NPS-LM-12-192

ACQUISITION RESEARCH SPONSORED REPORT SERIES

Total Life Cycle Management for the Special Operations Craft Riverine

4 December 2012

by

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Prepared for: Naval Postgraduate School, Monterey, California 93943

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **04 DEC 2012**	2. REPORT TYPE	3. DATES COVERED **00-00-2012 to 00-00-2012**

4. TITLE AND SUBTITLE **Total Life Cycle Management for the Special Operations Craft Riverine**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Graduate School of Business & Public Policy,555 Dyer Road, Ingersoll Hall,Monterey,CA,93943**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	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
Naval Special Warfare Group 4 (NSWG-4) provides Special Operations Craft Riverine (SOCR) and boat crews for operational use within Special Operations Command (SOCOM). In this report, we analyze the logistics support provided for these craft. We review the literature dealing with life cycle cost, life cycle management, operational availability, and repair kitting as they relate to the logistics support for the SOCR. We create a model for determining required pre-staged inventories needed to maintain an objective availability for SOCR. We also create a simulation to analyze the impacts of parameters affecting operational availability. We use the literature review and data analysis to inform recommendations to improve logistics support for the SOCR.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**95**	

The research presented in this report was supported by the Acquisition Research Program of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

ACQUISITION RESEARCH PROGRAM
GRADUATE SCHOOL OF BUSINESS & PUBLIC POLICY
NAVAL POSTGRADUATE SCHOOL

ABSTRACT

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ACKNOWLEDGMENTS

In the last 18 months of our education at the Naval Postgraduate School, we have been taught, mentored, assisted, and enabled by a multitude of people. It is fitting that we acknowledge just some of those who have made our education possible.

First and foremost, we acknowledge our families, who have provided the backbone and support for our careers and enabled us to get to the Naval Postgraduate School, and who have provided the hard work and dedication during our studies to enable us to focus on our learning. This contribution cannot be understated.

All of our professors have been the medium by which we have been able to achieve our education at the Naval Postgraduate School. We are grateful for all of their dedication and professionalism. More specifically, we thank Professors Keebom Kang and Michael Boudreau for advising, mentoring, and guiding our efforts in this project. They have brought our learning and education across the bridge from academia to practice and have provided relevance and understanding to the concepts they have taught us.

We would like to thank Commander Hawks for allowing us to use the SOCR program as a platform for research and for making available all the resources needed for this project.

Karl LaBauve and Vice President Tom Bunce provided invaluable knowledge, data, and insight into the SOCR program. Their technical expertise and guidance truly was the driving force that got our project off the ground. We thank them and the entire USMI family.

Finally, we thank the Acquisitions Research Program for accepting this project and providing the resources necessary for us to complete it.

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ABOUT THE AUTHORS

Captain Travis S. Bowser enlisted in the Marine Corps in 1995. During his enlisted tour in the military occupational specialty of supply administration, he was stationed at various duty stations including Headquarters Battalion 2nd Marine Division, Camp Lejeune, NC; III MEF Headquarters Group and Headquarters Battalion Marine Corps Base, Okinawa, Japan; and Newport, RI.

In 2006, he graduated from the University of Houston in Houston, TX, where he received a Bachelor of Science in economics, Bachelor of Business Administration in finance, and a Bachelor of Business Administration in marketing, all cum laude. After graduating from the University of Houston and receiving his commission, he continued to serve in the supply field as a supply officer.

After occupational specialty training, Capt Bowser served with 1st Battalion 5th Marines and deployed to Operation Enduring Freedom in Afghanistan in 2009. Upon return, he served as the supply officer and then as the Headquarters and Services company commander at 3D Assault Amphibian Battalion in Camp Pendleton, CA.

After completion of his Master of Business Administration at the Naval Postgraduate School, he will report to United States Marine Corps Logistics Command in Albany, GA.

He is married to the former Allison Gray of Cumberland, RI, and they have five children: Chance, Christopher, Jacob, Chloe, and T.J.

Captain Nathan Whitman Hatfield graduated in 1996 from Sequim High School and enlisted in the United States Marine Corps. During his enlisted service, he served with Alpha Company, 1st Light Armored Reconnaissance Battalion as an infantry scout. During this tour, he deployed with the 15th MEU(SOC) in 1997 and the 13th MEU(SOC) in 1998/99. He also deployed on a RIMPAC exercise in 1998. He received an honorable discharge and was transferred to Inactive Ready Reserve in February 2000.

In 2004, he graduated from the University of Washington, where he graduated cum laude with a degree in business administration (accounting) and returned to active service in the Marine Corps as a logistics officer.

As an officer, he has served as a motor transportation officer and an assistant logistics officer at 5th Air Naval Gunfire Liaison Company, as a general support motor transportation company commander at Combat Logistics Regiment 3, as a support company commander at Combat Logistics Battalion 4, and as a regimental logistics officer and a headquarters company commander at Combat Logistics Regiment 3.

He deployed to Operation Iraqi Freedom in 2007 and 2009.

After completion of his Master of Business Administration at the Naval Postgraduate School, he will report to United States Marine Corps Logistics Command in Albany, GA.
He is married to the former Catherine Simmons of Blackwater, Australia, and they have a daughter, two sons, and another son on the way.

Captain Lasse Horvik is a Norwegian Air Force supply officer with a background in logistics. He has served in both Norwegian and NATO commands since 1996. He started his military education as a conscript, after 3.5 years at the University of Oslo, where he studied physics and mathematics. His military education consists of a basic officer training course, and two years at both the basic and advanced level of the Royal Norwegian Air Force Academy. He also studied logistic and organizational development for an additional 1.5 years at Molde University College and at University of Tromsø during his service in the air force.

Capt Horvik volunteered for the first Norwegian Detachment during Operation Enduring Freedom in 2002 with a Norwegian C-130 Detachment to Manas Air Base, Kyrgyzstan. Since 2004, he has served as a supply squadron commander at Gardermoen Air Base, as a material manager at the Norwegian Logistics Defense Organization, and as a supply officer at the NATO AWACS Headquarters at Shape, Belgium.

After graduation, he will report to the Norwegian Defense Logistics Organization as a Foreign Military Sales (FMS) coordinator.

He is married to Ingunn Hågård Kvaale, a former air force fighter controller, and they have a son and a daughter, ages three and five.

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LIST OF ACRONYMS AND ABBREVIATIONS

A_O	Operational Availability
ALDT	Administrative Logistics Delay Time
AT-LAST	Aviation Total Life-Cycle Analysis Software Tool
CBM	Conditions-Based Maintenance
CM	Corrective Maintenance
CONUS	Continental United States
DDP	Detachment Deployment Package
D-Level	Depot Level
DLA	Defense Logistics Agency
DoD	Department of Defense
DSS	Decision Support System
ECP	Engineer Change Proposal
FMC	Full Mission Capable
GFE	Government-Furnished Equipment
GSA	General Services Administration
LCA	Life Cycle Analysis
LCC	Life Cycle Cost
LCM	Life Cycle Management
LMDSS	Logistics Management Decision Support System
LSC	Life Support Cost
MCT	Mean Corrective Time
M_{CMT}	Mean Corrective Maintenance Time
MDT	Mean Downtime

MIPR	Military Interdepartmental Purchase Request
MPT	Mean Preventive Time
MST	Maintenance Support Team
MTBCF	Mean Time Between Critical Failures
MTBF	Mean Time Between Failures
MTBM	Mean Time Between Maintenance
$MTBM_u$	Mean Interval of Corrective Maintenance
$MTBM_s$	Mean Interval of Preventive Maintenance
MTTR	Mean Time to Repair
NAVAIR	Naval Air Systems Command
NAVSUP	Naval Supply Systems Command
NMCT	Non-Mission Capable Time
NSWCCD	Naval Surface Warfare Center, Combat Craft Division
NSWG	Naval Special Warfare Group
O-Level	Operational Level
O&S	Operations and Support
PBL	Performance-Based Logistics
PIO	Provisioning Item Order
PM	Preventative Maintenance
PSM	Product Support Manager
R&D	Research and Development
RAB	Riverine Assault Boat
RAM	Reliability, Availability, Maintainability
RM&S	Reliability, Maintainability, and Supportability
SBS	Shore-Based Spares

SBT	Special Boat Team
SL	Service Level
SLEP	Service Life Extension Program
SOCOM	Special Operations Command
SOCR	Special Operations Craft Riverine
TLC	Total Life Cycle
TLCM–AT	Total Life Cycle Management–Assessment Tool
TOC	Total Ownership Cost
USMI	United States Marine Incorporated
WLC	Whole Life Cost
WSMIS	Weapon System Management Information System

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I. INTRODUCTION

A. BACKGROUND

1. System Description

Naval Special Warfare Support Group 4 (NSWG-4) provides Special Operations Craft Riverine (SOCR) and boat crews for operational use within Special Operations Command (SOCOM). NSWG-4 needs a craft with new capabilities, such as improved speed, weapons, and armor, that could be deployed quickly anywhere in the world. The SOCR system is air transportable and replaced Vietnam-era craft. This small, fast, armed, and armored combatant riverine craft is operated by a four-man crew and can insert and extract eight SEALS in a riverine environment.

