	1.8 days	2.0 days	1.1 days	2.3 days	1.7 days	1.6 days	1.8 days	1.9 days
ACWT (OCONUS)	1.9 days	2.1 days	2.1 days	2.5 days	2.0 days	2.5 days	2.6 days	2.5 days

According to the data gathered from Gansler (2006), the evaluation process of the Program office depends on defining the needs in the contract, reflecting them via different metrics and calculating each term's assessed values, and comparing them individually at the end. However, checking the assessed values with the contractual requirements indicates that there is a conflict between AWCT (CONUS) and the others at the forth month (D-04). Case 1 is analyzed with the same data via the 4SPEM.

The 4SPEM for Case 1

Step 1: Building the Current Evaluation Model (CEM).

According to the CEM model, there are conflicts between SMA, ACWT (OCONUS) and ACWT (CONUS) at the fourth period. The contractor satisfied the requirements for two metrics; however, the requirements of AWCT (CONUS) were not satisfied. (See Table 7)

Table 7. The CEM Model of Case 1

Metrics	SMA			ACWT (CONUS)			ACWT (OCONUS)		
Terms	Bottom-line	Actual-average	Satisfied	Bottom-line	Actual-average	Satisfied	Bottom-line	Actual-average	Satisfied
S-04 1	85%	92.1%	YES	2 days	1.8 days	YES	3 days	1.9 days	YES
O-04 2	85%	89.5%	YES	2 days	2.0 days	YES	3 days	2.1 days	YES
N-04 3	85%	91.1%	YES	2 days	1.1 days	YES	3 days	2.1 days	YES
D-04 4	85%	86.4%	YES	2 days	2.3 days	NO	3 days	2.5 days	YES
J-05 5	85%	100.0%	YES	2 days	1.7 days	YES	3 days	2.0 days	YES
F-05 6	85%	97.5%	YES	2 days	1.6 days	YES	3 days	2.5 days	YES
M-05 7	85%	97.6%	YES	2 days	1.8 days	YES	3 days	2.6 days	YES
A-05 8	85%	96.4%	YES	2 days	1.9 days	YES	3 days	2.5 days	YES

The CEM of Case 1 reveals that there's a conflict at the fourth month (D-04), because all performance metrics satisfied contractual requirements except ACWT (CONUS). In addition, all of the metrics have waving patterns. In conclusion, the overall performance trend of the system is hard to reveal.

Step 2: Building the Mathematical Model (MM).

First of all, ACWT (CONUS) and ACWT (OCONUS) are measuring the same behavior which is the Logistics Response Time (LRT). Second, the achieved values of ACWT (OCONUS) satisfied the contractual requirements. Thus, the MM is built via using two metrics which are: SMA and ACWT (CONUS) for illustration.

Additionally, the conflict experienced at the fourth month (D-04) can be resolved via proposing the OPM which would integrate the effects of two parameters into one metric.

Building the Customized Integration Formula (CIF) for Case 1.

First of all, the effect of each metric to the system should be understood in order to build the CIF; however, it is not necessary to calculate the correlations of the metrics. Defining an individual metric as bigger is better (+ effect), or smaller is better (- effect), is enough to build the formula. (See Table 8)

Table 8. The Effects of the metrics

Metrics	The bigger is better?	The effect of the metric
SMA	YES	**(+)**
ACWT (CONUS)	NO	**(-)**

The CIF is built according to defined effects of the metrics for Case 1 using Equation (1) and it is depicted in Equation (5).

$$OPM = \int_g^h SMA(t).d(t) \times \int_g^h \frac{1}{AWCT(t)} dt \qquad (5)$$

where

OPM	= the overall performance metric
SMA (t)	= time function of SMA metric
AWCT (t)	= time function of AWCT metric
g	= the beginning of the term
h	= the end of the term

Finding the Time Functions of the Metrics.

Two approaches are defined for finding time functions. In the first approach a continuous quadratic time function (CQTF) is built throughout the time scale from point zero to the latest data point for each term. In the second approach, a discrete linear time function (DLTF) is built from the previous data point to the current data point for each period. The following steps guide both approaches.

First the contractually-defined time functions of the parameters are calculated for each term of contract. Then the time functions of the achieved performance results are calculated for each term of the contract. Equations (2), (3) and (4) are used iteratively to calculate the time functions of each metric for the relevant terms via the Mathcad 14 program and the end of the 1st term (S-04) is accepted as the origin time (time zero) in our calculations.[24]

[24] Since we don't have the performance data of the previous term before S=04, we started from S-04. Therefore, S-04 = t_1=0, O-04 = t_2=1, …, A-05= t_8 =7

The time functions are unique both for each metric and for each term. This reflects reality, because in the real life, activities that take place to satisfy the contractual agreement are not stopped before the evaluation. Besides, a snapshot picture is taken and the evaluation is made while the system continuously keeps moving and the time functions are evolving relative to the data cumulated.

In this case, first the continuous quadratic time functions (CQTF) is found at the end of each term for each metric for both the contract and the assessed values.

1) Building Continuous Quadratic Time Functions (CQTF)

a) The contractually-defined CQTF's of the metrics for Case 1

Both metrics are defined to be satisfied as constant values at the bottom-line as seen in Table 7. Thus, they are represented as depicted in Equations (6) and (7) for all terms without changing.

$$SMA_c(t) = 85t^0 \tag{6}$$

where

SMA(t) = time function of SMA metric

$$AWCT_c(t) = 2t^0 \tag{7}$$

where

AWCT(t) = time function of AWCT metric

b) The assessed CQTF's of the Metrics for Case 1

After calculating the contractually-defined time functions of the parameters, the time functions of the assessed values of the parameters are calculated according to the actual annual averages of the parameters.

The iterative calculations defined in Equations (2), (3) and (4) are made via Matcad 14 to reveal the time functions for the assessed values of the defined metrics of the relevant terms. The calculations of first four terms are depicted in Appendix A.

The relevant time functions of the terms are depicted in Equation (8), through Equation (21).

$$SMA_{a1}(t) = -26t + 92.1 \tag{8}$$

where

SMA_{a1} (t) = time function of SMA metric for the 1st term

$$AWCT_{a1}(t) = 0.2t + 1.8 \tag{9}$$

where

$AWCT_{a1}$ (t) = time function of AWCT metric for the 1st term

$$SMA_{a2}(t) = -2.1t^2 - 47t + 92.1 \tag{10}$$

where

SMA_{a2} (t) = time function of SMA metric for the 2nd term

$$AWCT_{a2}(t) = -0.55t^2 + 0.75t + 1.8 \tag{11}$$

where

$AWCT_{a2}$ (t) = time function of AWCT metric for the 2nd term

$$SMA_{a3}(t) = -1.75t^3 + 7.35t^2 - 8.2t + 92.1 \tag{12}$$

where

SMA_{a3} (t) = time function of SMA metric for the 3rd term

$$AWCT_{a3}(t) = -0.533t^3 - 2.15t^2 + 1.817t + 1.8 \quad (13)$$

where

$AWCT_{a3}$ (t) = time function of AWCT metric for the 3rd term

$$SMA_{a4}(t) = 1.462t^4 - 10.52t^3 + 23.437t^2 - 16.975t + 92.1 \quad (14)$$

where

SMA_{a4} (t) = time function of SMA metric for the 4th term

$$AWCT_{a4}(t) = -0.296t^4 + 2.208t^3 - 5.404t^2 + 3.592t + 1.8 \quad (15)$$

where

$AWCT_{a4}$ (t) = time function of AWCT metric for the 4th term

$$SMA_{a5}(t) = -0.784t^5 + 9.304t^4 - 37.97t^3 + 62.646t^2 - 35.795t + 92.1 \quad (16)$$

where

SMA_{a5} (t) = time function of SMA metric for the 5th term

$$AWCT_{a5}(t) = 0.111t^5 - 1.404t^4 + 6.187t^3 - 10.946t^2 + 6.252t + 1.8 \quad (17)$$

where

$AWCT_{a5}$ (t) = time function of AWCT metric for the 5th term

$$SMA_{a6}(t) = 0.297t^6 - 5.253t^5 + 34.683t^4 - 105.256t^3 + 144.675t^2 - 71.746t + 92.1 \quad (18)$$

where

SMA_{a6} (t) = time function of SMA metric for the 6th term

$$AWCT_{a6}(t) = -0.032t^6 + 0.558t^5 - 4.112t^4 + 13.366t^3 - 19.698t^2 + 10.087t + 1.8 \quad (19)$$

where

$AWCT_{a6}$ (t) = time function of AWCT metric for the 6th term

$$SMA_{a7}(t) = 0.028t_1^7 - 0.317t_2^6 - 3.577\times10^{-3}t_3^5 + 12.147t_4^4 - 54.586t_5^3 + 88.914t_6^2 - 48.783t_7^1 + 92.1 \quad (20)$$

where

SMA_{a7} (t) = time function of SMA metric for the 7th term

$$AWCT_{a7}(t) = -3.179\times10^{-3}t_1^7 + 0.0037t_2^6 + 3.267\times10^{-4}t_3^5 - 1.591t_4^4 + 7.697t_5^3 - 13.459t_6^2 - 7.518t_7^1 + 1.8 \quad (21)$$

where

$AWCT_{a7}$ (t) = time function of AWCT metric for the 7th term

Calculation of OPMs for CQTF

Since we calculated all the necessary time functions of the relevant metrics for each term, we can calculate the OPMs for each term both for the contractual and the assessed performance values using Equation (5).

Table 9 organizes the calculated OPMs for both the contract and the assessed values. The mentioned terms in the table refer to the time frame between two consecutive terms of Table 7. For example, 1st term of Table 9 covers the time frame between S-04 and O-04 of Table 7. ΔOPMs refer to the difference between OPM ASSESSED and OPM CONTRACT in the table.

