NPS-AM-10-039

EXCERPT FROM THE
PROCEEDINGS

OF THE

SEVENTH ANNUAL ACQUISITION RESEARCH SYMPOSIUM
WEDNESDAY SESSIONS
VOLUME I

Acquisition Research
Creating Synergy for Informed Change

May 12 - 13, 2010

Published: 30 April 2010

Prepared for: Naval Postgraduate School, Monterey, California 93943

The research presented at the symposium was supported by the Acquisition Chair of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

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Attn: James B. Greene, RADM, USN, (Ret.)
Acquisition Chair
Graduate School of Business and Public Policy
Naval Postgraduate School
555 Dyer Road, Room 332
Monterey, CA 93943-5103
Tel: (831) 656-2092
Fax: (831) 656-2253
E-mail: jbgreene@nps.edu

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A Simulation Model for Setting Terms for Performance Based Contract Terms

Betty Jester—Betty C. Jester is employed by the Naval Undersea Warfare Center (NUWC) Division, Newport. She has extensive experience in torpedo systems, having worked on torpedo programs since graduating from the University of Rhode Island with a BS in Electronic Computer Engineering. Ms. Jester also earned an MBA from Salve Regina University. She derives her technical expertise from working on all aspects of torpedo life cycle development, from requirements definition through development and test, production and support, and maintenance for both lightweight and heavyweight torpedoes. Ms. Jester is currently the Technical Project Manager for Torpedo Production.

Betty C. Jester
1176 Howell Street
Code 8191, Building 990/3
Newport, Rhode Island 02841
Phone: 401-832-2303
Fax: 401-832-6859
Email: betty.jester@navy.mil

James C. Ferguson—James C. Ferguson is employed as an engineer by the Naval Undersea Warfare Center (NUWC) Division, Newport in the Production, Logistics, and Quality Assurance branch. He was hired in June 2009. He received a BS in Industrial and Systems Engineering from the University of Rhode Island in May 2009. He is currently pursuing an MS in Systems Engineering at the University of Rhode Island.

James C. Ferguson
1176 Howell Street
Code 8113, Building 148/1
Newport, Rhode Island 02841
Phone: 401-832-4809
Fax: 401-832-4194
Email: james.c.ferguson1@navy.mil

Marie E. Bussiere—Marie E. Bussiere is employed by the Naval Undersea Warfare Center (NUWC) Division, Newport. She is a graduate of the University of Rhode Island, where she earned a BS in Electrical Engineering. Ms. Bussiere also earned an MBA from Salve Regina University and received a diploma from the Naval War College for coursework in the areas of Strategy and Policy, National Security Decision Making, and Joint Maritime Operations. Ms. Bussiere is currently the Head of the Undersea Weapons Acquisition and Life Cycle Engineering Division in NUWC Division Newport’s Torpedo Systems Department. Ms. Bussiere is responsible for Torpedo Test Equipment; Propulsion and Mechanical Systems; Production, Logistics, and Quality Assurance; and Fleet Engineering Support.

Marie E. Bussiere
1176 Howell Street
Code 811, Building 148/1
Newport, Rhode Island 02841
Phone: 401-832-1420
Fax: 401-832-4194
Email: marie.bussiere@navy.mil

Manbir Sodhi—Dr. Manbir Sodhi is a Professor of Systems and Industrial Engineering in the Department of Mechanical, Industrial and Systems Engineering at the University of Rhode Island. He obtained his graduate degrees from the University of Arizona, and has taught courses in Systems

Design, Systems Simulation, Deterministic and Stochastic Optimization, etc. In addition to consulting for several companies, he has also worked as a visiting scientist at the Naval Undersea Warfare Center (NUWC) Division, Newport and at the NATO Undersea Research Center in La Spezia, Italy. His recent work has appeared in professional journals that include the Journal of Scheduling, International Journal of Production Research, and IIE Transactions. He is currently exploring decision models supporting supply chain planning in defense operations and is developing tools and concepts of operations for the use of unmanned undersea vehicles (UUVs) for a variety of search operations.

Dr. Manbir Sodhi
2 East Alumni Drive
Industrial and Systems Engineering
University of Rhode Island
Kingston, RI 02881
Phone: 401-874-5189
Fax: 401-874-5540
Email: sodhi@egr.uri.edu

Abstract

This paper sets forth a model-based approach for selecting terms applicable to a heavyweight torpedoes (HWT) Performance Based Logistics (PBL) contract capable of addressing both near- and long-term support considerations over the torpedo life cycle. Several performance measures commonly used in PBL contracts are described, and a model is presented that is based on an "availability" metric. This metric is calculated using the number of times a required part is not available at field maintenance sites. The metric is computed at the Functional Item Replacement (FIR) or modular level of replacement~~s~~. The contractor is made responsible for maintaining an inventory of parts on the shelf at the maintenance locations. This is referred to as the Coordinated Shipboard Allowance List (COSAL), which is not to exceed a negotiated maximum. Terms of the contract are not specified with regard to lead times such as logistical delays and manufacturing and restocking lags. These times are assumed to be under the contractor's control as are production quantities, quality, and responsiveness. A newsvendor approach for determining optimal shelf inventory levels is first developed. An augmented model is evaluated using a simulation to determine the performance sensitivity to changes in product quality, demand rates, and various supply chain related lead times. Practical collateral issues such as obsolescence, reliability, and cost are also discussed. This concept is being evaluated as a possible go-forward supportability strategy for the MK48 Common Broadband Advanced Sonar System (CBASS) Torpedo.