These craft are purchased by SOCOM under contract from United States Marine Incorporated (USMI) as a complete self-supporting weapon system. In addition to the craft, the weapon system consists of trucks as prime movers, trailers, detachment deployable packages (DDPs), integrated logistics support, and shore-based spares (SBS). The DDP consists of an ISU-90 container stocked with a notional supply of spares and repair parts designed to support an SOCR detachment during a 90-day deployment. The trailer, craft, and truck combination is capable of being loaded into C-130, C-141, C-17, and C-5 aircraft. Special Boat Team 22 (SBT-22) operates the craft. Figure 1 shows an SOCR detachment, which consists of two craft, two prime movers, two trailers, one DDP, integrated logistics support, two boat crews, and a maintenance support team (MST).

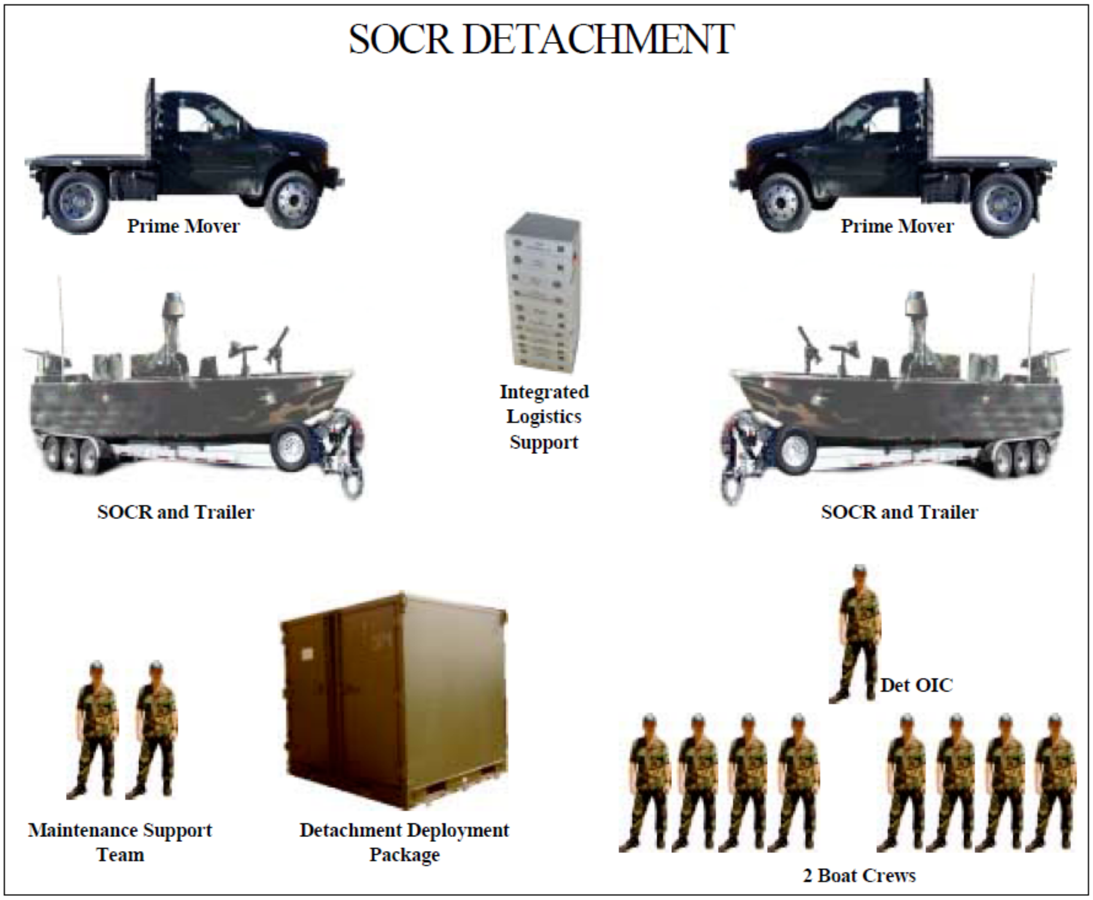

Figure 1. SOCR Weapon System
(SOCOM, 2002, p. 3)

The SOCR is 33 feet long overall, with a 9-foot beam aluminum hull. The craft is powered by twin turbocharged/aftercooled, six-cylinder marine diesel engines mounted side by side, with two water jets located on either side of the center line. The SOCR is provided with armor designed to protect against 7.62 mm x 39mm rifle fire. Table 1 is a summary of the SOCR characteristics.

Table 1. SOCR Characteristics
(SOCOM, 2002, p. 4)

Nomenclature	Characteristics
Length, overall	33 feet
Beam	9 feet
Top speed	40+ knots
Cruise speed	30+ knots
Range at cruise speed & full load	195+ nautical miles
Variable payload	4200 pounds
Full load	19,000 pounds
Armored load	20,500 pounds
Fuel capacity	190 gallons
Construction	Aluminum hull w/ FRP accessories
Engines	Yanmar 6LY2M-STE diesel, 440 HP @ 3300 RPM
Engine duty cycle	3300 RPM intermittent, 2850 RPM continuous
Marine gears	ZF IRM220, 1.237:1 reduction
Water jets	Hamilton HJ-292 w/ 17 kW impeller

2. Logistics Support

NSWG-4 maintains several varieties of craft within their subordinate units, some of them supported by the Defense Logistics Agency (DLA) and Naval Supply Systems Command (NAVSUP). Currently, the SOCR is not supported by either the DLA or NAVSUP, and SBT-22, as the owning unit, must provide all logistics, administrative, and maintenance support for the SOCR. When Department of Defense (DoD) service components purchase weapon systems through the normal acquisitions process, the DLA becomes the strategic-level logistics support activity. The DLA maintains the relationship between the DoD and suppliers to ensure that logistics support is available and provided to the operational level of logistics. At the operational level, which can be defined as theater/regional-level logistics, the service components must support the subordinate tactical commands. In the case of NSWG-4, NAVSUP is the logistics activity responsible for providing operational logistics support. Because the SOCR is not supported by the DLA, NSWG-4 must provide the tactical-level logistics outside of the strategic and operational logistics support structure. Figure 2 displays the direct and supporting relationship for logistics support.

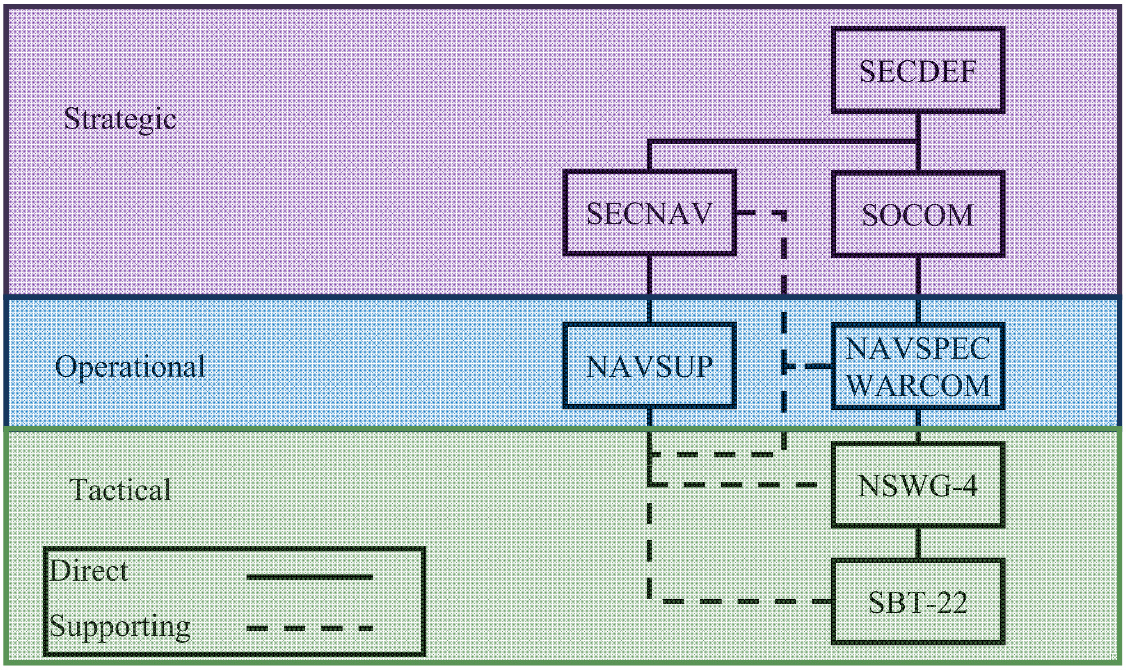

Figure 2. Operational Chain of Command

3. Maintenance Support

Through interviews with the government representative and management at USMI, we also gathered information about the maintenance and support concept for the SOCR. Maintenance for the SOCR is separated into two main categories: organizational level (O-level) and depot level (D-level). SBT-22 is able to do corrective maintenance (CM) and preventive maintenance (PM). USMI conducts the mid-life Service Life Extension Program (SLEP)—which is D-level maintenance—and they also perform programmed PM procedures that are scheduled for intervals that are six months or longer.

a. Organizational-Level Maintenance

The SOCR fielding plan (SOCOM, 2002) described the O-level maintenance as "a blend of operation, condition monitoring, planned maintenance actions and corrective maintenance actions" (p. 17). SBT-22 is responsible for all O-level maintenance; however, provision has been made in the purchasing contract that allows all scheduled

PM with intervals of six months or longer to be contracted out to USMI at the discretion of SBT-22 maintenance officers. The craft follows a repeating 24-month PM schedule and is sent to USMI for PM every six months to complete required checks and services that are due.