Table 9. The Calculated Values of OPMs via CQTF

TERMS	OPM CONTRACT	OPM ASSESSED	Δ OPM's
1st	42.5	47.834	5.334
2nd	42.5	56.377	13.877
3rd	42.5	68.43	25.93
4th	42.5	4656	4613.5
5th	42.5	75.133	32.633
6th	42.5	22.992	-19.508
7th	28.863	23.298	-5.565
All	283.863	4950.064	4666.2

Analysis of CQTF-included MM

The MM Model with CQTF Case 1 reveals that ACWT (CONUS) is not satisfied for the contractual requirements according to D-04 (4th month) at the CEM. The OPM satisfied the contractual requirements according to the contract between 3rd and 4th periods.

However, a fluctuation is experienced at the 4th period. The reflection of the previous term's performance effects might be considerable, but the amount of fluctuation makes it almost impossible. In addition to that, although the contractor's performance for both metrics was much higher for the 6th, 7th and 8th months as depicted in Table 7, our model proposes the reverse as seen from 6th and 7th terms of assessed OPM values as negative. Finally, discontinuities are experienced while the relevant terms' CQTF's are applied to Equation (5)[25].

In conclusion, CQTF-included MM is not validated because of the erroneous numbers caused by the use of continuous function. Thus, the MM is built according to a

[25] Equation (5) became discontinuous between 6,and 6.1759 at 7th term when Equations(20) and (21) were applied

second approach, which is Discrete Linear Time Functions (DLTF) included MM. Then the findings are examined in order to attempt to validate the approach and interpret the results if the model is validated.

Finding the Time Functions of the Metrics.

1) Building Discrete Linear Time Functions (DLTF)

a) The contractually-defined DLTF's of the metrics for Case 1

Both metrics are defined as being satisfied by the constant values at the bottom-line as seen in Table 7. Thus, they are represented as depicted in Equations (6) and (7) for all terms without changing.

b) The assessed DLTF's of the Metrics for Case 1

First of all, the iterative calculations defined in Equations (2), (3) and (4) are used for calculating the DLTF's for each metric. The relevant calculations are made from the previous term to the latest term via Matcad 14. By doing so, the time functions for the assessed values of defined metrics are revealed for relevant terms. The calculations of the first four terms are depicted in Appendix B. Secondly, the relevant time functions of the terms will be linear and they are depicted from Equation (22), to Equation (33).

$$SMA_{a1}(t) = -26t + 92.1 \tag{22}$$

where

SMA_{a1} (t) = time function of SMA metric for the 1st term

$$AWCT_{a1}(t) = 0.2t + 1.8 \tag{23}$$

where

$AWCT_{a1}$ (t) = time function of AWCT metric for the 1st term

$$SMA_{a2}(t) = 1.6t + 89.5 \tag{24}$$

where

SMA_{a2} (t) = time function of SMA metric for the 2nd term

$$AWCT_{a2}(t) = 0.9t + 2 \tag{25}$$

where

$AWCT_{a2}$ (t) = time function of AWCT metric for the 2nd term

$$SMA_{a3}(t) = -4.7t + 91.1 \tag{26}$$

where

SMA_{a3} (t) = time function of SMA metric for the 3rd term

$$AWCT_{a3}(t) = 1.2t + 1.1 \tag{27}$$

where

$AWCT_{a3}$ (t) = time function of AWCT metric for the 3rd term

$$SMA_{a4}(t) = 13.6t + 86.4 \tag{28}$$

where

SMA_{a4} (t) = time function of SMA metric for the 4th term

$$AWCT_{a4}(t) = -0.6t + 2.3 \tag{29}$$

where

$AWCT_{a4}$ (t) = time function of AWCT metric for the 4th term

$$SMA_{a5}(t) = -2.5t + 100 \tag{30}$$

where

SMA_{a5} (t) = time function of SMA metric for the 5th term

$$AWCT_{a5}(t) = -0.1t + 1.7 \tag{31}$$

where

$AWCT_{a5}$ (t) = time function of AWCT metric for the 5th term

$$SMA_{a6}(t) = 0.1t + 97.5 \tag{32}$$

where

SMA_{a6} (t) = time function of SMA metric for the 6th term

$$AWCT_{a6}(t) = 0.2t + 1.6 \tag{33}$$

where

$AWCT_{a6}$ (t) = time function of AWCT metric for the 6th term

$$SMA_{a7}(t) = -1.2t + 97.6 \tag{34}$$

where

SMA_{a7} (t) = time function of SMA metric for the 7th term

$$AWCT_{a7}(t) = 0.1t + 1.9 \tag{35}$$

where

$AWCT_{a7}$ (t) = time function of AWCT metric for the 7th term

Calculation of OPMs for DLTF-included MM.

Equation (5) is used to calculate the OPMs for each term both for the contractual and the assessed performance metrics, but this time, 0 (zero) and 1(one) are used for the boundaries of the integrals, because of using DLTF's. The area of interest is between the lines connecting the actual and assessed values.

Table 10 organizes the calculated OPMs for both the contract and the assessed values. The table refers to the time frame between two consecutive terms of Table 7. For example , the 1st term of Table 10 covers the time frame between S-04 and O-04 of Table 7. ΔOPMs refer to the difference between OPM ASSESSED and OPM CONTRACT in the table.

Table 10. The Calculated Values of OPMs via DLTF

TERMS	OPM CONTRACT	OPM ASSESSED	Δ OPM's
1st	42.5	47.8	5.334
2nd	42.5	60	17.483
3rd	42.5	54.6	12.052
4th	42.5	47	4.454
5th	42.5	59.9	17.367
6th	42.5	57.4	14.949
7th	42.5	49.8	7.254
All	283.863	376	78.893

Analysis of DLTF-included MM

First of all, DLTF-included MM is validated both via the experts' opinions and via the results gathered. The assessed OPM values indicate that the contractor satisfied the contractual requirements for all terms by means of OPMs. However, the overall performance of the contractor has a waving pattern as seen from the OPM ASSESSED values. The overall performance behavior of the system also has a waving pattern as seen from the values of ΔOPMs. In conclusion, the MM adds additional insights over the insights gained from the CEM and the IM is built at the next step.

Step 3: Building the Integrated Model (IM)

First of all, the data of Case 1are processed and analyzed at the individual metric level via the CEM and then the same data are processed and analyzed via the MM to calculate the overall performance at the system level. The next step is building the IM in order to organize and integrate the cumulated results of the CEM and the MM and a dashboard form is used for this purpose as depicted in Table 11.

Table 11. The Dashboard Form of Integrated Model (IM) of Case 1

THE INTEGRATED MODEL (IM)												
CEM							MM					
Metrics	SMA			ACWT (CONUS)			OPM					
Months	Bottom-line	Actual-average	Satisfied	Bottom-line	Actual-average	Satisfied	Months	Terms	OPM Contract	OPM Assessed	Satisfied	Δ OPM's
S-04 1	85%	92.10%	YES	2 days	1.8 days	YES	S-04&O-04	1	42.5	47.834	YES	**5.334**
O-04 2	85%	89.50%	YES	2 days	2.0 days	YES	O-04&N-04	2	42.5	59.983	YES	**17.483**
N-04 3	85%	91.10%	YES	2 days	1.1 days	YES	N-04&D-04	3	42.5	54.552	YES	**12.052**
D-04 4	85%	86.40%	YES	2 days	2.3 days	NO	D-04&J-04	4	42.5	46.954	YES	**4.454**
J-05 5	85%	100.00%	YES	2 days	1.7 days	YES	J-05&F-05	5	42.5	59.867	YES	**17.367**
F-05 6	85%	97.50%	YES	2 days	1.6 days	YES	F-05&M-05	6	42.5	57.449	YES	**14.949**
M-05 7	85%	97.60%	YES	2 days	1.8 days	YES	M-05&A-05	7	42.5	49.754	YES	**7.254**
A-05 8	85%	96.40%	YES	2 days	1.9 days	YES	ALL	ALL	297.5	376.393	YES	**78.893**

Step 4: Analysis and Interpretation of the Findings

First of all, although ACWT (CONUS) didn't satisfy the contractual requirements according to D-04 (4th month) at the CEM, the OPM values satisfied the contractual requirements according to the contract within the 3rd and 4th terms at the MM. However, this shouldn't be interpreted as favoring the contractor despite its low level of performance. On the contrary, the contractor should achieve at least 92% for the SMA metric and 1.9 days for the AWCT (CONUS) metric instead of 85% and 2 days respectively for the 4th term in order to satisfy the contractually-mandated OPM of 42.5 points according to our sensitivity analysis (See Appendix C).

As seen from this example, the OPM may also be a useful tool to resolve a potential conflict via creating a win-win situation for both parties. From the Government's perspective, although the contractual limits kept fixed for the relevant metrics, the OPM enabled the limits to increase dynamically from the point where the conflict was experienced to the next month. (4th term of Table 10) By this way, a chance is given to the contractor, but a higher performance requirement is set automatically. Thus, the contractor is motivated for a higher performance. From the contractor's perspective, a chance is given to him to prove its capabilities within one term without a penalty.