Keywords: Supportability, Operational Availability, Performance Based Logistics, and Torpedo Enterprise.

Introduction

The history of modern HWT production and the procurement of associated spares can be divided into four major phases starting in the early 1970s. Each phase was self sustaining for that period; however, with a typical torpedo life cycle of 25-40 years and a philosophy of upgrading existing inventories versus funding the production of new all-up-round (AUR) torpedoes, new approaches are needed to address the spares question. Current factors that combine to challenge those responsible for the continued maintenance of the entire torpedo inventory include limited yearly upgrade kit production quantities, implementation of torpedo acquisition reform requirements (starting in 1995), and the need to maintain a high state of readiness across the entire inventory at minimal cost.

The first modern US HWT, the MK 48 Mod 1, entered production in 1972 after an intensive “shootout” between competitors. This first HWT production contract was a sole source, high production quantity effort. It employed a fully documented “build to print” data package, which consisted of hundreds of military specifications and standards, as well as source/specification control drawings and detailed weapon specification packages. This type of production lasted for over 14 years. Thousands of torpedoes were produced during this period and spares were easy to produce concurrently with production. Since there was a well-documented data package, the Navy Supply System obtained all the spare assemblies and parts needed. This was a technically low risk approach since having proven product disclosure documentation essentially eliminated the risk. During this time period, torpedoes were not only produced but several upgrades were implemented and the configuration advanced to a MK 48 Mod 4 version.

As the enemy threat changed during the height of the Cold War with the emergence of quieter, faster, and deeper-diving nuclear submarines in the Soviet fleet, the US Navy initiated development of a more advanced and capable HWT. The areas of greatest technology improvement included the lowering of torpedo self-noise and the use of ruggedized, embedded, digital micro-processors. The latter capability made it possible for digitally controlled torpedoes to be upgraded with new software as threats and countermeasures evolved. The U.S. Navy initiated an advanced torpedo acquisition program to capitalize on these improvements and to counter quiet coated threat submarines capable of employing sophisticated acoustic countermeasures. The MK 48 Mod 5 Advanced Capability (ADCAP) submarine-launched HWT for anti-submarine warfare (ASW) and anti-surface warfare (ASUW) applications was the follow-on to the older MK 48 Mod 3/4. The MK 48 Mod 5 ADCAP entered pilot production in 1986. Production was at the AUR level and evolved into a series of dual-source competitive production contracts. This approach sustained the selected contractors by issuing various production quantities to each until 1992. At this time, a winner-take-all production contract was implemented due to reduced quantity requirements. During this time, torpedoes were still procured using a build-to-print fully disclosed documentation package in competitive contracts. As system requirements evolved, new torpedo variants were procured. Again, spares were readily available via competition and could be procured by the US Navy Supply system using fully documented disclosure packages at low risk. The ability to procure spares by the US Navy Supply system provided significant savings to the program’s logistics/acquisition disciplines. Separate funding sources ensured that sufficient spares would be available as the need arose. In the event torpedo spares were not transitioned into the US Navy Supply system due to a lack of adequate re-procurement documentation, the spares were procured using program funds. Therefore, it was important that the spares be well documented and transitioned into the supply system as soon as possible.

Starting in 1986 with the Packard Commission Report (1986), “A quest for excellence” and continuing into 2002, a number of acquisition reform initiatives were issued that changed the way the US Navy and other organizations acquired new systems. Perry (1994) started to shift the focus of the acquisition world from processes to outcomes. Since that time there has been a wholesale embracing of Acquisition Reform (AR) initiatives and cancellation of military specifications and standards. The US Navy torpedo program embraced the AR initiative and in 1995 was one of the first to issue a contract under AR guidance. The Torpedo MK 48 Modification Program low rate initial production (LRIP) Contract N00024-95-6190 eliminated the build-to-print technical disclosure package of the

Guidance and Control (G&C) Section and reduced the use of military specifications and standards to five. Detailed weapon specifications were also removed. The major thrust was to replace the proscriptive build-to-print and military specification requirements in the ADCAP production technical data package (TDP) with performance specifications and appropriate commercial specifications. The ADCAP propulsion section remained build-to-print because of its largely mechanical (versus electrical) design, maintenance/replacement complexities, and the effort required to validate/qualify any change in the design. The supply system retains support of the afterbody to this day, but it became the program's responsibility to support the forebody.

It was during this phase of torpedo production that modification kits instead of AURs were procured. The combination of AR requirements, kit procurement, and hardware complexities began to have an impact on forebody spares availability, as well as how spares could be procured. The HWT production contracts had transitioned from a technical "risk avoidance" construct based on the use of a proven detailed TDP that could be built by many qualified vendors to a "risk management" construct based on high level performance specifications. This transition requires vigilant management to avoid problems. Under AR the Navy cannot tell the vendor how to build the item being procured; it can only define the item's performance and interface requirements. Since each vendor has the latitude to build the end item in a different manner, the risk of compatibility within the system as well as across systems became more complex and presents a number of challenges related to production and logistics.