SBT-22 has the capability to fully support the maintenance requirements for SOCR weapon systems for O-level maintenance. As depicted in Figure 3, when deployed, SBT-22's organic capabilities are the only resources available. In garrison, SBT-22 performs PM and is responsible for emergent CM repairs.

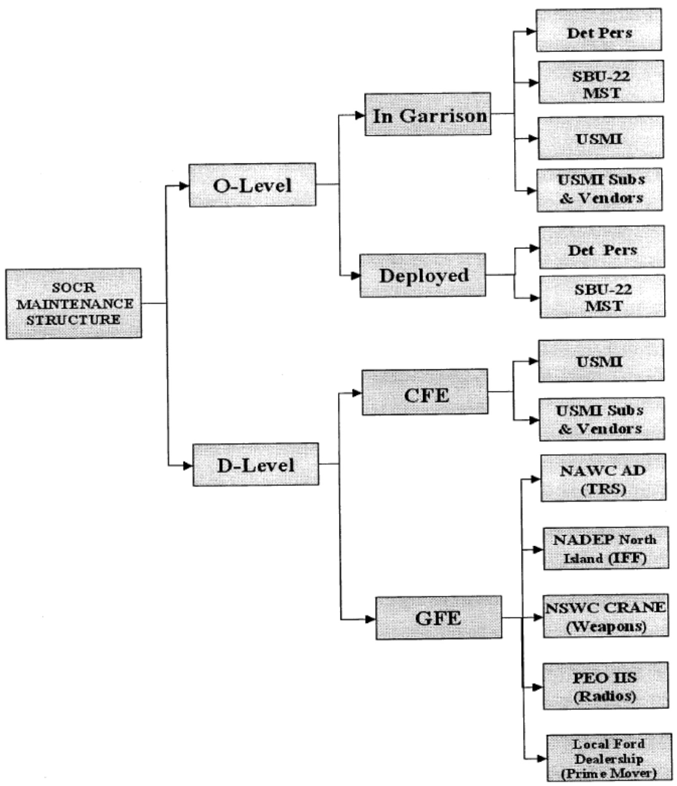

Figure 3. SOCR Maintenance Structure
(SOCOM, 2002, p. 18)

USMI-scheduled maintenance is based on a fixed-price pay-as-you-go service contract for specified PM and CM. Under this contract, there are fixed-price, menu-driven, PM procedures in place for six months or longer that USMI specifies and completes. When emergent CM is required, USMI provides a quote for costs on *conditions found* repairs, as well as a fixed fee, before receiving permission to conduct repairs. *Conditions found* encompasses any required maintenance that is identified during USMI's comprehensive checks and services process. Examples of *conditions found* repairs are dishing of the hull due to impacts in the water, CM of engine and drive train components found to be defective, or missing basic issue items. In addition to—but outside of—this support contract, all major systems within the craft are covered by a one- to five-year warranty on manufacturer defects. The contract for support with USMI is written by the SOCOM contracting office.

b. Depot-Level Maintenance

D-level maintenance is described in the fielding plan as maintenance that

> consists of overhaul and refurbishment of selected components and accessories (major engine overhaul, AN/APX-100 Transponder Set refurbishment, etc.), major repair actions (major hull repair, console replacement, etc.) and the accomplishment of directed maintenance actions such as Engineer Change Proposal (ECP) installation. (SOCOM, 2002 p.19)

The hull is designed to last for seven years, and between the three- and four-year marks of its service life, a mid-life SLEP allows for a refurbishing of the hull along with all installed systems. The SLEP takes 60 days on average, at a cost of $200,000 per craft on average.

4. Deployment Support

When riverine craft such as the SOCR deploy, they bring with them organic maintenance support called an MST. These MSTs are part of the organizational structure at SBT-22 and are available for use during garrison operations. In terms of training and equipment, NSWG-4 is capable of conducting maintenance up to major component replacement. To facilitate short lead-time for PM and CM, DDPs are an integrated part of the SOCR weapon system package. In these DDPs, there are pre-positioned parts based on anticipated need. Historically, when riverine craft have been deployed to combat, extra craft have also been maintained to ensure a higher level of availability for missions. For example, when SBT-22 deployed SOCR craft to Iraq, four craft were required for operational commitments; however, six craft were deployed to theater. If one of the operational craft becomes unserviceable, these additional craft are used until repairs can be conducted with parts from the DDP. As a final option, an additional craft can be flown from inventory held in the continental United States (CONUS). One additional option that is advertised by USMI, but has not been exercised, is *tiger team* support. This would be used in a situation in which USMI provides a maintenance team to travel to the deployed location and conduct necessary repairs.

5. Procurement of Materials

a. Financial Accountability

The procurement of parts for SBT-22 happens through funding passed from NSWG-4 to SOCOM through a military interdepartmental purchase request (MIPR). SBT-22 completes requisition requests for repair parts, which are sent to SOCOM for approval and then charged against the balance remaining on the MIPR. This system puts the financial responsibility for the SOCR on NSWG-4 but the administrative oversight and approval authority for expenditures on SOCOM.

b. Provisioning Order Items

Because the SOCR is not supported by the DLA and because there is a high volume of purchase requests that are processed every year, there is a provisioning items order (PIO) list. This list is generated once per year for all parts that would normally be line-item provisioning items supported by the DLA. The parts are competitively priced against competing vendors. The price is then fixed for the period of one year. USMI maintains these parts in inventory and then delivers the parts based on purchase requests received from SBT-22. Because USMI has an open production line and ongoing service contract maintenance, they already maintain an inventory of the parts on the PIO. They are able to provide the most competitive prices for these parts because they pass on their manufacturers' discounted price to SBT-22, with a 3% administrative markup (Bunce, 2012). Other vendors for these parts would normally be expected to charge a significantly higher profit margin.

B. PURPOSE OF RESEARCH

The purpose of this research is to develop an understanding of logistics support provided for the SOCR under the current structure and to evaluate how this logistics support compares with best business practices and support models currently in use with the objective of providing recommendations, which will optimize availability given the resources applied. We focused our research on the following four main areas:

- developing an understanding of the current logistics structure,
- identifying logistics concepts and models currently in use,
- exploring models for providing logistics support currently in use and identifying as best business practices, and
- providing recommendations for improving logistics for the SOCR and potentially for applying these models to other equipment in the DoD.

C. RESEARCH QUESTIONS

In order to provide recommendations to NSWG-4, we sought to answer the following research questions:

- What are the current logistics concepts used in supporting the SOCR?
- Is the current logistics support optimal?
- What are alternative or improved logistics models that could be applied to the SOCR?

D. BENEFITS OF RESEARCH

Through this research, we detail the current logistics structure for the SOCR, enabling management decision-making concerning risk and mission requirements. We also identify recommendations that might be applicable to all low-density equipment not supported under the DLA or O-level logistics support activities. The theoretical concepts applied and identified in this report will help decision-makers who plan logistics support.

E. LIMITATIONS OF RESEARCH

Life cycle cost encompasses cradle-to-grave cost. In this project, we recognized these costs, but there are three main cost areas that we did not address:

- Costs that are too broad to address. An example of this would be the cost of disposal. Historically, SOCR have been disposed of through sales to other government agencies or foreign militaries. Including these costs would require data and cooperation from multiple agencies, to include the State Department.
- Other costs that have already been realized by the government and are no longer part of the decision-making process. Research and development (R&D), test and evaluation, personnel, training, and acquisition costs have already been expended for this craft.
- Costs for which there is insufficient data. An example of this is mean time between failures (MTBF) for individual components. For this reason, the MTBF must be imputed using analytical means and requires analysis at an aggregate level rather than an individual component level.

The acquisitions process includes many different agencies, stakeholders, or players. We did not address all of these players and how they interact; instead, we focused our attention on the interaction between NSWG-4/SBT-22 and USMI.