It is also seen that the contractor is struggling to set his performance at a high level. Basically there's a waving pattern of the contractor's performance and the overall performance of the contractor should be investigated and analyzed. This may be revealed by comparing the contractual overall performance metric (OPM) with the assessed OPM by the contractor. (See Figure 15)

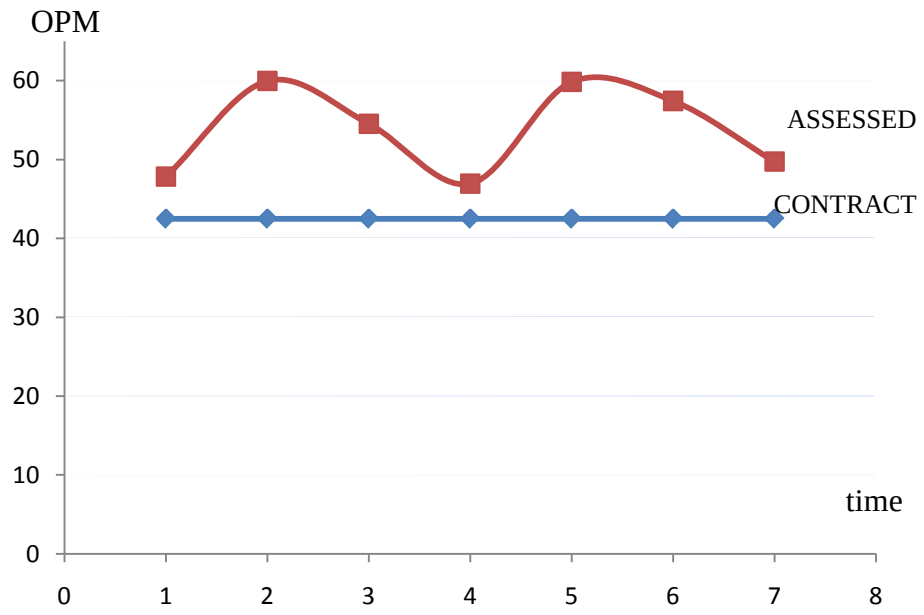

Figure 14. The Comparison of Assessed OPMs with Contractual OPMs

As seen in the figure, the contractor's overall performance has a waving pattern with a period of four months, in which the first two months have an increasing behavior and the last two months have a decreasing behavior.

Although the amount of the data may not be enough to make a forecast about the following terms, it may be expected that the following two months after the 7th month will be an inclining period of overall performance and there would be a decrease of performance between the 9th and 11th months. The lowest points of this waving pattern are very close to the contractually-defined bottom line and the 11th month may be very risky for both parties by means of satisfying the contractual requirements. Figure 16 depicts the overall performance trend of the system via considering the differences of the assessed OPMs and contractual OPMs.

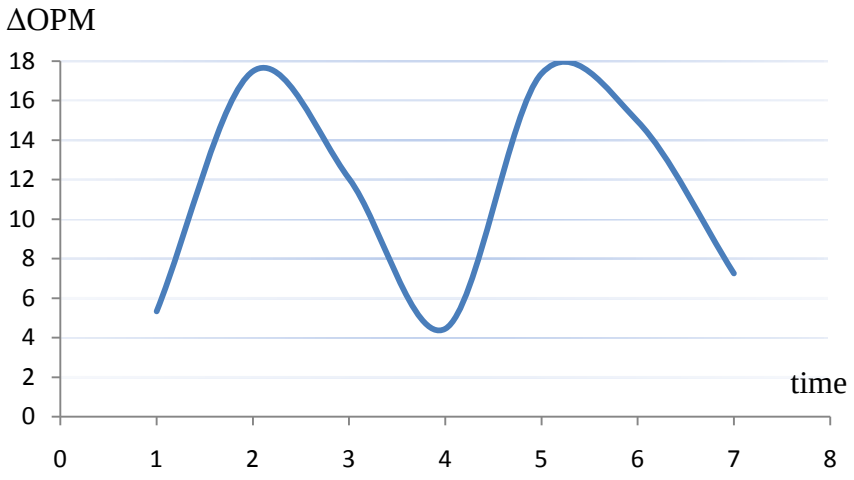

Figure 15. The Performance Trend of the System

First of all, the overall performance of the system is not stabilized. It peaks at the 2nd term and the bottom point is at the 4th term. Secondly, the difference of the bottom and the peak performance points of the system are nearly 14 points. Finally, the bottom point is nearly 4 points and it is very close to the zero level performance which is the border of satisfaction and dissatisfaction level of the system.

Case 2

C-17 Globemaster Sustainment Program;

In this case there are five metrics that can be examined using the 4SPEM and the following section is taken from Mahon, 2007 until the first step of the 4SPEM.

1. The desired performance outcomes are mentioned in the PBL contract as:

> Globemaster Sustainment Aircraft Availability (GSAA): The required performance in this measure is to maximize the number of aircraft available for missions. The requirement equals the percentage of mission capable aircraft relative to total fleet assigned. It is a monthly measurement and is adjusted to account for aircraft undergoing modification. The measure provides a 90-day period following surge operations during which Boeing is relieved of meeting the performance measurement if the metric variance is five percent less than the previous 12 months average as measured prior to the surge. The annual performance will be the 12-month average of the adjusted GSAA requirement (Mahon, 2007, p 62).
>
> Flying Hours Achievable (FHA): The required performance in this measure is to maintain the highest level of flying hours available for wartime mission availability based upon the Weapon System Management Information System- Sustainability Assessment Module (WSMIS-SAM). The measurement is the percent of wartime flying hours achieved given spares availability compared to the number of required hours as compiled by WSMIS-SAM. It is measured the first week of the month. Upon receipt of readiness spares packages (RSP), Boeing is given a 60-day grace period to reconcile the RSP, during which the measurement is not counted (Mahon, 2007, p 63).
>
> Mission Capable (MICAP): The required performance in this measure is to deliver MICAP assets within 48 hours in the continental United States (CONUS) and within 96 hours in the FMS United Kingdom. The measurement is the percent of MICAP events successfully fulfilled within the 48 hours CONUS or 96 hours UK compared to the actual number of MICAP events. The event starts when the Government requests MICAP services and documents it in a MICAP log and ends when the MICAP item is received at the end destination and entered into the Standard Base Supply System (Mahon, 2007, p 63).
>
> Aircraft Depot Maintenance Scheduling Effectiveness (ADMSE): The required performance in this measure is completion of scheduled maintenance

tasks to include negotiated and approved work, including over and above work requirements, within the negotiated schedule time. Performance is calculated by dividing the number of days taken to complete scheduled maintenance tasks by the negotiated number of days. The goal is to maximize the amount of work done within the negotiated time. (Mahon, 2007, p 63)

Issue Effectiveness (IE): It represents the number of issue requests filled compared to the number received and is a monthly measure. Issue effectiveness at new bed down bases will not be counted in overall issue effectiveness during the time aircraft are being delivered. This measure has incentives to forecast demand rather than rely on past demands. (Mahon, 2007, p 63)

Customer Satisfaction (CS): The required performance in this measure is customer satisfaction. Using a concept called the shared destiny/operating principles, the customer scores 11 focus areas of the performance work statement across six criteria .Administered quarterly, the survey coincides with the award-fee schedule. The survey is distributed to the C-17 Special Program Office, C-17 system support manager, using commands and the Defense Contract Management Agency. The rating is determined by averaging scores in each focus area and then averaging all areas to obtain a single rating. (Mahon, 2007, p 63)

The contractually-defined requirements for the Case 2 are organized and depicted in Table 12.

Table 12. Contractual Requirements for Case 2
(Adapted from Mahon, 2007)

REQUIRED PERFORMANCE FOR RELATED METRICS	FISCAL YEARS				
	FY04	FY05	FY06	FY07	FY08
GSAA[26]	69	71.7	74.2	78.4	79.1
FHA	95	95	95	95	95
MICAP	80	80	80	80	80
ADMSE	98-100	98-100	98-100	98-100	98-100
IE (XD items)	82	82	82	82	82
IE (All other items)	67	75	78	80	80
CS	2-5	2-5	2-5	2-5	2-5

[26] The contractual requirement of GSAA for the first three periods were: 75.0% , 76.3%, 77.6% and they were revised as it is mentioned in Table 13.

3. The achieved performance levels of the first three years are depicted in Table 13.

Table 13. Achieved Average Performance Results for Case 2
(Adapted from Mahon, 2008)

ACHIEVED PERFORMANCE FOR RELATED METRICS	FISCAL YEARS		
	FY04	FY05	FY06
GSAA[27]	74.1	73.7	74.4
FHA	97.3	98.9	99.2
MICAP	90.2	96.1	91.5
ADMSE	100.06	100.08	100.4
IE	76.5	76.2	79
CS	N/A	N/A	N/A

According to the data gathered from Mahon, 2008 we can start to build the 4SPEM of Case 2.

the 4SPEM for Case 2

Step 1: Building the Current Evaluation Model (CEM).

First of all the GSAA, FHA, MICAP, ADMSE and IE are used in the CEM. Second, for GSAA the adjusted requirement, for ADMSE the minimum range and for the rest of the metrics the requirements are be used as bottom-line constraints.

Secondly, the bottom-line of each individual metric is defined according to the contract and then the assessed values of these metrics are checked for the relevant terms in CEM. The CEM of the C-17 program is depicted in Table 14.

[27] Eighty-five percent of the award fee is based upon the GSAA performance measurement.

Table 14. The CEM of C-17 Globemaster

Fiscal Years	FY04			FY05			FY06		
Metrics	Bottom-line	Actual-Annual average	Satis-fied	Bottom-line	Actual-Annual average	Satis-fied	Bottom-line	Actual-Annual average	Satis-fied
GSAA	69.0	74.1	YES	71.7	73.7	YES	74.2	74.4	YES
FHA	95	97.3	YES	95	98.9	YES	95	99.2	YES
MICAP	80	90.2	YES	80	96.1	YES	80	91.5	YES
ADMSE	98	100.06	YES	98	100.08	YES	98	100.4	YES
IE	67	76.5	YES	75	76.2	YES	78	79	YES

As seen from the CEM, each one of the performance metrics satisfied the contractual requirements individually. However, some of the assessed values of the metrics are plateauing such as GSAA, some of them have an upward trend such as FHA and ADMSE, and some of them have waving patterns such as MICAP and IE. Additionally, the overall performance trend of the system is hard to reveal.

Step 2: Building the Mathematical Model (MM).

Building the Customized Integration Formulas (CIF's) for Case 2.

First of all, the effects of each metric should be understood from the system's perspective. However, it is not necessary to calculate the correlations of the metrics. Defining an individual metric as bigger is better (+ effect), or smaller is better (- effect), is enough to build the integration formula. Table 15 depicts the defined effects of the metrics according to the contract.