The Supply System Construct

Supply support for the HWT program has been provided by the Navy Supply (NAVSUP) system. The Navy Inventory Control Point (NAVICP) manages supply support for what is referred to as Depot Level Repairables (DLR) (i.e., unique torpedo items) and the Defense Logistics Agency (DLA) manages supply support for consumable items. For the HWT, NAVICP (Mechanicsburg, PA) is the Program Support Inventory Control Point (PSICP). They receive the TDP for the torpedo-unique hardware from the MK48 In-Service

Engineering Agent and initiate the provisioning process for the required items. The PSICP assigns National Stock Numbers (NSN) to the items and updates the COSALs for the various Intermediate Maintenance Activities (IMA). This supply system construct is depicted in Figure 1.

Figure 1. Torpedo Supply Chain Construct

Supply system stocking levels are forecasted based on past demand. A rolling average for the demand from the past eight quarters is used to trigger procurement or repairs. Procurement lead times are adversely impacted by diminishing manufacturing sources, obsolescence, rejected deliverables, and contract defaults. At times, the program must directly compensate for these deficiencies in availability by making their own procurements. Demand for items filled from outside the supply system (i.e., procurements made by the program) is provided to the PSICP via an unfunded "Demand Requisition Only" document, so this data may be factored into overall demand for the item. Attempts have been made to utilize alternative methods to forecast future demand such as "anticipated workload." These types of forecasts can be submitted using "Special Program Requirements" (SPR) to NAVICP and "Demand Data Exchange" (DDE) to DLA. It has proven difficult to identify long term workload requirements and fluctuations, and as a result the program has had limited success using these methodologies. Another attempt to compensate for extensive procurement lead times was the establishment of a program-funded Centralized Logistics Support (CLS) in 2005. The idea was to improve parts availability utilizing central procurement and management for all IMAs. This organization's charter was to overcome shortages and improve availability at the IMAs. CLS was disbanded in 2009 as it was deemed too costly. In parallel with CLS efforts, the enterprise attempted various methods to contract with the prime HWT OEM to provide total commercial supply support responsibility for the HWT program without success; the Request for Proposal (RFP) was never issued.

For support of the major FIR hardware items, which are still being produced (CBASS kits), there exists Contract Line Item Numbers (CLIN) on the production contract to buy spare FIRs and repair FIRs. At this time, the quantity of spares procured is based on known failure rates (calculated by the Government) and limited by the available spares budget. The repair CLINs have a small amount of funding available for a "pay-as-you-go," best effort type arrangement with very few requirements and no contractual obligation. The contractor is not responsible to repair the item if he encounters obsolescence issues. As a result, availability suffers as spares are consumed and/or when failure rates exceed anticipated levels.

As the follow-on production contract was being established, a supportability CLIN was proposed, which would have implemented a PBL-like methodology that established a FIR availability requirement at the IMA as the contractor's responsibility. The contractor would negotiate a firm fixed price to provide a defined percentage of availability for the FIRs he produces over a given performance period. This CLIN was not added to the RFP due to the perception that it was not affordable, and that it might limit competition. As a result, the enterprise decided to continue with the established methodology of procuring spares on the production contract in conjunction with repair CLINs.

Several recent papers have highlighted the reluctance of Program Managers to implement the PBL construct within the DoD. In Fowler (2009), a comparison is made between performance-based logistics (also called performance-based life cycle product support) and the fictional superhero Batman. Like Batman, PBL has received a poor reputation because of the unconventional techniques it employs. PBL is usually accused by critics of “contracting out” logistical support through the use of a Product-Support Integrator (PSI). The author points out that the PSI only integrates the product support, and does not eliminate the need for logistical services within the DoD. He further points out that the PSI does not have to be the OEM but can be either a government or industry entity. However, because in most cases the OEM is the PSI, the misconception has developed that the PSI must be the OEM. The author also provides figures showing recent cost and time savings within the DoD, which can be directly attributed to a program’s use of PBL strategies.

Kim, Cohen and Netessine (2007) also recognize the difficulties encountered when seeking to implement PBL contracts. This paper provides guidance with respect to what type of contract should be used in certain contractual situations. In this paper, the authors present a PBL strategy of purchasing the “results of a product” as opposed to buying the actual repair parts, spares, and maintenance activities. Due to its success in the private sector, PBL was implemented in the DoD as the preferred method for purchasing product life cycle support. The PBL approach does not specify how a contractor must support the product, only the required level of support. However, very few contractors have embraced PBL, and the Government Accountability Office stated that savings related to the implementation of PBL could not be demonstrated. With this background, the authors seek to show how a PBL-type contract can be successfully executed based on the participants’ risk strategies. The authors also seek to show which type of contract (fixed-price, cost-plus, or PBL) or combination of contracts is best suited for certain contractual settings. Their results show that if a contractor’s decisions are able to be observed and defined, a fixed-price/cost-plus contract is preferable. However, if the contractor’s services are unobservable and all parties are risk neutral, a fixed-price contract with PBL incentives is best. Lastly, the authors determine that if any of the parties is risk averse, an optimal contract cannot be executed. In this case, the best contract combines elements of each of the evaluated contract types. The models used in this paper to analyze the different contracting environments are an inventory allocation model and the moral hazard model.