F. METHODOLOGY

We conducted this research by collecting data from NSWG-4, SBT-22, and USMI. We collected both qualitative and quantitative data. The qualitative data described the support structure in place and background information about the SOCR weapon system. This data was focused on providing an overview and descriptive picture of the total life cycle (TLC) support for the SOCR. The quantitative data was a two-year history of parts requisitions and maintenance support provided for the craft and historical readiness information. This data allowed the application of theoretical models to the logistics support problem. Through our research, we applied prior research from literature review and logistics support concepts to the SOCR.

G. ORGANIZATION OF REPORT

We have organized this report into five chapters. In this first chapter, we have described the SOCR as a system and provided background on the current life cycle support for the SOCR. The chapter has laid out the purpose for our research, the benefits we expected from the research, and the research questions that we intended to answer through this project. Due to the complex nature of TLC sustainment, we also have discussed the limitations of our research.

In Chapter II, we present a literature review of research pertinent to life cycle sustainment and the logistics support for the SOCR. In this chapter, we review prior research dealing with life cycle management (LCM), A_O, logistics decision support systems (DSS), and repair kitting. In addition, Chapter II provides an academic understanding of the concepts relating to the research questions.

In Chapter III, we discuss research methodology, including what type of data we needed to gather in our research, how this data answers our research questions, what we were able to gather, and how the data applies to our analysis.

In Chapter IV, we analyze the data in relation to best business practices and the current system being employed. We use analytical methods in relation to the current practices and provide models for management decision-making.

In Chapter V, we provide recommendations for the application of the logistics concepts and best business practices. We also identify areas of further potential research.

H. SUMMARY

In this chapter, we reviewed the SOCR program and the current logistics support. We provided a background for the program with a specific focus on the areas we analyzed in this project. We stated the purpose of this research and the benefits it will provide. We described the methodology we used in the research and the organization of the report. In the next chapter, we discuss the academic concept and research pertaining to the areas we covered in Chapter I.

II. LITERATURE REVIEW

A. INTRODUCTION

In this chapter, we discuss the academic concepts and research pertaining to our research questions. We review in depth the concepts that we focus on in this MBA report. Our literature review is purposely broad and includes many factors that contribute to life cycle costs (LCCs) and other areas pertinent to the SOCR. We use our literature review in development of a model. Our model gives both cost and readiness for SOCR based on the concepts discussed in our literature review. By keeping our literature review broad and creating a specific application in our model, other low-density systems can use our research to apply the model to their system.

B. LIFE CYCLE COST AND TOTAL COST OF OWNERSHIP

1. Introduction

In *Integrated Logistics Support Handbook*, James Jones (2006) discussed cost of ownership and the key elements that factor into this important topic:

> The prediction of the total costs that will be incurred throughout the life of a system, or any other equipment, procured serves an important role in the acquisition process. It is a valuable aid in making decisions about different options or alternatives related to the design characteristics of the system, the support infrastructure to support the system, and the physical resources required to operate and maintain the system. The concept of cost of ownership is used to project the future financial obligations and liabilities that will be necessary to own the system. The use of cost of ownership during acquisition focuses on total costs over the life of the system rather than just purchase price. Supportability engineering uses various methods to predict cost of ownership during acquisition to identify significant issues that cause costs to rise so that these costs, and the factors that contribute to them, can be analyzed for determination of ways in which they can be reduced without lowering performance or operational availability. (p. 171)

2. Cost of Ownership

Jones (2006) defined cost of ownership as "the total of all costs incurred to own and use a capability including research and development costs, acquisition costs, operating costs, support costs, and disposal costs" (p. 171). Jones continued, "There are three basic concepts used by supportability engineering to estimate cost of ownership: Life cycle cost (LCC), through life cost, and whole life cost (WLC). Each of these methods have different purposes and applications during acquisition" (p. 171). Jones defined LCC as "a technical process which compares the cost of the relative merits of two or more options" (p. 171). The Defense Acquisition University defined LCC as "the total cost to the government of acquisition and ownership of a system over its useful life. It includes the cost of development, acquisition, operations, and support (to include manpower), and where applicable, disposal" ("Life Cycle Cost," n.d.).

The DoD has directed that new acquisitions programs be evaluated using LCC. LCC includes development cost, production cost, operating and support cost, and program disposal cost (McArthur & Snyder, 1989). By using LCC, both suppliers and government agencies are able to assess the full cost of ownership for a proposed program. This is particularly important for military acquisitions programs because budgets are approved on an annual basis; yet, unless the program is cancelled, the cost of an acquisition and sustainment will continue into future years. With LCC, analytical techniques differentiate between those costs associated with procurement, such as development and production costs, and those that will be associated with sustainment, such as operating, support, and disposal costs (McArthur & Snyder, 1989). Generally, procurement costs will be a near term investment and sustainment costs will be allocated over the useful life of the acquisition.

Sustainment costs are also referred to as operations and support (O&S). O&S costs are often the largest input for an LCC estimate. For this reason, O&S estimates are of particular importance when designing a potential acquisition (McArthur & Snyder, 1989). An example of O&S would be fuel consumption. If the Navy sets an upper limit on the LCC of a new conventionally powered vessel, fuel consumption over the lifetime of that vessel can be greater than the cost of building the vessel, especially if the vessel is intended for worldwide service. For this reason, a supplier may make a design decision in order to meet the cost limits set by the Navy. Because personnel, material, and facilities are all elements of O&S, it is easy to see that there are many variables operating under one cost constraint.

When procurement is made without considering LCC, the buyer may not understand that the sustainment cost is likely to be two or three times the cost of the original purchase. In addition, the cost drivers for sustainment may also be unknown. Purchases are made through the General Services Administration (GSA), not through the DLA. Considering the benefits of knowing the LCC as well as the cost drivers, many institutions—both private and public—use an LCC approach. LCC estimation is required by law and regulation when acquiring DoD major weapon systems.

In their 2002 article "Total Cost of Ownership Models: An Exploratory Study," Ferrin and Plank stated that total ownership cost (TOC) data is not readily available. What is available is TLC support information that addresses responsibility and procedures for the support of the SOCR but not the associated LCC involved. This makes the information available for the SOCR craft *normal* rather than *abnormal*, in terms of Ferrin and Plank's (2002) article. Military procurements that go through acquisitions programs can be classified as capital goods in the private sector (purchases that would be capitalized and depreciated over time). In Ferrin and Plank's (2002) survey, only 28.8% of respondents indicated that they used TOC estimates. Many of the responses indicated that they try to use TOC but "believe they are struggling in their attempts to use TOC valuation logic in supply management, or at best doing an average job" (Ferrin & Plank, 2002, p. 24). Ferrin and Plank (2002) further identify the reason these firms are struggling: because of the difficulty in determining TOC drivers. If a firm is not able to accurately determine the drivers, or if the drivers are too complex, a firm may not feel confident in the estimate. Another challenge to identifying cost drivers is the open-ended nature of the estimate; there is not a defined list of cost drivers to calculate, which can lead to omission of large cost drivers or a large quantity of smaller cost drivers, which, in aggregate, account for a large amount of TOC.

These open-ended cost drivers are demonstrated in the responses that Ferrin and Plank (2002) received: "A total of 73 responses generated a list totaling 237 cost drivers, with individual respondents providing between one and six cost drivers" (p. 24). With so much variation in response, Ferrin and Plank (2002) sought to categorize all the cost drivers and came up with 13 main categories.

Ferrin and Plank (2002) concluded that TOC is a very difficult process for a firm. It is easy to see that there are large benefits for firms able to conduct TOC; therefore, firms "are making significant efforts at TOC valuation" (Ferrin & Plank, 2002, p. 28). They also concluded that the large variation in cost drivers, as well as the way they are categorized, makes it very unlikely that a standardized model for TOC can be made. A standardized model is further complicated by variation from industry to industry.

In their 1998 article "Total Cost of Ownership: A Key Concept in Strategic Cost Management Decisions," Ellram and Siferd identified the means in which different firms determine their cost drivers for TOC. They also identified that data availability is a common challenge for all firms. Firms develop automated systems, establish common cost information, or create teams to gather data from suppliers, manuals, and automated systems (Ellram & Siferd, 1998).

In this section, we discussed the complexity of calculating TOC and the importance of TOC as it relates to private firms. For the DoD, calculation of LCC is mandated in law through the Weapons Systems Acquisition Reform Act of 2009, and the means of LCC determination are directed by law. Operational costs are estimated as costing 60–85% of a typical DoD system. Our discussion of TOC as it relates to Ferrin and Plank (2002) and Ellram and Siferd (1998) emphasizes that the challenges of accurate LCC calculations are not unique to DoD.

For the SOCR, we have identified only operational costs as the relevant costs for this project because the government has already absorbed the development and purchasing costs, and those costs cannot be changed at this point. Likewise, the disposal costs are an obligation made at the purchase of the SOCR, so disposal costs are not germane to NSWG-4's decision processes. By using cost drivers in determination of the

O&S costs, NSWG-4 will be able to determine activity cost. Additionally, these cost drivers will contain data useful in determining material support needed for the SOCR.