Table 15. The Effects of the metrics

Metrics	The bigger is better?	The effect of the metric
GSAA	YES	**(+)**
FHA	YES	**(+)**
MICAP	YES	**(+)**
ADMSE	YES	**(+)**
IE	YES	**(+)**

Secondly, all of the defined metrics have positive effects on the system according to the gathered data. Although it's out of the scope of this study, it may be argued to define only positive effect metrics in the contract at Pre-PBL phase may be a concern. One or more negative effect metrics should be defined in any kinds of PBL contracts to avoid the "more is better" only mindset.

Finally, the CIF is built according to defined effects of the metrics for Case 2 using Equation (1) and it is depicted in Equation (36).

$$OPM = \int_g^h GSAA(t).dt \times \int_g^h FHA(t).dt \times \int_g^h MICAP(t).dt \times \int_g^g ADMSE(t).dt \times \int_g^h IE(t).dt \qquad (36)$$

where

GSAA(t) = the relevant time function of GSAA metric
FHA(t) = the relevant time function of FHA metric
MICAP(t) = relevant time function of MICAP metric
ADMSE(t) = relevant time function of ADMSE metric
IE(t) = relevant time function of IE metric
g = the beginning of the term
h = the end of the term

Finding the Time Functions of the Metrics.

1) Building Discrete Linear Time Functions (DLTF)

First of all, building the MM via discrete linear time functions (DLTF's) was shown in Case 1. Thus, the iterative calculations which were defined in Equations (2), (3) and (4) are used for calculating the DLTF's for each metric from the previous term to the latest term to reveal the time functions for both the contractually-defined and the assessed values of the metrics for relevant terms. (See Appendix D)

Secondly, the relevant time functions of the terms are linear and they are depicted from Equation (37), to Equation (56).

a) The Contractually-defined DLTF's of the Metrics for Case 2

The contractually-defined time functions of the relevant metrics for the 1st and the 2nd terms are depicted from Equation (37) to Equation (46).

$$GSAA_{c1}(t) = 2.7t + 69 \tag{37}$$

where

$GSAA_{c1}$ (t) = the time function of GSAA metric for the 1st term

$$FHA_{c1}(t) = 95 \tag{38}$$

where

FHA_{c1} (t) = the time function of FHA metric for the 1st term

$$MICAP_{c1}(t) = 80 \tag{39}$$

where

$MICAP_{c1}$ (t) = the time function of MICAP metric for the 1st term

$$ADMSE_{c1}(t) = 98 \tag{40}$$

where

$ADMSE_{c1}$ (t) = the time function of ADMSE metric for the 1st term

$$IE_{c1}(t) = 8t + 67 \tag{41}$$

where

IE_{c1} (t) = the time function of IE metric for the 1st term

$$GSAA_{c2}(t) = 2.5t + 71.7 \tag{42}$$

where

$GSAA_{c2}$ (t) = the time function of GSAA metric for the 2nd term

$$FHA_{c2}(t) = 95 \tag{43}$$

where

FHA_{c2} (t) = the time function of FHA metric for the 2nd term

$$MICAP_{c2}(t) = 80 \tag{44}$$

where

$MICAP_{c2}$ (t) = the time function of MICAP metric for the 2nd term

$$ADMSE_{c2}(t) = 98 \tag{45}$$

where

$ADMSE_{c2}$ (t) = the time function of ADMSE metric for the 2nd term

$$IE_{c2}(t) = 3t + 75 \tag{46}$$

where

IE_{c2} (t) = the time function of IE metric for the 2nd term

b) The Assessed DLTF's of the Metrics for Case 2

The assessed time functions of the relevant metrics for the 1st and the 2nd terms are depicted from Equation (47) to Equation (56).

$$GSAA_{a1}(t) = -4t + 74.1 \tag{47}$$

where

$GSAA_{a1}$ (t) = the time function of GSAA metric for the 1st term

$$FHA_{a1}(t) = 1.6t + 97.3 \tag{48}$$

where

FHA $_{a1}$ (t) = the time function of FHA metric for the 1st term

$$MICAP_{a1}(t) = 5.9t + 90.2 \tag{49}$$

where

MICAP $_{a1}$ (t) = the time function of MICAP metric for the 1st term

$$ADMSE_{a1}(t) = 02t + 100.6 \tag{50}$$

where

ADMSE $_{a1}$ (t) = the time function of ADMSE metric for the 1st term

$$IE_{a1}(t) = -0.3t + 76.5 \tag{51}$$

where

IE $_{a1}$ (t) = the time function of IE metric for the 1st term

$$GSAA_{a2}(t) = 0.7t + 73.7 \tag{52}$$

where

GSAA$_{a2}$ (t) = the time function of GSAA metric for the 2nd term

$$FHA_{a2}(t) = 0.3t + 98.9 \tag{53}$$

where

FHA $_{a2}$ (t) = the time function of FHA metric for the 2nd term

$$MICAP_{a2}(t) = -4.6t + 96.1 \tag{54}$$

where

MICAP $_{a2}$ (t) = the time function of MICAP metric for the 2nd term

$$ADMSE_{a2}(t) = 0.32t + 100.08 \tag{55}$$

where

ADMSE $_{a2}$ (t) = the time function of ADMSE metric for the 2nd term

$$IE_{a2}(t) = 2.8t + 76.2 \tag{56}$$

where

IE $_{a2}$ (t) = the time function of IE metric for the 2nd term

Calculation of OPMs for Case 2.

Since we calculated all the necessary time functions of the relevant metrics, we will use Equation (36) to calculate the OPMs for each term both for the contractual and the assessed performance metrics.

Fiscal year (FY) 2004 is accepted as the origin time (time zero) in our calculations[28] and Table 16 organizes the calculated OPMs for both the contractual and the assessed values. The terms in the table refer to the time frame between two consecutive terms of Table 14. ΔOPMs refer to the differences between OPM ASSESSED and OPM CONTRACT in the table.

Table 16. The Calculated Values of OPMs

TERMS	OPM CONTRACT ($x10^9$)	OPM ASSESSED ($x10^9$)	Δ OPM's ($x10^9$)
1st	3.72	5.192	1.472
2nd	4.156	5.352	1.196
All	7.876	10.544	2.668

Analysis of the MM for Case 2

First of all, the contractually demanded overall performance requirements were satisfied for both terms. However, the overall performance of the contractor has a plateauing trend as seen from the OPM ASSESSED values. A declining trend is also seen for the overall performance behavior of the system via the values of ΔOPMs.

[28] FY 2004 = t_1=0, FY2005 = t_2=1, FY 2006 = t_3 = 2

Secondly, it is revealed that the Government set the OPM low for the first term and the contractor achieved nearly 40% higher OPM. The Government's OPM expectation increased 11.72% for the second term, but the contractor's performance of achieving OPM stayed very low relative to that expectation and increased only 3% for the second term.

Step 3: Building the Integrated Model (IM)

First of all the data of Case 2 are processed and analyzed at the individual metric level via the CEM and then the same data are processed and analyzed via the MM to calculate the overall performance at the system level. The next step is building the IM in order to organize and integrate the cumulated results of the CEM and the MM and a dashboard form is used for this purpose as depicted in Table 17.

Finally, the overall performance trend of the contractor and the overall performance trend of the system are investigated and analyzed. The amount of the data may seem not enough to make a forecast; however, the data belong to already processed annual terms which includes 36 monthly terms. Table 17 organizes and integrates the cumulated results of the CEM and the MM and represents the main body of the IM.

Table 17. The Dashboard Form of Integrated Model (IM) of Case 2

THE INTEGRATED MODEL (IM)									
CEM									
Fiscal Years	FY04			FY05			FY06		
Metrics	Bottom-line	Actual-Annual average	Satisfied	Bottom-line	Actual-Annual average	Satisfied	Bottom-line	Actual-Annual average	Satisfied
GSAA	69	74.1	YES	71.7	73.7	YES	74.2	74.4	YES
FHA	95	97.3	YES	95	98.9	YES	95	99.2	YES
MICAP	80	90.2	YES	80	96.1	YES	80	91.5	YES
ADMSE	98	100.06	YES	98	100.08	YES	98	100.4	YES
IE	67	76.5	YES	75	76.2	YES	78	79	YES
MM									
OPM	Fiscal Years	Terms	OPM Contract		OPM Assessed		Satisfied	Δ OPM's	
	FY04-FY05	1	**3.72**		**5.192**		YES	**1.472**	
	FY05-FY06	2	**4.156**		**5.352**		YES	**1.196**	
	FY04-FY06	ALL	**7.876**		**10.544**		YES	**2.668**	

Step 4: Analysis and Interpretation of the Findings

First of all, the contractor satisfied all the contractual requirements both at the individual and at the overall metric level. Although each assessed value of the individual metrics has a different trend at every term, the assessed values of the OPMs have a very stable trend for the relevant terms.

Secondly, there's no conflict experienced so far; however, the contractor's overall performance trend is plateauing while time passes. On the contrary, the overall performance expectanctions of the Government is increasing; therefore, a conflict may be experienced in the following terms when the Government's increasing expectations became infeasible for the contractor.

Furthermore, the success of the contractor may be arguable for the first term. Because according to a basic comparison between the contractually-defined OPM and the assessed value of the OPM for the first term, the bottom-line OPM may be set lower than

necessary for the first term by the Government, and the contractor may pick the lower hanging fruit.

Figure 17 depicts the comparison of the contractually-defined OPMs with the assessed values of the OPMs.

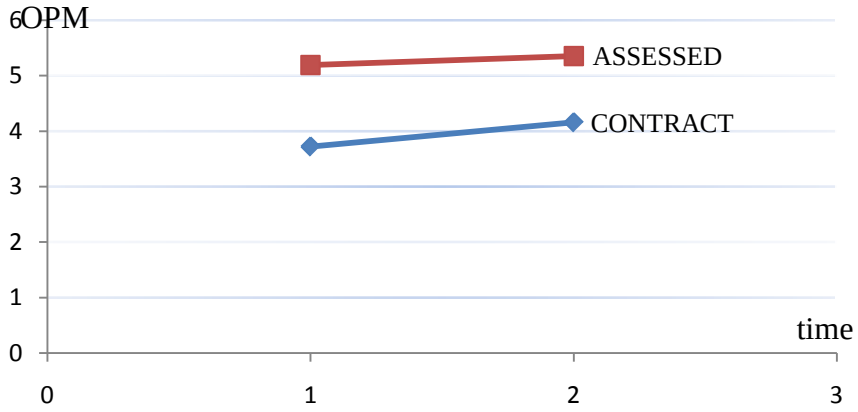

Figure 16. The Comparison of Assessed OPMs with Contractual OPMs

As seen from the figure, the contractor's overall performance has a slightly upward trend, but the contractual expectation for the overall performance has a relatively higher upward trend. The slope of the ASSESSED function in the figure is 0.16; however, the slope of the CONTRACT is 0.436 which is nearly 2.725 times greater than the ASSESSED.