The importance of optimizing how we buy and implement supportability is a vital part of the acquisition process. Critical factors impacting procurement of supportability are limited funding from disparate sources coupled with an uncertain time frame in which the OEM is available to provide the spares/repair capability associated with modern torpedoes and for which the OEM holds the product design and repair know-how. As a result, it is more important than ever to implement a sound methodology that can quickly and accurately address our spares requirements. The following section compares and contrasts PBL versus traditional life cycle support.

Pay Me Now, Pay Me Later

When considering the trade-offs between the performance-based contracting approach (pay me now) and the standard contracting approach (pay me later), it is important to analyze several factors associated with the product or system to be acquired. These factors include, but are not limited to, the overall life-cycle cost, the expected future service and spares’ costs, the acquisition’s complexity, and the life-cycle length.

In the standard approach to contract writing, services and spares are purchased post-production as needed. This offers several distinct advantages and disadvantages. Because the costs for future services and parts are not added into the contract’s overall cost, the starting contract cost is reduced. This in turn lowers the budget allocated to the contract, and allows the unused money to be used for other program needs. However, even though the costs of services and spares are not seen in the original contract cost, they are expected to be purchased as needed in the future. This can cause several problems for the customer. First, in the case of products with a long life cycle (let us assume a life cycle greater than 10 years), if replacement parts or spares are needed for the product after manufacturing has ended, the customer has limited (and often expensive) options for obtaining the needed parts. The customer could approach the original contractor about restarting production, which is likely to be more expensive than the original production cost. This is because the part may be obsolete at this point and unable to be sold or used for any purpose other than as a spare. The customer could also approach a new contractor about recreating the original part. This approach can face problems due to lack of know-how, incomplete documentation on the original part, and testing time and money needed to integrate the new part into the original system. The last option would be to design an entirely new part, which could boost the functionality of the system but would most likely be time consuming and expensive to build and test.

In the PBL approach, spares and services based on a performance measure are purchased up-front and included in the cost of the production contract. This approach also has several advantages and disadvantages. The main hurdle to this approach is the early planning to reprogram out-year supportability funding into the current contract year (aka transition year). The transition year necessitates auxiliary funding to pay for the PBL CLIN. This contributes to a perceived increase in the overall contract cost at contract inception. If the negotiated costs associated with the PBL CLIN were equal to or less than the cost of spares, there would be no increased cost to the enterprise. Purchasing services and spares based on a performance measure, such as operational availability, can save money in the long term. The source of auxiliary funding could be the funding currently used to procure spares; this also requires reprogramming money intended for hardware spares procurement to purchase “supportability” services. An additional challenge for the TE is the inconsistency between the production contract period of performance and torpedo life-cycle. The production contract has a period of performance of six years (i.e., one base year, four option years, one warranty year), whereas the torpedo’s life-cycle is 25 to 40 years (although its maintenance due date is significantly less than that). If a contractor is obligated to support and provide a system’s spares for the full life cycle, the disadvantages for the standard contracting approach become the advantages of the PBL approach. The money (and perhaps the time) that would have to be spent in the future is eliminated. It becomes the contractor’s responsibility to determine how the system will be supported. The contractor can manufacture a large surplus of spares and stock-pile them for the future, maintain (or mothball) a small production line to satisfy future demand, and/or build a highly reliable product that minimizes (or eliminates) the need for the first two options.

In conclusion, when determining which contracting method to employ, it is important to determine the complexity, life-cycle length, and expected costs associated with the product being acquired. Simple products that should not require extensive or unique sparing and servicing in the future might be better suited to the standard approach. Likewise, short life cycle products that are not expected to outlive the manufacturing processes producing them might also be better suited to the standard approach. However, complex and extended life cycle products would most likely be better supported and maintained using a PBL contract. The final factor when determining which contract to use is the expected life cycle cost of the system. If the future costs for sparing and services of the system are expected to exceed the extra cost associated with a PBL contract, then a PBL contract should be used. Cost estimates need to consider the future cost of money in this process. After deciding to utilize the PBL contract methodology, contract requirements in the form of metrics must be selected and defined.

A Short Discussion of Common Inventory Metrics

To better understand the status of an inventory's current state and level of effectiveness, an abbreviated list of relevant and commonly used inventory metrics are identified below. The metrics selected (DAU, 2010) are separated into two categories: "Enterprise" and "Source." Enterprise metrics measure the variables determined by the customer, while Source metrics measure the variables determined by the contractor.

First we will discuss the Enterprise inventory metrics. These include:

- Inventory turns,
- Perfect order fulfillment rate,
- Supply chain response time, and
- Weapon non-mission-capable (NMC) rate.