3. Life Cycle Cost Categories

The DoD 5000.4 manual, *Cost Analysis Guidance and Procedures* (Office of the Assistant Secretary of Defense [Program Analysis & Evaluation], 1992), defined LCC categories to use when viewing LCC. These categories are R&D, investment, O&S, and disposal. Jones (2006) further defined the categories of TLC phases as the following: concept, assessment, test and select, design and manufacture, operation, and disposal.

R&D includes costs for all research and development, from program initiation through the full-rate production decision. During this R&D phase, acquisition managers must predict the cost of ownership. Jones (2006) discussed this and referred to it as "presystem acquisition stage."

In terms of this project, the R&D/presystem acquisition stage, as well as the investment stage has already occurred. We focus on the O&S category. With that said, understanding the R&D and investment stages are important to fully understand the TLC cost of the SOCR.

The bulk of LCC occurs in the O&S category. It is important to look at direct costs within the O&S category. This category was the most significant for our focus within this project. Jones (2006) defined direct costs as follows: "Any cost that has a direct relationship to the operation or support of a system is considered a direct cost" (p. 174). Jones (2006) emphasized that costs for personnel and training are an important direct cost.

Movements of the SOCR to include the craft itself, as well as the parts necessary to maintain it, are direct costs. Jones (2006) stated, "Packaging, handling, storage, and transportation costs include all movements of the system due to operation or maintenance needs after initial delivery, and the movement of spares and repair parts between maintenance facilities, supply facilities, and the user" (p. 176).

Lastly, an important direct cost that we addressed in this project is engineering costs with relationship to militarizing the maritime craft to fit the needs of the user. Jones (2006) defined these costs as "All engineering changes and other modifications to the system that occur after deployment are direct O&S costs. Modification costs are considered sustaining investment costs that are necessary to enhance the reliability, maintainability, supportability, or operational capabilities of the system" (p. 175).

A final category within the LCC is disposal. Jones (2006) stated,

> A cost element that is often ignored is the cost of disposing of a system as it becomes obsolete or is replaced. In some instances, the equipment may have salvage or resale value which may offset the cost of disposal[;] however, costs can be incurred. (p. 176)

Within this project, demilitarization may occur. Jones (2006) defined demilitarization as "the act of rendering an item useless for military purposes. Government regulations require that certain classes of items be demilitarized before disposal. If the system being disposed of requires such actions, then the costs are accrued as disposal costs" (p. 176).

Jones (2006) summarized the steps within understanding LCCs in terms of what percentage of cost of ownership goes into each phase:

> The actual cost of ownership of every system is different and may vary greatly; however, the ratio between R&D, investment, O&S, and disposal for most system[s] tends to be similar. This similarity has been the subject of many studies. The general consensus of these studies suggests that, for an average system, 2 percent of cost of ownership occurs during R&D, 12 percent during investment, 85 percent during O&S, and 1 percent during disposal. These studies also suggest an even more important point, that is, when decisions are made the[y] effect cost of ownership. (p. 176)

Figure 4 illustrates some of the unseen items that go into total cost visibility. Again, we addressed some of these items in this project and not others. It is important to try to estimate all possible items that contribute to the total cost of the SOCR's life cycle.

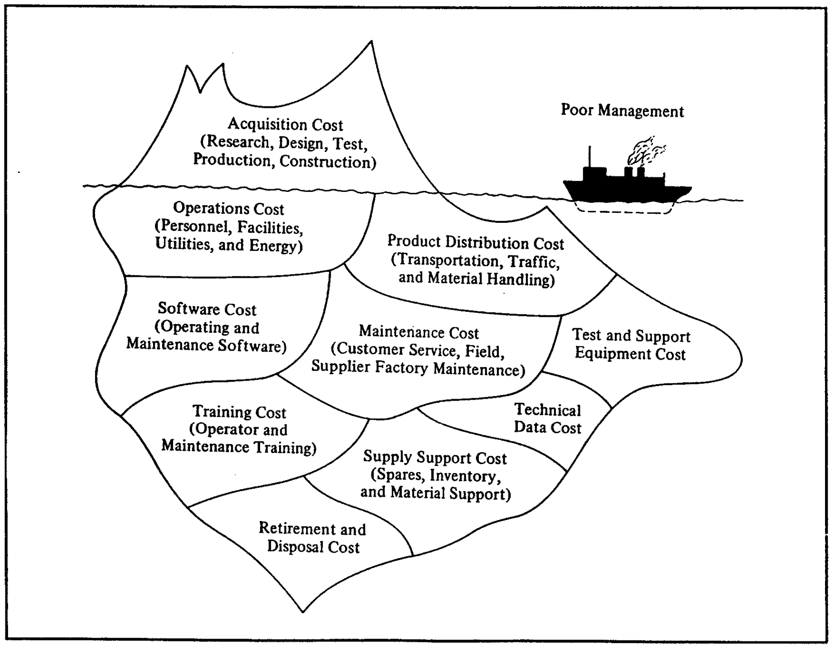

Figure 4. Total Cost Visibility
(Blanchard, 2004)

In this section, we discuss the life cycle cost categories addressed by private firms. For DoD systems, the Office of Secretary of Defense has provided guidance in the *Product Support Manager Guidebook* (2011) for identifying areas that will be used for estimating support requirements. The *Product Support Manager Guidebook* identifies these areas as the 12 Integrated Product Support Elements. These elements are intended to be inclusive of the life cycle cost categories identified in Jones (2006).

C. LIFE CYCLE MANAGEMENT

1. Integration and Optimization

With regard to President Barack Obama's approval of the Fiscal Year 2010 National Defense Authorization Act (NDAA; 2009), and especially Section 805, Life Cycle Management and Product Support, Kobren (2010) argued that the government again addressed the importance of keeping cost down while meeting the warfighters' readiness demand. The legislation states that "every major weapon system shall be supported by a product support manager (PSM)" and that the Secretary of Defense shall issue a "comprehensive guidance on life-cycle management and the development and implementation of product support strategies for major weapon systems" (Kobren, 2010, p. 1).

By establishing a PSM, the new legislation focuses on desired performance outcomes and reduces product support costs (Kobren, 2010). However, in order to optimize logistics support cost by reducing TOC, and in the attempt to meet required readiness and system availability, several LCM principles must be adopted. Besides important areas such as system reliability, availability, and maintainability (RAM), Kobren (2010) also included the following areas to be considered by the PSM for major weapon systems:

- application of systems engineering processes,
- designing with supportability in mind,
- long-term sustainment planning,
- aggressive root cause analysis and failure resolution,
- proactive obsolescence and diminishing manufacturing sources and material shortages mitigation, and
- planned technology upgrades.

Further, the new legislation facilitates LCM because it covers the flow from acquisition through O&S to disposal of the weapon system (Kobren, 2010). Therefore, LCM is not a single operation but focuses on integration and optimization between the several stages and levels of the weapon system to satisfy the objective readiness level. Further, integrating sustainability in the planning and management of the acquisition and production phase, throughout the termination of the weapon system, is important and will lower the LCC.

2. Cost and Performance Integrated in the Design Phase

During the design of Gripen Fighter Aircraft, the Swedish aerospace industry and the Swedish Air Force took advantage of a unique relationship and established an early focus on availability performance and life support cost (LSC), with the goal of both building high-performance aircraft and achieving cost effectiveness. The designers defined availability performance "to be dependent on reliability (low failure rate), maintainability (easy to repair quickly if necessary), and supportability (logistic resources in the form of spares, equipment and personnel at the right place at the right time)" (Sandberg & Stromberg, 1999).

According to Sandberg and Stromberg (1999), future O&S costs increase if these costs are not considered in the early acquisition phase decisions. In the early phases, the foundation for the weapon system is established, and as time goes by, the opportunities for lowering the LCC while also reaching a high availability performance are significantly reduced. Failure to focus attention on O&S cost in early phases results in increased LCC throughout the system's operating life.

In designing the Gripen Fighter Aircraft, the Swedish Air Force's contract with the aircraft producer included logistics parameters defining information over future support, operational cost, and available performance (Sandberg & Stromberg, 1999). These parameters were the following:

- failure rate;
- maintenance workload on all levels (organizational, intermediate, and depot);
- mission success probability;
- downtime per flight hour (in a wartime scenario);
- turnaround time (at O-level); and
- LSC, including those elements significantly affected by changes in the technical or support system, as follows:
  - investment in support equipment,
  - investment in spares,
  - annual cost depending on maintenance personnel, and
  - annual cost for consumables.

This contractual agreement between the Swedish Air Force and the maker of the Gripen Fighter Aircraft serves as an example in the early acquisition phases for other weapon systems.