Briefly, the contractual expectation increases 2.725 units for each unit increment of contractor's achievement so far. This supports our proposal of expectation for a conflict in the near future between the Government and the contractor for this case.

Additionally, the overall performance trend of the system should also be taken into consideration. Figure 18 reveals this trend via the reflecting the differences of the assessed OPMs and contractual OPMs.

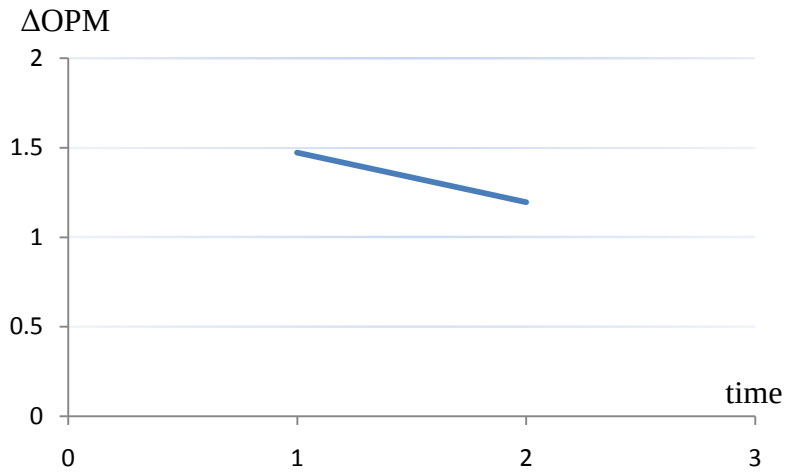

Figure 17. The Performance Trend of the System

The overall performance trend of the system has a downward trend and the slope of this function is -0.276. It may be proposed that the system is heading to the zero level performance difference which is the border of satisfaction level.

Conclusion

First of all, the 4SPEM is applied to two real life cases to investigate whether or not it could reveal additional insights for the decision makers. Each one of the cases has different properties and both of them are benefit from assess the model.

Case 1 has both positive and negative effect metrics and two main problems were experienced which are: discontinuity effects and huge fluctuations while applying the Continuous Quadratic Time Functions (CQTF's) included MM. Further investigation revealed that the relevant continuous time functions became very problematic, especially the ones that belong to the negative effect metrics, while applying the CIF because of high quadratic terms and increasing values of coefficients. Therefore, the 4SPEM is upgraded, and the Discrete Linear Time Functions (DLTF's) approach is used. Additionally, a conflict situation is investigated and a reasonable resolution for that situation is proposed via the 4SPEM. After examining the model results, it is understood that it may be applicable to other cases.

Case 2 has many different metrics and the applicability of the model is tested for many-metrics situation. Additionally, there is an increasing set of contractual requirements in the case. The Government's decision of setting an upward trend for the minimum level of satisfaction for the selected metrics may imply two issues. First, there may be conflicts between the assessed values of the metrics at the individual level if the contractor finds it easier to play on some metrics rather than all. Second, demanding an incremental trend for individual metrics may be demanding an infeasible overall performance from the contractor eventually.

Finally, we could analyze the overall performance patterns of both the contractor and the system for the short run. Furthermore the 4SPEM enabled us to make forecasts as well as gain additional insights for the long run.

V. Conclusions

Introduction

First of all, PBL is a relatively new and challenging concept and it was created to satisfy the highly-elastic needs of the war fighter through the GWOT. The main promise of the PBL is: enabling and sustaining a desired level of performance with a reasonable cost via the innovative approaches and the cumulated experiences of the contractors.

However, this study revealed that the promised benefits are not always gathered by the Government for all cases. Two possible causes of this situation may be inappropriately-defined metrics and incapability of evaluation processes.

In this study a holistic approach is adopted and the post-PBL period is concentrated on, to contribute to the area of evaluation processes. Therefore, the 4-Step Process Evaluation Model (the 4SPEM) is proposed for evaluation of the defined metrics to monitor the system and to make healthy decisions about it. Then the model is examined via applying it to two selected real life cases.

The research revealed that the 4SPEM may be a very useful tool for the decision makers. First, it can be applicable to different kinds of PBL contracts. Second, it helps to gain additional insights about the performance of the system both at the individual metrics level and at the overall system level. Third, it may reveal the possible future performance patterns of both the contractors and the system. Finally, it may offer a possible resolution of a conflict situation to both parties of a PBL contract.

In conclusion, the core objectives which are: simplicity, reasonability, elasticity, precision, capability, integrality and objectivity are fulfilled while proposing the 4-SPEM.

The Gathered Answers to Investigative Questions

1) What are the general metrics defined in the contracts?

Actually, there's neither a standard template for PBL contracts, nor standardized metrics. However, relevant to their knowledge about PBL, the Defense Acquisition University (DAU) mentioned some useful metrics as: Operational Availability (Ao), Operational Reliability (R), Cost per Unit Usage (CUU), Logistics Footprint (LF) and Logistics Response Time (LRT) in their published book of "Performance Based Logistics: A Program Manager's Product Support Guide", also known as PBL Guide. (DAU, 2005)

However, some academics mentioned that these metrics are high level composite metrics (Kumar et al., 2007). So in each PBL contract, some or all of these metrics should be tailored according to the desired goals and would be negotiated with the contractor/s.

2) What is the general current evaluation method of the metrics?

According to the experts' opinions, in most of the PBL contracts, the metrics are evaluated by a two step process that is:

a) Collecting assessed values of the metrics within the contractually-defined terms. (ex: average monthly values)

b) Comparing assessed values of the metrics with the contractually targeted numbers of those metrics individually.[29]

3) What are the gaps of the current evaluation method?

a) According to the laws of statistics, each one of the pair wise comparisons includes risks of making type 1 and type 2 errors, which are the probabilities of making misjudgments depending on a statistical comparison. The probability of making a mistake in comparisons increases as the number of pairs compared increases.

b) According to the Theory of Constraints; local improvements do not necessarily mean that the whole system improved (Goldratt and Cox, 1992). By monitoring each metric individually, we may not visualize the big picture and make healthy decisions at a strategic level.

c) The current evaluation method may be useful in order to understand if the assessed values of the individual metrics satisfied the contractual agreements. However, as some academics mentioned, there may be conflicts between the metrics such as: "some metrics may be over performing while the others are underperforming" (Sols et al., 2007).

d) "The scarcest resource in an organization is a manager's time" (Kaplan and Cooper. 1997, p.144). The evaluation of the metrics individually may consume more time than necessary especially for the senior executives for two reasons. First, there may be an excessive amount of defined parameters and the decision maker may need time to understand the impact of each one of them on the system.

[29] In addition to these two processes, some experts mentioned in some cases a process of weighing the parameters and calculating a single number for strategic decisions. This additional step to the current evaluation method is mentioned under the subject heading of "Evaluation Process of PBL" at the end of the Literature Review.

Second, there may be conflicts between parameters. Although the decision maker may spend much time and effort, s/he may not use the performance data appropriately in the decision-making process (US GAO July 2008, Highlights).

4) How should the metrics be evaluated to improve decision making?

First, the assessed values of the individual metrics should be evaluated by means of satisfying the contractual requirements at the bottom-line. Second, a further step would be taken and the system should be evaluated as a whole. Third, the gathered results of the evaluations should be organized and integrated. Finally, the results should be analyzed and the interpreted.

The 4SPEM is built according to the four logical steps of evaluation which were mentioned earlier. The Current Evaluation Model (CEM) is built for the first step and checked whether or not the metrics were satisfied in each time period. Then, the Mathematical Model (MM) is built in order to calculate a single value representing the overall performance of the system called the Overall Performance Metric (OPM) and the model analyzed the calculated OPMs for the relevant terms. Next the Integrated Model (IM) is built to organize and integrate the findings of the CEM and the MM.

Finally, the cumulated knowledge gathered from IM is analyzed and the results are interpreted as the fourth step.

5) What should be the core objectives of an evaluation model?

The reviewed literature revealed that some models were introduced for the evaluation processes in PBL and some of the models are mentioned in the current study. Additionally the 4-SPEM is developed throughout the current study and according to the

cumulated knowledge. The objectives of a model which would be used in evaluation processes may be proposed as:

- Simplicity : The model must be easy-to-understand and apply by the decision makers.
- Reasonability: The assumptions and the results of a model must make sense to the decision maker.
- Elasticity : A model should be dynamic and can be applied any kinds of PBL contracts.
- Precision : The results should be precise to guide the decision maker.
- Capability : A model should be capable of processing any number of metrics within many time periods.
- Integrality : A model should be capable of integrating all metrics and calculate a single value as the overall performance.
- Objectivity : The data processing and the outcomes of a model should be the same, no matter who performs them. Therefore, the model should be quantitative and relatively closed to subjective comments.

6) Can the proposed model in this thesis be used for forecasting, or building new PBL contracts?

According to the scope of this thesis, the offered approach is reactive, so at the very beginning of a PBL contract concerned with a brand new system, this approach may not be an effective tool for forecasting.

However, while the data are cumulatively gathered according to the metrics defined in the contract, the 4SPEM would be a highly effective tool in order to monitor the overall performance pattern of the contractor and the PBL-governed system.

7) At which decision level may the proposed model be used?