The *inventory turns* metric measures how much inventory is being used compared to the amount of inventory that is on hand (average) over a certain time period. It can be defined as how much of a certain measure of inventory (i.e., monetary worth, amount, or number of assemblies) is removed from the inventory divided by the average of that measure over the time period being analyzed. In the case of the HWT spares inventory being discussed, the spares stored are used to replace parts (FIRs) internal to the product (HWTs). For this reason, the optimal value for the spares *inventory turns* metric is zero, which correlates to an organization that never needs to replace parts internal to its products.

Perfect order fulfillment rate, when related to the organization's inventory, is defined as the ratio of perfectly satisfied orders and total orders filled from the organization's inventory. A perfectly satisfied order is defined as an order delivered with all of the ordered parts in perfect condition, on time and with all of the necessary documentation.

The *supply chain response time* of an enterprise is defined as the average amount of time it takes from recognizing the need for a certain part to the time the part arrives at the organization and is ready for use. This metric can be broken down into more discrete segments such as the time it takes to plan an order, the time it takes to source the part, and the amount of time it takes for the part to be delivered to the organization.

The metric referred to as the *weapon Non-Mission-Capable (NMC) rate* is the ratio of weapons in the fleet that cannot be used to complete their specified mission and the total amount of weapons in the fleet. This is a very important metric for the TE because it helps define the mission readiness of the larger submarine enterprise. If the submarine's primary weapon is not mission ready at an acceptable rate, then the mission readiness of the submarine will be greatly decreased and therefore the mission readiness of the Navy will be adversely impacted.

We will now proceed to discuss some common Source inventory metrics. The following metrics are mostly concerned with the quality of the delivered order and the time it takes for an order to be delivered. They are:

- Percent of perfect order fulfillment,
- Percent of correct quantity deliveries,
- Percent of defect-free deliveries,
- Percent of deliveries with correct documentation,

- Percent of on-time deliveries,
- Total source lead-time,
- Handling lead times,
- Receiving lead time, and
- Supplier lead time.

Percent of perfect order fulfillment if shown in a Venn diagram would be the unity of the percent of correct quantity deliveries, percent of defect-free deliveries, percent of deliveries with correct documentation, and percent of on-time deliveries metrics. These metrics are relatively straight forward to measure and are self defining. The importance of the percent of perfect order fulfillment is that it gives a high-level view of the a contractor's actual order fulfillment capability, while the metrics that make up a perfect order are more granular and point to actual problems the contractor might be experiencing in their order filling process. These insights can then lead to correction strategies for these problems.

The metric *total source lead time* is very similar to the Enterprise metric *supply chain response time*, except that this lead time is calculated from the contractor's point of view. *Total source lead time* can be viewed as the amount of contractor time elapsed, from the time they become aware of an order being placed to the time that order becomes available to the customer. This is equal to the *supply chain response time* minus the time it takes for the customer to recognize its need to order a part and the order being placed.

Handling lead time refers to the amount of time it takes from receipt of a shipment until the individual parts are put in their first official storage positions at the customer's facility. In the case of an order of office supplies, this lead time would be the amount of time elapsed between the shipment being recognized as arriving at the office and the supplies being placed in the supply buffer area.

Receiving lead time is slightly different than *handling lead time*. *Receiving lead time* is the time immediately before *handling lead time*. *Receiving lead time* is the amount of time that elapses between delivery to the customer's facility and the time when the ordering facility recognizes the shipment as being received. Using the office supplies example again, let's suppose that the shipment were delivered to the office building after hours and the box was first found by the secretary the next morning. The time between delivery and the secretary finding the box would be the *receiving lead time*.

Supplier lead time is defined as the amount of time it takes from order confirmation to the time the order arrives at the ordering facility. Again using the office supplies example, if the secretary ordered the office supplies online, this would be the amount of time from when the secretary received the order confirmation e-mail to the time the shipment was left at the office building by the delivery company.

Several other metrics commonly associated with inventories are:

- System Reliability,
- Product Reliability,
- Operational Availability,
- Mean Time to Repair (MTTR),
- Mean Time to Failure (MTTF),

- Mean Logistics Delay Time (MLDT),
- Mean Supply Response Time (MSRT), and
- Mean Accumulated Down Time (MADT).

System reliability refers to the ability of a system to achieve its specified goals and is measured as a percentage value. For the purpose of this discussion, it is assumed that a system is comprised of many products. In our case, the system we are considering is the torpedo and the products are the FIRs. The torpedo's reliability can be calculated by dividing the number of in-water runs in which there are no failures by the total number of in-water runs. It is important to remember that torpedo reliability is determined by the reliability of the torpedo components.

Product reliability is calculated by dividing, at the FIR level, the number of times a product performs its task correctly by the number of times the product is asked to perform its specified task. As stated in the previous paragraph, *product reliability* determines *system reliability*. Therefore, *system reliability* cannot be greater than *product reliability*.

Operational Availability (A_o) is determined by a number of factors, including *system reliability*. *Operational availability* is defined as the percentage of time that a group of products or systems is available to be used for its intended purpose or the percentage of the group's up-time.

Mean time to repair is the expected amount of time it takes from the time a product or system fails until that product or system is available for use again.

Mean time to failure is the expected amount of time a product is available for use after a repair or purchase until the product or system experiences its next major (or debilitating) failure.