With regard to the design phase for the Gripen Fighter Aircraft, the contract statement of work established the following:

- Requirements breakdown and allocation—defines the maintenance requirements from customer needs with the purpose to allocate maintenance performance and design criteria to vendors and technical design areas.
- Design review, maintenance aspects—requires continuous involvement with the design department and vendors to ensure that maintenance and test criteria are met.
- Maintenance needs analysis—defines the need for corrective and PM that is required to retain airworthiness during the operational life of the aircraft. Includes also identification of significant maintenance items, maintenance task analysis, and definition of maintenance intervals for PM.
- Test methods—defines and specifies the total test and registration needs of the aircraft.
- Maintenance resource requirements—for identification, analysis, and recommendation of all the maintenance resources required to support the aircraft throughout the life cycle. The resources include technical publications, training level/personnel recommendation, support equipment including tools, facilities, spares, and so forth.
- Logistics analysis—includes LSC analysis, maintenance-level analysis, repair/discard analysis, and various availability performance calculations, including reliability, maintainability, and supportability (RM&S) trade-off analysis (Sandberg & Stromberg, 1999).

By including these works in the design phase, the manufacturer managed to achieve higher availability performance while at the same time lowering the LSC for the Gripen Fighter Aircraft, which could be a good methodology for other weapon systems (Sandberg & Stromberg, 1999).

During the operational phase, the Gripen Fighter Aircraft was also monitored and evaluated to achieve better availability performance and lower LSC. Statistical and operational data was collected and stored in an information system linked with the manufacturers. By constantly monitoring the performance metrics, adjustments and changes were planned in a cost-effective way (Sandberg & Stromberg, 1999).

3. Classification of Parts Due to Priority

For several weapon systems, spare parts are classified by different attributes, such as how critical or essential they are to the operation and mission; these attributes indicate the importance of the specific part to the system (Deshpande, Cohen, & Donohue, 2003). Storing parts often leads to conflicting goals, and the trade-off between holding and inventory cost, as opposed to readiness, is a well-known dilemma.

The study on DLA by Deshpande, Cohen,and Donohue (2003) indicated that cost was the dominant performance driver, not criticality or essentiality. In their study, Deshpande, Cohen, and Donohue (2003) recommended classifying parts into different priority categories depending on the service level required for different parts, giving higher service levels to the most critical parts. Service level is the probability that a given part will not be available in inventory given average demand and variability in demand. Deshpande, Cohen, and Donohue (2003) claim that setting different service levels on different parts can be accomplished without a significant rise in inventory cost.

4. Commercial Items in Weapon Systems

The use of commercial items in weapon systems has been a clear focus for the DoD, due to the expected reduction in weapon system LCC. Some weapon system programs have included commercial items at the component level, and others have used commercial items in the whole program. Often, programs have used commercial items with some modification to tailor them to specific military requirements (Meyer, 2001).

Procuring commercial items for use in weapon systems could be beneficial in different ways but might also raise some challenges. The program managers are not controlling the development of the item; rather, the marketplace is responding to customers' demands. In the marketplace, the DoD is often a small customer for commercial items. As a product changes, the supportability of the program changes accordingly, this again can have a negative impact on the TLC. Moreover, commercial items must be tested and evaluated after potential modifications and changes (Meyer, 2001).

During a study of different issues regarding the acquisition of commercial items in the DoD, Meyer (2001) found several challenges that program managers need to be aware of. For instance, improper identification of user requirements might lead to procurement of a product that does not meet exact military specifications, which can also be the consequence of an improper market investigation. Further, lack of risk analysis and improper test and evaluation often have a negative impact on the TLC cost, and performance, reliability, and maintainability data might not correlate to a military application or meet required levels for military use. In general, mistakes and unawareness in procuring commercial items might cost more than predicted, in terms of both time and money, and reduce the availability of the weapon system (Meyer, 2001).

D. OPERATIONAL AVAILABILITY

1. Introduction

So far in history, mankind has not been able to construct an eternity machine; every system fails at some point. However, most systems can be repaired or fixed given a period of downtime. One definition of availability is "the probability that an item is in an operable and committable state when called for at an unknown (random) time" (Jones, 2006), and availability can be predicted and measured.

Reliability can be defined as "the probability that a system or product will perform in a satisfactory manner for a given period of time used under specified operating conditions" (Blanchard, 2004). The MTBF is the average length of time between the system failures and is related to the failure rate, λ, as follows: $MTBF = 1/\lambda$. When a system or component fails, it will not be available for operational use, and the time until it is repaired or fixed is called the mean downtime (MDT). This is the average time that the system or component will be inoperable. MDT is also referred to as non-mission capable time (NMCT). The mean time between maintenance (MTBM) includes both corrective and preventive maintenance, whereas MTBF only consider how often a system or item fails.

The operational availability (A_O) can be expressed as the following:

$$A_o = \frac{UpTime}{(UpTime + DownTime)} = \frac{MTBM}{(MTBM + MDT)}, \tag{1}$$

where

$$MDT = MCT + MPT + ALDT, \tag{2}$$

and where

$$MTBM = \frac{1}{\frac{1}{MTBM_U} + \frac{1}{MTBM_S}} = \frac{1}{\lambda + fpt}. \tag{3}$$

In Equation 3, $MTBM_u$ (same as MTBF) is the mean interval of corrective maintenance, and $MTBM_s$ is the mean interval of PM. Further, *fpt* (=1/ $MTBM_s$) is the frequency of the PM action per system operating hour.

Further, the MDT can be divided into mean corrective time (MCT) and mean preventive time (MPT). MCT can be expressed by the following formula, where M_{CMT} is the mean corrective maintenance time:

$$MCT = \frac{Annual\ Missions\ Hours}{Mean\ Time\ Between\ Critical\ Failures} \times M_{CMT} \tag{4}$$

In other words, MCT first estimates the number of critical failures per year and then calculates the time in terms of CM when the system will not be available (Jones, 2006). MPT is a product of the number of PM events, average PM event frequency, and average time it takes to perform a PM event.

In addition, administrative and logistics delay time (ALDT) has an impact on the MDT, meaning that the MDT includes both active maintenance and logistics delay. The ALDT is a result of the following factors:

- spares availability,
- support equipment availability,
- personnel availability,
- maintenance facility capacity,

- transportation/shipping time, and
- administrative delay time (Jones, 2006).

The A_O is the commonly used readiness measure for weapon systems (K. Kang, personal communication, June 22, 2012) and can be improved by addressing the following targets:

- reliability—mean time between critical failures (MTBCF),
- maintainability—mean time to repair (MTTR),
- testability—diagnostics,
- scheduled maintenance requirements,
- logistics support infrastructure,
- spares availability,
- support equipment availability,
- personnel availability,
- facility capacity and utilization rate,
- transportation responsiveness, and
- administration requirements (Jones, 2006).

2. Improvement on Component Level: Impact on Operational Availability

One of the ways to reduce LCC, while at the same time improving the A_O, is using performance-based logistics (PBL) contracts, in which the vendor is responsible for meeting certain performance criteria for the specific weapon system. The organization sets these performance criteria, and the mission value of a logistical service can be seen as a function of weapon-system performance (Kang, Doerr, Boudreau, & Apte, 2005). One way to measure the weapon-system performance is to monitor the A_O, because A_O measures the percentage of the weapon systems (e.g., aircraft in a squadron) that are mission-capable at any given time.

There are often several subsystems and components that can be improved. Improvement of a component A_O within a system can improve the A_O for a weapon system as a whole; however, an increase of the A_O for one specific component doesn't necessarily improve the weapon system A_O by the same percentage of the component improvement. An improvement on the component level must be related to the performance of other related parts. Kang et al. (2005) recommended that the use of different spreadsheets and discrete-event simulation models can act as a decision support model for managers in terms of estimating the A_O of a weapon system based on the component-level reliability and maintainability data (Kang et al., 2005). Their discrete-event simulation models were used to show how a change or improvement in one or several components can affect the overall A_O for the weapon system and calculate the individual cost associated with the specific component improvement. Hence, this methodology can be valuable for the decision-maker in determining which improvement initiative at the component level has the greatest impact on the A_O for the weapon system.

3. Logistics Impact on Operational Availability

The study *Impact of Logistics on Readiness and Life Cycle Cost: A Life Cycle Management Approach* at the Naval Postgraduate School demonstrated possible positive relations between certain logistical parameters and A_O using simulation and modeling tools (Balafas, Krimizas, & Stage, 2010). In the study, Balafas, Krimizas, and Stage (2010) used the light armored vehicle equipped with a 25-mm gun system (LAV-25) to estimate how A_O, readiness, and TLC cost are related by running different scenarios in a model. Although it is a simplified model Balafas et al. believed it can be applied to other military systems with some minor adjustments.

Balafas et al.'s (2010) study showed that the best way to improve A_O was to improve the fourth-echelon maintenance turnaround time, which also had the biggest impact on the readiness risk. Further, the study concluded that an increased MTBF in combination with reduced turnaround time had a significant positive impact on LCC as well. Moreover, Balafas et al. (2010) also found that increasing the inventory of spare parts only, and not reducing the turnaround time, does not have a significant impact on the A_O and readiness risk but only increases the LCC.