First of all, this approach may be used both for operational-level decisions such as: reward and penalty decisions within a contract and at the strategic-level such as extending or terminating the contractual agreement with the same contractor or making a new contract about the same system with another contractor.

Secondly, the 4SPEM may be used to resolve the conflicts between the Government and the contractor if the individual metrics of a term conflicts with each other, such as one metric is above the defined limits whereas another is below.

Finally, the sub-components of the 4SPEM may be useful for specific evaluation needs within a contract. For example, we may use the MM in the process of calculating a single number for composite metrics such as the Logistics Foot Print (LFP).

Relevant Findings and Recommendations

First of all, the definition of metrics plays an important role in the successful implementation of PBL. Since the aim is satisfying the war fighter's needs, the operational units at the customer side should have the responsibility and authority to define specifically what they need. Then the supporting units should tailor the metrics with a cause and effect relationship to fulfill the operational needs. If any of the

individual metrics could not be satisfied, the customer should penalize the contractor and even terminate the contract if necessary.

Secondly, the evaluation processes should be determined and customized according to the defined metrics. Although developing an evaluation process prior to defining the metrics may be perceived as easier and pragmatic, metrics should not be defined according to an evaluation process.

Third, subjective approaches such as weighting of metrics, or normalization of evaluation processes are not recommended at this time. Basically, favoring one metric over another, or making misassumptions about the limits of the metrics may lead both the Government and the contractor in the wrong direction.

All the metrics should be perceived as: the defined needs of the war fighter, thus, none of the metrics should be treated differently than the others.

Finally, an evaluation process considering and calculating an overall performance value or score may let the decision makers gain more insights into the system they govern. Thus, overall performance metrics may play a more effective role in the decision-making process than the individual metrics.

Limitations

First of all, PBL is a new and sensitive approach, because it both deals with critical weapon systems and there have been some failures experienced so far. Thus, finding a sponsorship and gathering specific raw data about PBL systems were limited

throughout the current study. Although a theoretical model is built in the current study, only published sources of data were obtrained.

Secondly, the best practices are selected for the publications generally and they included very limited and aggregated data such as annual averages of related metrics, or comparisons of only some of the metrics that were defined in the contracts.

Future Studies

First of all, the 4SPEM model should be tested via more real life data. An application of this model to a PBL program that has intense real life data via a sponsorship may prove useful.

Secondly, the best practices of PBL may be useful to concentrate on the efforts, however; considering other practices than the best ones and application of this model on them may help acquisition professionals to gain more insight into PBL contracts.

Conclusion

PBL is an innovative approach to satisfy the highly elastic needs of the warfighter and a new approach, which may be adopted as an evaluation process in PBL is proposed in this thesis. The 4SPEM attempts to fill some of the gaps in the area of evaluation processes and may be a promising model. However, further studies depending on intense real life raw data via the sponsorships of the PBL Program Offices are needed to investigate the limitations and true benefits of this model.

APPENDIX A

Calculation of CQTFs and OPMs for Case 1
)

Calculation of CQTFs and OPMs for Contractual Values
(The calculations are depicted for 4 terms

$$OPM = \int_g^h SMA(t).d(t) \times \int_g^h \frac{1}{AWCT(t)} dt$$

1st Term

$SMA01(t) := 85$ $\qquad$ $AWCT01(t) := 2$

$$\int_0^1 SMA01(t)\ dt \int_0^1 \frac{1}{AWCT01(t)}\ dt = 42.5$$

2nd Term

$SMA01(t) := 85$ $\qquad$ $AWCT01(t) := 2$

$$\int_1^2 SMA01(t)\ dt \int_1^2 \frac{1}{AWCT01(t)}\ dt = 42.5$$

3rd Term

$SMA01(t) := 85$ $\qquad$ $AWCT01(t) := 2$

$$\int_2^3 SMA01(t)\ dt \int_2^3 \frac{1}{AWCT01(t)}\ dt = 42.5$$

4th Term

$SMA01(t) := 85$ $\qquad$ $AWCT01(t) := 2$

$$\int_3^4 SMA01(t)\ dt \int_3^4 \frac{1}{AWCT01(t)}\ dt = 42.5$$

Calculation of CQTFs and OPMs for Assessed Values

(The calculations are depicted for 4 terms)

Original Form of time functions

Matrix Form of time functions

$$f(t) = A \times B = C$$

$$f(t) = \sum_{i=1}^{n} x_i t^{(n-i)} = y_k \qquad A = \begin{pmatrix} t_1^{(n-1)} & \dots & t_1^0 \\ \dots & \dots & \dots \\ t_n^{(n-1)} & \dots & t_n^0 \end{pmatrix}_{nxn}, \quad B = \begin{pmatrix} x_1 \\ \dots \\ x_n \end{pmatrix}_{nx1}, \quad C = \begin{pmatrix} y_1 \\ \dots \\ y_n \end{pmatrix}_n$$

A and C matrices, are known, B matrix is required to calculate time functions

$$A \times A^{-1} \times B = C \times A^{-1} \qquad B = C \times A^{-1}$$

1st Term

$$A1 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C11 := \begin{pmatrix} 92.1 \\ 89.5 \end{pmatrix} \qquad C12 := \begin{pmatrix} 1.8 \\ 2 \end{pmatrix}$$

$$A1^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad A1^{-1} \cdot C11 = \begin{pmatrix} -2.6 \\ 92.1 \end{pmatrix} \qquad A1^{-1} \cdot C12 = \begin{pmatrix} 0.2 \\ 1.8 \end{pmatrix}$$

$$SMA1(t) := -2.6t + 92.1 \qquad AWCT1(t) := 0.2t + 1.8$$

$$\int_0^1 SMA1(t)\, dt \int_0^1 \frac{1}{AWCT1(t)}\, dt = 47.834$$

2nd Term

$$A2 := \begin{pmatrix} 0 & 0 & 1 \\ 1 & 1 & 1 \\ 4 & 2 & 1 \end{pmatrix} \qquad C21 := \begin{pmatrix} 92.1 \\ 89.5 \\ 91.1 \end{pmatrix} \qquad C22 := \begin{pmatrix} 1.8 \\ 2 \\ 1.1 \end{pmatrix}$$

$$A2^{-1} = \begin{pmatrix} 0.5 & -1 & 0.5 \\ -1.5 & 2 & -0.5 \\ 1 & 0 & 0 \end{pmatrix} \qquad A2^{-1} \cdot C21 = \begin{pmatrix} 2.1 \\ -4.7 \\ 92.1 \end{pmatrix} \qquad A2^{-1} \cdot C22 = \begin{pmatrix} -0.55 \\ 0.75 \\ 1.8 \end{pmatrix}$$

$$SMA2(t) := 2.1t^2 - 4.7t + 92.1 \qquad AWCT2(t) := -0.55t^2 + 0.75t + 1.$$

$$\int_1^2 SMA2(t)\ dt \int_1^2 \frac{1}{AWCT2(t)}\ dt = 56.377$$

3rd Term

$$A3 := \begin{pmatrix} 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 \\ 8 & 4 & 2 & 1 \\ 27 & 9 & 3 & 1 \end{pmatrix} \qquad C31 := \begin{pmatrix} 92.1 \\ 89.5 \\ 91.1 \\ 86.4 \end{pmatrix} \qquad C32 := \begin{pmatrix} 1.8 \\ 2 \\ 1.1 \\ 2.3 \end{pmatrix}$$

$$A3^{-1} = \begin{pmatrix} -0.167 & 0.5 & -0.5 & 0.167 \\ 1 & -2.5 & 2 & -0.5 \\ -1.833 & 3 & -1.5 & 0.333 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

$$A3^{-1} \cdot C31 = \begin{pmatrix} -1.75 \\ 7.35 \\ -8.2 \\ 92.1 \end{pmatrix} \qquad A3^{-1} \cdot C32 = \begin{pmatrix} 0.533 \\ -2.15 \\ 1.817 \\ 1.8 \end{pmatrix}$$

$$SMA3(t) := -1.75t^3 + 7.35t^2 - 8.2t + 92.1 \qquad AWCT3(t) := 0.533t^3 - 2.15t^2 + 1.817t + 1.8$$

$$\int_2^3 SMA3(t)\ dt \int_2^3 \frac{1}{AWCT3(t)}\ dt = 68.43$$

4th Term

$$A4 := \begin{pmatrix} 0 & 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 16 & 8 & 4 & 2 & 1 \\ 81 & 27 & 9 & 3 & 1 \\ 256 & 64 & 16 & 4 & 1 \end{pmatrix} \qquad C41 := \begin{pmatrix} 92.1 \\ 89.5 \\ 91.1 \\ 86.4 \\ 100 \end{pmatrix} \qquad C42 := \begin{pmatrix} 1.8 \\ 2 \\ 1.1 \\ 2.3 \\ 1.7 \end{pmatrix}$$

$$A4^{-1} = \begin{pmatrix} 0.042 & -0.167 & 0.25 & -0.167 & 0.042 \\ -0.417 & 1.5 & -2 & 1.167 & -0.25 \\ 1.458 & -4.333 & 4.75 & -2.333 & 0.458 \\ -2.083 & 4 & -3 & 1.333 & -0.25 \\ 1 & 0 & 0 & 0 & 0 \end{pmatrix}$$

$$A4^{-1} \cdot C41 = \begin{pmatrix} 1.462 \\ -10.525 \\ 23.437 \\ -16.975 \\ 92.1 \end{pmatrix} \qquad A4^{-1} \cdot C42 = \begin{pmatrix} -0.296 \\ 2.308 \\ -5.404 \\ 3.592 \\ 1.8 \end{pmatrix}$$

$$SMA4(t) := 1.462t^4 \cdot -10.525t^3 + 23.437t^2 - 16.975t + 92.1$$

$$AWCT4(t) := -0.296t^4 + 2.308t^3 - 5.404t^2 + 3.592t + 1.8$$

$$\int_3^4 SMA4(t)\ dt \int_3^4 \frac{1}{AWCT4(t)}\ dt = -4.656 \times 10^4$$

APPENDIX B

Calculation of DLTF's and OPMs for Case 1

Calculation of DLTF's and OPMs for Contractual Values
(The calculations are depicted for 4 terms)