Mean logistics delay time is the sum of the two logistical activities at the beginning and end of the *mean time to repair* metric. The first logistical activity is the amount of time from when the product or system fails to the time it arrives at the repair facility and is available for the needed reparatory action. The second logistical activity is the amount of time it takes from the time the repair is completed to the time the product or system is again able to be used by the product's (or system's) owner.

Mean supply response time is the expected amount of time it takes for a product's or system's supply system to respond to, repair or replace, and return the working product/system to the user.

Mean accumulated down time is the time that a group of systems or products is not operational and can be seen as an inverse metric to operational availability.

Metrics are Not a Two-way Street

The relationship between the metrics is illustrated in Table 1. When viewing Table 1 please note that while the metrics on the horizontal X- and vertical Y-axis are the same, the variables on the X-axis are the independent variables and the variables on the Y-axis are the dependent variables. This means that while variable "a" might influence variable "b," variable "b" does not therefore have an influence on variable "a."

This can be understood in Table 1 by considering the metrics “system reliability” and “product reliability” with the assumption that multiple products make up a system. In this case, the reliability of the individual products influences the reliability of the system. However, the system’s reliability does not influence the individual products’ reliabilities.

Table 1.

			Independent Metrics																			
		Optimal Values		%	00%	00%	00%	00%	00%						00%	00%	00%					
	Optimal Values		Inventory Turns	Weapon System NMC Rates	Perfect Order Fulfillment Rate	Percent of Correct uantity Deliveries	Percent of Defect-Free Deliveries	Percent of Deliveries with ect Documentation	Percent of On-Time Deliveries	Supply Chain Response Time	Total Source Lead-Time	Handling Lead Times	Receiving Lead Time	Supplier Lead Time	System Reliability	Product Reliability	Operational Availability	Mean Time To Repair (MTTR)	Mean Time To Failure (MTTF)	Mean Logistics Delay Time (MLDT)	Mean Supply Response Time (MSRT)	Mean Accumulated Down Time (MADT)
Dependent Metrics		Inventory Turns																				
	%	Weapon System NMC Rates																				
	00%	Perfect Order Fulfillment Rate																				
	00%	% of Correct Quantity Deliveries																				
	00%	% of Defect-Free Deliveries																				
	00%	% Deliveries with Correct Documentation																				
	00%	% of On-Time Deliveries																				
		Supply Chain Response Time																				
		Total Source Lead-Time																				
		Handling Lead Times																				
		Receiving Lead Time																				
		Supplier Lead Time																				
	00%	System Reliability																				
	00%	Product Reliability																				
	00%	Operational Availability																				
		Mean Time To Repair (MTTR)																				
		Mean Time To Failure (MTTF)																				
		Mean Logistics Delay Time (MLDT)																				
		Mean Supply Response Time (MSRT)																				
		Mean Accumulated Down Time (MADT)																				

As shown in this matrix, the “availability” metric is affected by many of the other metrics and may serve as a good indicator of the contractor’s performance on a PBL contract.

Newsvendor-based Approaches for Designing PBL Contracts

The newsvendor problem is a single period mathematical model used to determine optimal inventory levels when the demand is uncertain (Porteus, 1991). The model assumes that a decision to procure a certain number of items (***Q***) is made at the start of a period. Subsequently, the random demand (***D***) for the item is revealed. The distribution of ***D*** is assumed to be ***F(D)***, with a mean μ. An ordering/restocking cost of *C* is charged per unit. If the number of items procured exceeds the realized demand, a per unit effective disposal cost of C_H is charged for the period. However, if the demand exceeds the amount procured, a per unit shortage cost of C_P is assessed for the period. An assumption is made that $F(x) = 0$ for $x < 0$. In this scenario, the cost function for one period is:

$$g(y) = Cy + \int_0^y C_H(y-\zeta)dF(\zeta) + \int_y^\infty C_P(\zeta - y)dF(\zeta)$$

The optimal order quantity that minimizes the cost is then computed as:

$$F(q^*) = \left(\frac{C_P - C}{C_P + C_H}\right).$$

Or

$$q^* = F^{-1}\left(\frac{C_P - C}{C_P + C_H}\right)$$

Here, F^{-1} is the inverse of the distribution function. The quantity $(C_P – C)/(C_P + C_H)$ is the critical fractile and is the optimal probability of not stocking out (Porteus, 1991).

The newsvendor problem has been used as a starting point for analyzing many scenarios. A review of some extensions can be found in Khouja (1999). Among the cases that can be related to the analysis of contractor performance are Dada, Petruzzi, and Schwarz (2006); Bensoussan, Feng, and Sethi (2004); Kim et al. (2007); and others. In Dada et al., a newsvendor model is used to structure a scenario when a single newsvendor is served by several suppliers, some or all of whom may be unreliable. This can be used for modeling operations in PBL when several vendors are contracted to maintain a supply of either weapon assemblies or subsystems (FIRS). In Bensoussan (2004), a vendor commits to an initial purchase, following which some estimate of the demand is revealed. Additional purchases can be made for a higher cost, subsequent to which the final demand is realized. An overall service constraint is also satisfied in determining the solutions to the two stages for ordering. In the context of PBL, each stage can represent the ordering decision at the IMA and the manufacturing facility for the vendor, while the service constraint can guarantee the availability. However, as noted by the authors, when there is private forecast information, the mechanism for coordination of the fleet and vendor’s decisions remains to be determined.