E. DECISION SUPPORT SYSTEMS

1. Introduction

Over time, people have developed a variety of systems to make their decisions easier, both in private life and in the business world. In terms of acquiring a weapon system, several decisions have to be made on different levels and at different stages. Often, there are complex situations with several factors that need to be evaluated and considered before these decisions are made. Cost-benefit analysis and net present value calculations are examples of approaches to ease some of these decisions. Some systems are also designed to make decisions, such as automated processes where human interaction is not needed.

A decision support system (DSS) is exactly what it is called—a system to support decisions, not make decisions. Computer-based systems are designed to handle several different parameters and factors and to provide a simplified set of target values, which decision-makers can take into consideration. By populating the system with available data, the respective programs show how the outcomes differ as input changes.

Reducing life cycle support cost while maintaining the desired readiness level is a challenge for logisticians. For many weapon systems, O&S cost normally covers the major cost for a system, although initial cost, like acquisition cost, and disposal cost, also have an impact on the TLC cost. One of several ways to reduce LCC is to utilize the available logistic management DSS. There are different types of DSSs for different weapon systems and organizations.

Using a DSS, managers simulate different changes and observe how changes in different factors have an impact on the overall system A_O. The DSS might also reflect how different changes relate to the total cost for the system. Managers therefore often have to evaluate improved A_O against cost when different parameters are changed in their models and DSS.

2. Logistics Management Decision Support System

Trade-offs between readiness and cost are common for most weapon systems, and the challenge is to find the best combination, often described as *affordable readiness*. Affordable readiness is the level of readiness in the weapon system that the budget constraints allow it to meet and sustain. Flexible sustainment, sustained maintenance planning, right sourcing, and TOC are different ways to approach the support of a weapon system (Dizek, n.d.). Moore and Snyder (1998) listed six areas within O&S cost that relate to affordable readiness: maintenance concept, inventory, manpower, technical data, infrastructure, and warranties. Further, another term used is *ownership cost*, which is a component of manpower, infrastructure, and materials. Savings within these areas must be evaluated in relation to availability and reliability of the relevant weapon system (Moore & Snyder, 1998).

According to Moore and Snyder (1998), a Logistics Management Decision Support System (LMDSS) must meet certain criteria to be an effective DSS. An LMDSS must meet the data management and dialog management component criteria. Further, it has to include a modeling and sensitivity analysis capability. Additionally, an LMDSS should provide enough information and statistics to enable users to analyze logistics areas. The data quality must be high in terms of accessibility, consistency, and validity. An effective LMDSS can be a valuable tool for managers to identify areas for reduced life cycle support cost.

3. Total Life Cycle Management–Assessment Tool

As an example of another DSS, the U.S. Marine Corps has used the total life cycle management–assessment tool (TLCM–AT) to control LCC and maintain its required readiness level, and it has proven to be an effective decision support tool. The TLCM–AT combines operations, maintenance, and logistics and gives an overall picture of the LCC for the weapon system (Young, 2008). Further, the TLCM–AT also has a model structure and organization that let decision-makers run different models and what-if scenarios to evaluate the way that different changes impact the LCC in the long term. Moreover, studies show that implementing the concepts of data farming and design of experiments and Java programs could enhance the TLCM–AT capabilities in terms of analyzing LCC (Young, 2008).

4. Closed-Loop, Simulation-Based, Systems Engineering Approach

One definition of LCM is “a management technique which bases programmatic decisions on the anticipated mission-related and economic benefits derived over the life of a weapon system” (Connors, Gauldin, & Smith, 2002). To be able to plan for future logistics and engineering support, decision-makers must know the characteristics of the weapon system and be able to run simulations to determine which improvements have the most impact on the LCC for the system while at the same time meeting required readiness. Quantifiable data and proper analyses of the weapon system are requirements for supporting management decisions.

Connors et al. (2002) defined life cycle analysis (LCA) as

> a formal process for establishing a quantitative basis in support of LCM decisions. LCA consists of: (i) building a model representation of a real world system or process, (ii) obtaining data to populate or instantiate the model, (iii) using the populated model to predict future behavior—e.g., performance and costs—for a range of defined system designs or use scenarios, (iv) validating the model predictions, and (v) presenting the analysis results to decision makers. (pp.1–2)

The main costs for a weapon system and performance drivers can be divided into the following segments:

- operations and maintenance (O-, I-, and D-level),
- management,
- engineering, and
- supply/logistics.

The LCA of a weapon system is designed to quantify these segments of the system, and LCM has a goal to optimize and control the same system segments (Connors et al., 2002).

Additionally, there can be several different LCA models within the DoD, as follows:

- supply models;

- level of repair analysis models;
- reliability, availability, and maintainability models; and
- LCC models (Connors et al., 2002).

Often these models are used independently on different levels within the organization and can have impacts on each other's input and output. LCA in segments, rather than as a whole, might have an adverse impact on the quality of the results because the related impacts and possible interfaces between segments might be lost or missed. Clockwork Solution has developed a tool called Aviation Total Life-Cycle Analysis Software Tool (AT-LAST), which takes the segmented approach to LCA into consideration and focuses on a closed-loop, simulation-based, systems engineering approach to LCA (Connors et al., 2002). The closed-loop, simulation-based model integrates operation, maintenance, supply, and other relevant factors and estimates a more reliable and true picture of the system. The Clockwork Solution simulation models can be utilized in several logistics-related areas for the subject weapon system, which can improve the A_O.

5. Weapon System Management Information System

Another DSS available for logistics managers is the Weapon System Management Information System (WSMIS), which "is designed to give logistics managers a better tool to prioritize their task to meet required readiness" (Tripp et al., 1991). An important factor for the WSMIS was to identify measures for the logistics areas that are directly related to A_O and performance goals. For instance, the number of available aircraft at a given point for a specific war scenario could be such a measurement (Tripp et al., 1991). To support a given scenario with logistics, managers need appropriate data to support operations plans involving numbers of flying hours or other operational factors. More important, the variation within each of the segments over the time period of the operations is vital for logistics planning.

The WSMIS is designed to capture when a wartime sortie is at risk and trace that risk back to specific resource shortages or other logistics shortfalls. Further, the WSMIS can distinguish between planned and actual logistics support capabilities. The WSMIS was designed to do the following:

- to predict the availability rates of weapon systems for any scenario as a function of existing logistics resources and current process performances;
- to project the specific logistics resources, identified down to the specific problem part, most likely to limit the attainment of particular goals;
- to provide a list of problem items and processes so that decision-makers could develop solutions; and
- to provide each decision-maker with a sensitivity analysis capability so that he or she could determine the effects of alternative plans for improvement before implementing a solution (Tripp et al., 1991).

The WSMIS was developed over time in incremental steps, and both senior Air Force officers and members of the RAND staff developed the philosophy and framework. The Air Force Logistics Command implemented the WSMIS systems in the 1980s to estimate the logistics impact on the potential wartime capabilities.

F. REPAIR KITTING

1. Deployment Kitting

When NSWG-4 deploys one of its craft in support of Navy SEAL teams, they must send with it a crew and maintenance capability. Once deployed, NSWG-4 will not see this craft again until it returns. As part of the SOCR weapon system, a DDP is deployed with every two craft. This DDP is intended to provide parts for expected corrective and PM during a given deployment period. Mamer and Smith (1982) developed a model in their paper "Optimizing Field Repair Kits Based on Job Completion Rate." The model was for service call–type processes in which repair part inventories were required to make repairs. This is a very similar concept to the DDP, except that SOCR deployments have a longer deployment period than a typical service call–type repair. Mamer and Smith (1982) recognized the relationship between the cost of holding inventory and the cost of "broken jobs." A broken job would be defined as any job in which a maintenance task is attempted, but due to inadequate spares or equipment, there is additional downtime while required resources are procured or delivered.

Because of this relationship, Mamer and Smith (1982) created a model that nested broken job cost within inventory cost to create an optimization model for repair kits. They treated job completion rates in a similar manner to a fill rate for inventory. They also correlated part failures and requirements with repair procedures to allow for pooling of part inventories for multiple procedures, which lowers the risk of not having parts on hand that are used for multiple procedures, thus allowing a lower inventory level with the same service level.

2. Kitting with Variation in Broken Cost Penalty

Mamer and Smith's (1982) model treated all broken jobs as having the same cost. In reality, there is not an equal penalty for every broken job. For this reason, March and Scudder (1984) addressed this point in their article "On 'Optimizing Field Repair Kits Based on Job Completion Rate.'" In their work, March and Scudder (1984) acknowledged that it is very difficult to find the exact penalty a firm will pay for a broken job, but they proposed that by finding a range for penalty cost, the model can be improved.