1st Term

$SMA01(t) := 85$ $\qquad$ $AWCT01(t) := 2$

$$\int_0^1 SMA01(t)\,dt \int_0^1 \frac{1}{AWCT01(t)}\,dt = 42.5$$

2nd Term

$SMA01(t) := 85$ $\qquad$ $AWCT01(t) := 2$

$$\int_1^2 SMA01(t)\,dt \int_1^2 \frac{1}{AWCT01(t)}\,dt = 42.5$$

3rd Term

$SMA01(t) := 85$ $\qquad$ $AWCT01(t) := 2$

$$\int_2^3 SMA01(t)\,dt \int_2^3 \frac{1}{AWCT01(t)}\,dt = 42.5$$

4th Term

$SMA01(t) := 85$ $\qquad$ $AWCT01(t) := 2$

$$\int_3^4 SMA01(t)\,dt \int_3^4 \frac{1}{AWCT01(t)}\,dt = 42.5$$

Calculation of DLTF's and OPMs for Assessed Values
(The calculations are depicted for 4 terms

$$A1 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C101 := \begin{pmatrix} 92.1 \\ 89.5 \end{pmatrix} \qquad C102 := \begin{pmatrix} 1.8 \\ 2 \end{pmatrix}$$

$$A1^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad A1^{-1} \cdot C101 = \begin{pmatrix} -2.6 \\ 92.1 \end{pmatrix} \qquad A1^{-1} \cdot C102 = \begin{pmatrix} 0.2 \\ 1.8 \end{pmatrix}$$

$$SMA101(t) := -2.6t + 92.1 \qquad AWCT101(t) := 0.2t + 1.8$$

$$\int_0^1 SMA101(t)\, dt \int_0^1 \frac{1}{AWCT101(t)}\, dt = 47.834$$

Since DLTFs are considered, A1=A2=A3=A4

2nd Term

$$A1 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C103 := \begin{pmatrix} 89.5 \\ 91.1 \end{pmatrix} \qquad C104 := \begin{pmatrix} 2 \\ 1.1 \end{pmatrix}$$

$$A1^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad A1^{-1} \cdot C103 = \begin{pmatrix} 1.6 \\ 89.5 \end{pmatrix} \qquad A1^{-1} \cdot C104 = \begin{pmatrix} -0.9 \\ 2 \end{pmatrix}$$

$$SMA102(t) := 1.6t + 89.5 \qquad AWCT102(t) := -0.9t + 2$$

$$\int_0^1 SMA102(t)\, dt \int_0^1 \frac{1}{AWCT102(t)}\, dt = 59.983$$

3rd Term

$$A1 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C105 := \begin{pmatrix} 91.1 \\ 86.4 \end{pmatrix} \qquad C106 := \begin{pmatrix} 1.1 \\ 2.3 \end{pmatrix}$$

$$A1^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad A1^{-1} \cdot C105 = \begin{pmatrix} -4.7 \\ 91.1 \end{pmatrix} \qquad A1^{-1} \cdot C106 = \begin{pmatrix} 1.2 \\ 1.1 \end{pmatrix}$$

$$SMA103(t) := -4.7t + 91.1 \qquad AWCT103(t) := 1.2t + 1.1$$

$$\int_0^1 SMA103(t)\, dt \int_0^1 \frac{1}{AWCT103(t)}\, dt = 54.552$$

4th Term

$$A1 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C107 := \begin{pmatrix} 86.4 \\ 100 \end{pmatrix} \qquad C108 := \begin{pmatrix} 2.3 \\ 1.7 \end{pmatrix}$$

$$A1^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad A1^{-1} \cdot C107 = \begin{pmatrix} 13.6 \\ 86.4 \end{pmatrix} \qquad A1^{-1} \cdot C108 = \begin{pmatrix} -0.6 \\ 2.3 \end{pmatrix}$$

$$SMA104(t) := 13.6t + 86.4 \qquad AWCT104(t) := -0.6t + 2.3$$

$$\int_0^1 SMA104(t)\, dt \int_0^1 \frac{1}{AWCT104(t)}\, dt = 46.954$$

APPENDIX C

Sensitivity Analysis for the Conflict Situation

4th Term

AWCT(CONUS) = 85% SMA = 2 days $OPM_{REQUIREMENT}$ = 42.5

$$A1 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C1070 := \begin{pmatrix} 86.4 \\ 85 \end{pmatrix} \qquad C1080 := \begin{pmatrix} 2.3 \\ 2 \end{pmatrix}$$

$$A1^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad A1^{-1} \cdot C1070 = \begin{pmatrix} -1.4 \\ 86.4 \end{pmatrix} \qquad A1^{-1} \cdot C1080 = \begin{pmatrix} -0.3 \\ 2.3 \end{pmatrix}$$

$$SMA1040(t) := -1.4t + 86.4 \qquad AWCT1040(t) := -0.3t + 2.3$$

$$\int_0^1 SMA1040(t)\,dt \int_0^1 \frac{1}{AWCT1040(t)}\,dt = 39.925$$

$OPM_{ASSESSED} < OPM_{REQUIREMENT}$

39.925<42.5 (CONTRACTOR FAILED)

AWCT(CONUS) =91.5% SMA = 1.9 days $OPM_{REQUIREMENT}$ =42.5

$$A1 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C1071 := \begin{pmatrix} 86.4 \\ 91.5 \end{pmatrix} \qquad C1081 := \begin{pmatrix} 2.3 \\ 1.9 \end{pmatrix}$$

$$A1^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad A1^{-1} \cdot C1071 = \begin{pmatrix} 5.1 \\ 86.4 \end{pmatrix} \qquad A1^{-1} \cdot C1081 = \begin{pmatrix} -0.4 \\ 2.3 \end{pmatrix}$$

$$SMA1041(t) := 5.1t + 86.4 \qquad AWCT1041(t) := -0.4t + 2.3$$

$$\int_0^1 SMA1041(t)\,dt \int_0^1 \frac{1}{AWCT1041(t)}\,dt = 42.486$$

$OPM_{ASSESSED} < OPM_{REQUIREMENT}$

42.486<42.5 (CONTRACTOR FAILED)

AWCT(CONUS) =92% SMA = 1.9 days $OPM_{REQUIREMENT}$ = 42.5

$$A1 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C1071 := \begin{pmatrix} 86.4 \\ 92 \end{pmatrix} \qquad C1081 := \begin{pmatrix} 2.3 \\ 1.9 \end{pmatrix}$$

$$A1^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad A1^{-1} \cdot C1071 = \begin{pmatrix} 5.6 \\ 86.4 \end{pmatrix} \qquad A1^{-1} \cdot C1081 = \begin{pmatrix} -0.4 \\ 2.3 \end{pmatrix}$$

$$SMA1042(t) := 5.6t + 86.4 \qquad AWCT1042(t) := -0.4t + 2.3$$

$$\int_0^1 SMA1042(t)\,dt \int_0^1 \frac{1}{AWCT1042(t)}\,dt = 42.605$$

$OPM_{ASSESSED} > OPM_{REQUIREMENT}$

42.925<42.5 (CONTRACTOR SURVIVED)

APPENDIX D

Calculation of DLTF's and OPMs for Case 2

Calculation of DLTF's and OPMs for Contractual Values

(The calculations are depicted for 4 terms

1st Term

$$A101 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C101 := \begin{pmatrix} 69 \\ 71.7 \end{pmatrix} \qquad C102 := \begin{pmatrix} 67 \\ 75 \end{pmatrix}$$

$$(A101)^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad (A101)^{-1} \cdot C101 = \begin{pmatrix} 2.7 \\ 69 \end{pmatrix} \qquad (A101)^{-1} \cdot C102 = \begin{pmatrix} 8 \\ 67 \end{pmatrix}$$

$GSAAC101(t) := 2.7t + 69$

$IEC101(t) := 8t + 67$

$FHAC101(t) := 95$

$MICAPEC101(t) := 80$

$ADMSEC101(t) := 98$

$$\int_0^1 GSAAC101(t)\,dt \int_0^1 FHAC101(t)\,dt \int_0^1 MICAPEC101(t)\,dt \int_0^1 ADMSEC101(t)\,dt \int_0^1 IEC101(t)\,dt = 3.72 \times 10^9$$

2nd Term

$$A102 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C103 := \begin{pmatrix} 71.7 \\ 74.2 \end{pmatrix} \qquad C104 := \begin{pmatrix} 75 \\ 78 \end{pmatrix}$$

$$(A102)^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad (A102)^{-1} \cdot C103 = \begin{pmatrix} 2.5 \\ 71.7 \end{pmatrix} \qquad (A102)^{-1} \cdot C104 = \begin{pmatrix} 3 \\ 75 \end{pmatrix}$$

$GSAAC102(t) := 2.5t + 71.7$

$IEC102(t) := 3t + 75$

$FHAC102(t) := 95$

$MICAPEC102(t) := 80$

$ADMSEC102(t) := 98$

$$\int_0^1 GSAAC102(t)\,dt \int_0^1 FHAC102(t)\,dt \int_0^1 MICAPEC102(t)\,dt \int_0^1 ADMSEC102(t)\,dt \int_0^1 IEC102(t)\,dt = 4.156 \times 10^9$$

Calculation of DLTF's and OPMs for Assessed Values

(The calculations are depicted for 4 terms)