As mentioned earlier, Kim et al. (2007) evaluated PBL as a strategy for purchasing the “results of a product” as opposed to buying the actual repair parts, spares and maintenance activities. One of the significant factors identified by the authors when designing incentives for PBL is the observability of contractor performance and the tolerance for risk by the parties involved in the contract.

In Kang, Doerr, and Sanchez (2006), it was noted that PBL specifies outcomes, not numbers of spare parts or hours of maintenance. The emphasis of the contract is on metrics to be achieved by the contractor (in this paper the metrics are operational availability and readiness risk) not the way in which the contractor must achieve the specified metrics. The authors use a simulation to show which alternatives customers should specify to increase operational availability and reduce readiness risk. Their simulation then helps estimate which alternatives will best improve the specified metrics for a given contractual environment. The model shows that transportation/administrative delay is a main determining factor for operational availability, whereas number of spares on the shelf is not.

In the context of torpedo production, under PBL contracts, the interaction between the contractor and the IMA is shown in Figure 2.

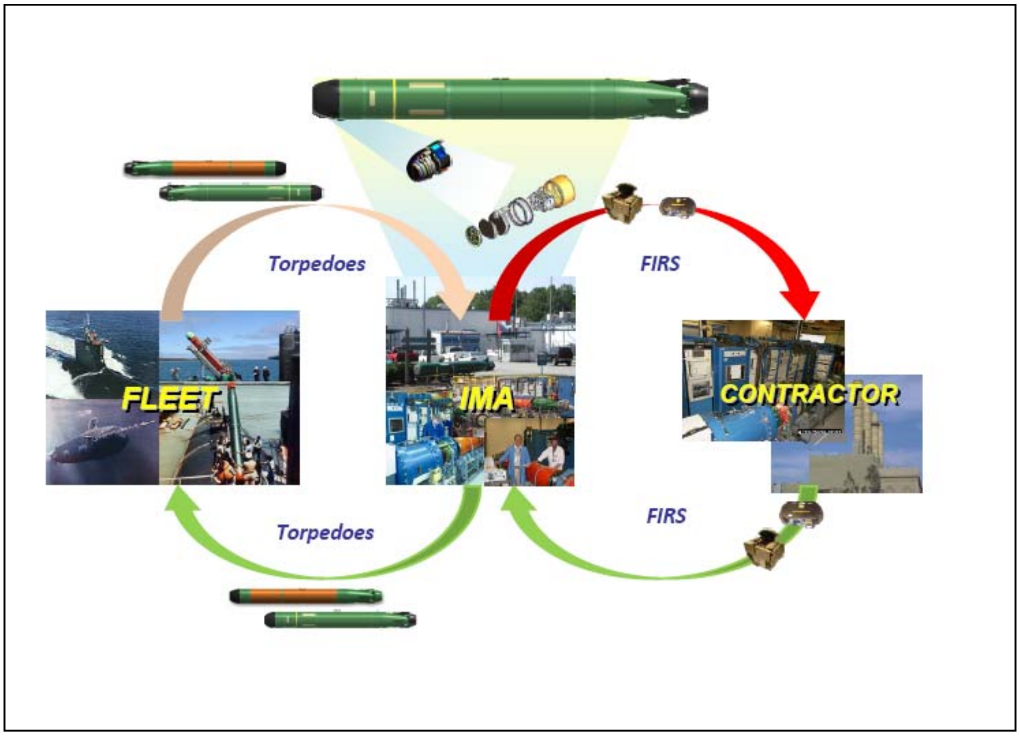

Figure 2. Contractor's Role in the Spares Support Process

The COSAL is the safety stock, and the random demand is generated by fleet usage. The cost of understocking is the total time spent by the IMA waiting for a particular FIR. The cost of overstocking can be assumed to be related to the average amount that it costs a single FIR to be shipped and the cost of managing and maintaining the inventory. Typically, the overstocking cost is low relative to the understocking cost, which implies that the vendor will have an incentive to maintain a large shelf inventory. However, in the context of PBL, the contractor must incentivize lower inventory levels so that the ultimate thrust is on reducing the need for an inventory (i.e. reducing the number of failures during fleet usage).

Simulation-Based Models of PBL Operations

Based on the discussion above, the following protocol for operating a PBL has been proposed: The contractor is made responsible for maintaining spares for the FIRs at the

IMA. The maximum number of FIRs is specified in the COSAL for each IMA, and modifications to the COSAL to meet the required availability can be negotiated as part of this contract. When an incoming torpedo needs a replacement FIR, the inventory status of the FIR is determined by the current availability number in the system (**a**). If **a** is zero or negative, a request for immediate replenishment will be issued to the contractor. If **a** is positive, the spare FIR is removed from the container and issued to the IMA floor. The failed FIR is placed in the empty container and returned to the contractor. The contractor has visibility into the inventory level at each IMA at all times.

Clearly, the COSAL should relate to the failure level of a FIR. If the FIR never fails in service, then the corresponding COSAL value can be set to zero. However, since a zero failure rate is unlikely to be achieved, the COSAL must be set to some positive value. Based on analytical and simulation models and using specified reliability numbers for the FIRs, appropriate COSAL levels can be determined that will achieve desired supportability levels. If the contractor cannot meet availability numbers using the COSAL levels in the contract, this is an indicator that the reliability for the FIR has slipped below the expected reliability, and appropriate action must be taken to address this.

The following measure of performance has been developed for availability for an initial analysis:

$$\text{Availability} = 1 - \frac{\sum^{T} \textit{number of units short}}{\textit{total demand in the quarter}},$$

The performance of this measure is a function of the failure rate, the stock level on shelf, and the variation in failure rates. Based on a hypothetical usage rate in excess of five hundred per year, Table 2, below, shows the results of a simulation exploring the relationship between the failure rate, the variation in failure rate (which would also represent the variation in the demand or number of torpedoes needed per week), and the COSAL values.

Table 2. Simulation Results for Evaluating Interaction of COSAL and Failure Rates

Availability (OPTEMPO = above 500 per year, Logistic Delay = 1 week)												
	Failure Rate Variation											
FIR Failure Rate	25%			50%			75%			100%		
↓	Common Shipboard Allowance Level (COSAL)											
	1	2	3	1	2	3	1	2	3	1	2	3
0.05	96.1%	100.0%	100.0%	96.1%	100.0%	100.0%	87.9%	100.0%	100.0%	76.5%	100.0%	100.0%
0.06	89.7%	100.0%	100.0%	83.9%	100.0%	100.0%	74.3%	100.0%	100.0%	65.8%	100.0%	100.0%
0.07	73.2%	100.0%	100.0%	67.5%	100.0%	100.0%	63.4%	97.8%	100.0%	57.1%	95.7%	100.0%
0.08	63.4%	100.0%	100.0%	59.1%	97.9%	100.0%	54.2%	96.0%	100.0%	48.1%	88.3%	100.0%
0.09	56.5%	100.0%	100.0%	51.5%	97.0%	100.0%	46.4%	94.4%	100.0%	43.7%	85.0%	99.2%
0.1	50.0%	100.0%	100.0%	47.3%	93.6%	100.0%	42.6%	84.4%	100.0%	39.1%	75.4%	98.5%

0.11	47.7%	93.6%	100.0%	41.3%	85.2%	100.0%	40.3%	74.5%	99.3%	35.4%	71.7%	94.6%
0.12	40.9%	86.7%	100.0%	38.5%	77.6%	100.0%	35.4%	70.7%	97.3%	32.7%	65.8%	92.0%
0.13	38.8%	78.8%	100.0%	35.9%	69.8%	98.6%	32.7%	64.6%	93.7%	30.6%	61.5%	88.9%
0.14	36.9%	73.8%	100.0%	34.2%	65.0%	95.5%	30.4%	62.3%	88.8%	27.7%	55.6%	82.0%
0.15	33.5%	70.3%	98.7%	30.4%	62.7%	90.1%	28.4%	58.1%	84.2%	26.1%	52.0%	78.3%

The entries in the table are the average (over 1,000 runs) of the Availability metric for a given failure rate (row label), and a random variation (for now, uniformly distributed–column group header) and different COSAL levels. This simulation, implemented in a spreadsheet, verifies that as failure rates drop, the COSAL required to support fleet operations is smaller. The entries in this sheet could have been computed using a newsvendor approach directly—this did not require simulation. However, the actual nature of variation is somewhat more complicated. The simulation is designed to take variations in exercise rates typically encountered throughout the year and changes in the logistic delay to determine the optimal COSAL required to support the fleet. Furthermore, this simulation can also be used when negotiating with the contractors prior to the award of contract to determine what the contractors' estimates of their own failure rates are and to work with them to set mutually satisfactory expectations.

As mentioned in Kang et al. (2006), the transportation delay correlates most significantly with the operational availability. This is also borne out by the simulations performed above. Because of this, the responsibility for delivery to the shelf is best delegated to the contractor in a PBL setting.

An extension of this simulation allows an optimization of the COSAL required to achieve a given service level. This is not dissimilar to the approaches developed in Schneider (1978) and Shang and Song (2004), but the advantage of the simulation/optimization is that it dispenses with the assumptions of independence of failure rates that are often necessary for analytical solutions and the distributional assumptions that go along as well.

Conclusion

This paper discusses the application of Performance Based Logistics (PBL) contracts for supporting the Torpedo Enterprise. Several performance measures commonly used in PBL contracts are described, and a model is presented that uses an "availability" metric for observing and measuring contractor performance. This metric is calculated using the number of times a required part is not available to field maintenance sites. Terms of the contract are not specified with regard to lead times such as logistical delays and manufacturing and restocking lags. These times are assumed to be under the contractor's control, as are production quantities, quality, and responsiveness. A newsvendor approach for determining optimal shelf inventory levels is developed. An augmented model is evaluated using a simulation to determine the performance sensitivity to changes in product quality, demand rates, and various supply chain-related lead times. Practical collateral issues such as obsolescence, reliability, and cost are also discussed.

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