1st Term

$$A103 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C41 := \begin{pmatrix} 74.1 \\ 73.7 \end{pmatrix}$$

$$A103^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad A103^{-1} \cdot C41 = \begin{pmatrix} -0.4 \\ 74.1 \end{pmatrix}$$

$$GSAAA103(t) := -0.4t + 74.1$$

$$A104 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C43 := \begin{pmatrix} 97.3 \\ 98.9 \end{pmatrix}$$

$$A104^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad A104^{-1} \cdot C43 = \begin{pmatrix} 1.6 \\ 97.3 \end{pmatrix}$$

$$FHAA103(t) := 1.6t + 97.3$$

$$A105 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C45 := \begin{pmatrix} 90.2 \\ 96.1 \end{pmatrix}$$

$$A105^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad A105^{-1} \cdot C45 = \begin{pmatrix} 5.9 \\ 90.2 \end{pmatrix}$$

$$MICAPEA103(t) := 5.9t + 90.2$$

$$A106 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C47 := \begin{pmatrix} 100.6 \\ 100.8 \end{pmatrix}$$

$$A106^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad A106^{-1} \cdot C47 = \begin{pmatrix} 0.2 \\ 100.6 \end{pmatrix}$$

$$ADMSEA103(t) := 0.2t + 100.6$$

$$A107 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix} \qquad C49 := \begin{pmatrix} 76.5 \\ 76.2 \end{pmatrix}$$

$$A107^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix} \qquad A107^{-1} \cdot C49 = \begin{pmatrix} -0.3 \\ 76.5 \end{pmatrix}$$

$$IEA103(t) := -0.3t + 76.5$$

$$\int_0^1 GSAAA103(t)\,dt \int_0^1 FHAA103(t)\,dt \int_0^1 MICAPEA103(t)\,dt \int_0^1 ADMSEA103(t)\,dt \int_0^1 IEA103(t)\,dt = 5.192 \times 10^9$$

2nd Term

$A103 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix}$ $\qquad$ $C42 := \begin{pmatrix} 73.7 \\ 74.4 \end{pmatrix}$

$A103^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix}$ $\qquad$ $A103^{-1} \cdot C42 = \begin{pmatrix} 0.7 \\ 73.7 \end{pmatrix}$

$GSAAA104(t) := 0.7t + 73.7$

$A104 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix}$ $\qquad$ $C44 := \begin{pmatrix} 98.9 \\ 99.2 \end{pmatrix}$

$A104^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix}$ $\qquad$ $A104^{-1} \cdot C44 = \begin{pmatrix} 0.3 \\ 98.9 \end{pmatrix}$

$FHAA104(t) := 0.3t + 98.9$

$A105 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix}$ $\qquad$ $C46 := \begin{pmatrix} 96.1 \\ 91.5 \end{pmatrix}$

$A105^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix}$ $\qquad$ $A105^{-1} \cdot C46 = \begin{pmatrix} -4.6 \\ 96.1 \end{pmatrix}$

$MICAPEA104(t) := -4.6t + 96.1$

$A106 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix}$ $\qquad$ $C48 := \begin{pmatrix} 100.08 \\ 100.4 \end{pmatrix}$

$A106^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix}$ $\qquad$ $A106^{-1} \cdot C48 = \begin{pmatrix} 0.32 \\ 100.08 \end{pmatrix}$

$ADMSEA104(t) := 0.32t + 100.08$

$A107 := \begin{pmatrix} 0 & 1 \\ 1 & 1 \end{pmatrix}$ $\qquad$ $C50 := \begin{pmatrix} 76.2 \\ 79 \end{pmatrix}$

$A107^{-1} = \begin{pmatrix} -1 & 1 \\ 1 & 0 \end{pmatrix}$ $\qquad$ $A107^{-1} \cdot C50 = \begin{pmatrix} 2.8 \\ 76.2 \end{pmatrix}$

$IEA104(t) := 2.8t + 76.2$

$$\int_0^1 GSAAA104(t)\,dt \int_0^1 FHAA104(t)\,dt \int_0^1 MICAPEA104(t)\,dt \int_0^1 ADMSEA104(t)\,dt \int_0^1 IEA104(t)\,dt = 5.352 \times 10^9$$

APPENDIX E

The Blue Dart

1st Lt Ferit BUYUKGURAL, Student, AFIT
Word count: 823

Beyond any question the most remarkable global developments of the end of the 20th Century and the beginning of the 21st Century were: the ending of the Cold War and the 9/11 attacks. The Cold War resulted in the dissolution of the Union of Soviet Socialist Republics (USSR) and the Warsaw Treaty. The collapse of the USSR resulted in large part due to the misallocation of their resources and inefficiencies of their system. Although there was one enemy, it was spread out geographically, making it hard for the USSR to carry the heavy burden of logistics support for its system. History clarifies that using a large conventional army makes war very expensive and requires a large support system to maintain effectiveness.

The terrorist attacks of September 11, 2001 (9/11) resulted in implementation of the Global War on Terrorism (GWOT) by the US and its allies. The concept of GWOT represents shifting from traditional army warfare to asymmetric warfare. Briefly, there's no enemy country but there's an enemy, there are no borders of conflict zone, but everywhere is potentially a conflict zone and showing presence of big conventional armed forces in an area is no more a show of superiority, but becoming a bigger target for the shadow enemy. The necessities of the new era mandated every country to allocate their resources relative to the new war concepts that are evolved from the previous ones and Performance-Based Logistics (PBL) is introduced under these conditions.

PBL is buying performance instead of buying materials and it is DoD's preferred product support approach in order to satisfy vitally important war-fighter needs. The mindset behind the PBL approach is: if the contractor knows how to produce a high-technology product or service, then s/he knows how to sustain it better than the customer. But to what extend can we trust contractors and authorize them for our weapon system? Additionally, the elasticity of the needs makes it impossible to build a one-fits-all PBL contract template that would be applicable for a number of scenarios. If there's no template, how should it be implemented correctly? How can anybody be sure about obtaining the best results via using PBL?

The needs should be defined clearly by the operational units and the supporting units. Then the system should be monitored and governed accordingly. Basically, we should define the metrics concerned with the desired outcomes, come to an agreement with the contractor/s about the metrics that we define, collect the data of that metrics, and evaluate them in order to monitor our system. Otherwise, we would not be able to manage our system in a healthy manner.

Both economic metrics such as: Cost per Unit Usage and non-economic metrics such as: Availability, Reliability, Logistics Foot Print and Logistics Response Time can be defined and tailored according to each individual program. However, evaluation of the success of a PBL contract gets harder proportional to the increased number of different types of metrics. According to the experts' opinions, in most of the PBL contracts, the metrics are evaluated by collecting assessed values of the metrics within the contractually-defined terms. (e.g., average monthly values) and comparing assessed values of the metrics with the contractually targeted numbers of that metrics individually.

However, there are some issues concerned with this approach. First, every pair of comparisons includes a risk of making misjudgments statistically, and this risk increases as the number of pairs increase. Second, there may be conflicts between the metrics such as some metrics may be over performing while the others are underperforming, and it complicates the situation for the decision makers. Most recently, the US Government Accountability Office (US GAO) declared that although many performance metrics have been used in contracts, they have not been used in the decision making processes.

This thesis investigates and proposes an alternative approach to monitor the Performance Based Logistics (PBL) supported systems both at the individual metrics level and at the whole system level. The proposed approach is the 4-Step Process Evaluation Model (4-SPEM), consisting of 1) Building the Current Evaluation Model (CEM), 2) Building the Mathematical Model (MM), 3) Building the Integrated Model (IM) and 4)Analysis and Interpretation. Briefly, the defined metrics of the PBL contracts are assessed against individual target performance levels by time period (CEM). The individual metrics are then integrated into a mathematical model (MM). The CEM and MM are integrated to assess results and gain insights at both the individual metric and overall system performance levels. Analysis could include forecasting future performance based on performance to targets to identify potential issues.

This approach may be used in operational-level decisions such as reward and penalty decisions within a contract or strategic-level decisions such as extending the contract with the same contractor, terminating the contract and negotiating with other contractors. In a more general sense, this approach could be applied to other

management and monitoring decisions that involve multiple metrics with different measurement characteristics across multiple time periods.

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Vita

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His first assignment was at Cigli, Izmir as a student in basic pilot training in 2002. He continued his training at Air Technical Schools in Gaziemir Izmir and upon completion his education there, he was assigned to the Turkish Air Force Academy (TUAFA) Supply Command, Istanbul in 2003. He attended Combat Search and Rescue training in 2004 and completed scuba diving, basic commando training, automatic, free and tactical parachute and first aid courses He served as Inventory and Distribution Commander between 2005 and 2007. In August 2007, he entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation, he will be assigned to a logistics post in the Turkish Air Force. He is married and he has a child.

REPORT DOCUMENTATION PAGE

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1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From – To)*
26-03-2009	Master's Thesis	Mar 2008 – Mar 2009

4. Title and subtitle
A 4-STEP PROCESS EVALUATION MODEL TO ASSESS THE SUCCESS OF PERFORMANCE BASED LOGISTICS CONTRACTS

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Buyukgural, Ferit, 1st Lieutenant, TUAF

5d. PROJECT NUMBER
N/A

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)
Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
2950 Hobson Way, Building 640
WPAFB OH 45433-8865

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GLM/ENS/09-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Performance-Based Logistics (PBL) is DoD' s preferred product support approach in order to satisfy vitally-important war fighter needs. The elasticity of these needs makes it impossible to build a one-fits-all template PBL contract with the contractors. Thus, both economic metrics such as Cost per Unit Usage and non-economic metrics such as Availability, Reliability, Logistics Foot Print and Logistics Response Time can be defined and tailored according to each individual program. However, evaluation of the success of a PBL contract gets harder proportional to the increased number of different types of metrics. This research suggests an integrated model approach for combining multiple criteria when assessing the success of a PBL contract. This approach may be used in operational-level decisions such as reward and penalty decisions within a contract, or strategic-level decisions such as extending the contract with the same contractor, terminating the contract and negotiating with other contractors.

15. SUBJECT TERMS
PERFORMANCE BASED LOGISTICS, EVALUATION, 4-SPEM

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Martha Cooper, PhD, ENS
U	U	U	UU	128	19b. TELEPHONE NUMBER *(Include area code)* (937) 785-3636, ext 4708 (Martha.Cooper.ctr@afit.edu)

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Prescribed by ANSI Std. Z39-18