3. Improved Kitting Model

Mamer and Smith (1985) again addressed the issue of optimization for repair kits in their article "Job Completion Based Inventory Systems: Optimal Policies for Repair Kits and Spare Machines." In this article, Mamer and Smith (1985) improved on the optimization process by including spare machines. This is a very important concept that applies directly to NSWG-4's maritime craft. When the craft deploy, NSWG-4 doctrine dictates that the repair kit must be capable of providing maintenance supplies for a period of 90 days, which is referred to as a *knapsack model*. A ground rule of the knapsack model is that resupply is not possible; therefore, the optimum combination of supplies must be included within the resource constraints. Any supplies placed in the knapsack that are not used will incur a disposal cost. The knapsack reference comes from the idea of packing supplies in a knapsack for a day hike. If a winter jacket is put in the sack, there will be no room for other items such as food. The decision-maker must then make decisions on which items are the most important because some items will be left behind.

The reason for requiring 90 days of supply for deployments is that resupply is often very difficult at the beginning of deployments, and the variance in lead-time is very high or unpredictable for parts ordered. With the inclusion of spares components in addition to repair kits, the risk of having a broken job is lowered. If the kit is not sufficient to complete the repair, then the spare will be used and a new one will be placed on order. In their 1985 article, Mamer and Smith discussed machines, but on maritime craft, machines would be substituted by major components such as outdrives or engines. Some repairs are so infrequent that parts are not included in the knapsack model, so having a spare component would provide coverage for all of these low-frequency jobs without stocking large quantities of low-usage repair parts.

In some cases, it is likely that component failures are not independent of each other. An example of this could be a seawater pump on a boat. These pumps remove seawater to cycle through a heat sync, which cools the engines. Because the pumps are prone to fail over time, they are replaced at regular intervals. In the case of structural failure of the pump in between PM intervals, it is likely that the pump's failure will be discovered after the engine overheats and other damage has occurred. Because of this correlation, it is easy to imagine a situation in which a water pump kit is included in the knapsack; but parts for the correlated damage due to overheating, such as head gaskets, are not included. Ultimately, Mamer and Smith (1985) demonstrated that it is the service level for job completion that should be focused on. By adding machines—or, in the case of maritime craft, by adding major assemblies—job completion can be raised significantly, especially in cases where there is a catastrophic failure, as is sometimes the case when component failure is correlated. In the case of engine failure due to pump failure, the replacement engine would be available and there would be no broken job.

When considering a knapsack model, it is likely that cost is not the primary concern for optimization for NSWG-4. For private industry firms that go on repair jobs, their exposure period is relatively short. The exposure period for a craft on deployment is long, and additional resources are far away. On deployment, space is constrained to one ISU-90 container, so space is a proxy for cost for NSWG-4.

4. Repair Kitting in Application

Although much of the repair-kitting research was conducted in the early 1980s, there are examples in which these concepts are still relevant and the benefits are demonstrated. Gorman and Ahire (2006) wrote the article "A Major Appliance Manufacturer Rethinks Its Inventory Policies for Service Vehicles," which demonstrated that service-kitting optimization improves the job completion rate for appliance repair technicians during first-time visits. In their research, Gorman and Ahire (2006) found that a major appliance company operated a central repair parts warehouse. From this central location, four regional warehouses were serviced. The regional warehouses, in turn, serviced technicians who conducted repair calls from service vehicles. This company identified that it was very important for their customers that the appliances be repaired on the first visit.

Further, this company used a simple aggregation measuring the frequency of part usage to determine what should be put in the repair vehicles. Gorman and Ahire's (2006) research averaged one-year's usage of repair parts. The approach Gorman and Ahire (2006) took to optimization differed from Mamer and Smith's (1985) model because Gorman and Ahire assumed that there was independence in part failure. They did include cubic space constraints, repair part lead-times, replenishment periods, and inventory carrying costs. Their conclusion showed that both high demand and small parts should be included in their model. The reason for this was the low cubic cost of keeping small parts, in comparison to the high cost of a broken job if that part is not on hand (Gorman & Ahire, 2006).

Gorman and Ahire's (2006) study is very applicable to our research with NSWG-4's maritime craft. For the SOCR, there are high levels of complexity and interdependent parts that makes them different from appliances. For this reason, NSWG-4 would have to analyze their craft like Mamer and Smith (1985) recommended in their model. When a repair must be conducted, NSWG-4 must assume that there is an array of parts that will be needed. At the same time, because these craft will be deployed, space is at a premium. NSWG-4 should then look at their problem in the same terms as a repair truck (which conducts a repair without resupply) and balance high-frequency parts with low-volume parts. Although March and Scudder (1984) pointed out that not all broken jobs have the same penalty, in the case of NSWG-4, a vessel that cannot be used for any reason carries the same penalty. For this reason, any model used by NSWG-4 can be simplified to include one penalty for any broken jobs. Finally, we can see that the risk that NSWG-4 is exposed to will be greatly improved if they stock major assemblies. Additions of major assemblies have a high space premium, so their inclusion should be weighed by the frequency of failure.

III. RESEARCH METHODOLOGY

A. INTRODUCTION

In this chapter, we discuss the methodology we used to conduct our research. This includes the data we collected, the data questions that we asked, and the process we used to analyze the data.

B. METHODS USED IN DATA COLLECTION

1. Qualitative Data

Qualitative data required for our project describes the SOCR system and the logistics support structure. We gathered qualitative data from government literature and doctrinal publications for the SOCR and SBT-22. In addition, we interviewed personnel at NSWG-4 and SBT-22, as well as conducting a tour of operations at both locations. Further, we visited and interviewed personnel at Navy Surface Warfare Center, Combat Craft Division (NSWCCD). This unit supports the Riverine Assault Boat (RAB). The RAB is an almost identical craft to the SOCR and is also manufactured by USMI.

2. Quantitative Data

We were able to get a two-year history of all parts procured through USMI for the SOCR, as well as the objective inventory levels for the SBS and DDPs from SBT-22 Supply. We got quantitative data on A_O for each of the SOCR currently in service since their date of manufacture from historical management reports used by SBT-22. Because the RAB is an analogous system, we collected one year's worth of purchases by NSWCCD, which we used to compare the support of these two systems under different logistics models.

C. DATA COLLECTION QUESTIONS

1. System and Components

At the highest level of data collection, we needed to determine what the system and its components were. This allowed us to determine which components are parallel and which are serial. Parallel components serve the same function as each other, and the system can operate with only one of them operational, such as two engines in the same craft; however, a serial component is reliant on other components in the system to be operational in order for them to also operate, such as the propulsion system which is reliant on the engine. Through interviews with USMI, the government representative to USMI, and SOCR maintainers, we collected qualitative data that enabled the determination of the major components within the SOCR.

The SOCR has two power generators, which are Yanmar 6LY2-STE diesel engines. Although the engine is a system in itself, with parallel and serial components, we treated it as one of the single major components for two reasons.

First, most of the components in a single engine are serial components; if one fails, the entire engine is inoperable. For those components that are not serial, there is a high correlation factor involved. For example, the starter, alternator, and water pump are all serial components; the pistons, fuel injectors, and valves are all parallel components. Although these engines will still operate if a valve or piston fails, the performance will be degraded and the strain on the rest of the engine greatly increases the likelihood of catastrophic failure of the engine. Once the engine is degraded, it is highly likely that the craft will not be employed, and if it is already on a mission when failure of these parallel components occurs, it could result in termination of the mission for that craft.

The second reason for treating the engine as a single component is that it is very easy to replace the engine. The DDPs each contain one spare engine, and the craft was specifically engineered to make replacement of the engine very simple.

An IRM 220 PL Marine gearbox is in line with the engine and transfers power to the drive system. Like the engine, the components of the gearbox are serial, so any failure should be treated as a gearbox failure.

Each engine and gearbox drives a Hamilton HJ-292 Water Jet propulsion system. These water jets draw water into an impeller and provide the forward thrust for the craft. They are aligned and operate parallel to each other. Because each engine drives a single water jet, the engine, gearbox, and water jet are a serial system. Likewise, because the craft can be propelled with only one water jet, each of these systems is parallel to each other.

The hull is another main component. The failure of the hull will cause all other components in the SOCR system to fail. Hull failure is very rarely catastrophic to the system. Although there have been impacts that have compromised the hull, they are very rare and are typically due to underwater impacts or battle damage. These failures should be controlled with operational decisions rather than logistics decisions. The elements within the hull that are more likely to cause system failure are the hydraulic and electrical systems installed to control the craft.

The final component in the SOCR system is government-furnished equipment (GFE). This equipment consists of everything outside the actual craft and its drive train. Examples of this component are the prime mover (F550 truck), trailer, radios, radars, guns, and navigation system. We treated GFE as a single component for the purpose of acknowledging them. GFE is not furnished by USMI and is not within the logistics structure for supporting the SOCR. In addition, most GFE is interchangeable between the SOCR and is supported by traditional Navy logistics.

Figure 5 shows the SOCR system based on the data we gathered. Having this diagram will allow for a determination of the SOCR system reliability, component reliability, and sensitivity analysis on each component, which will enable logistics decision-makers to achieve objective readiness.

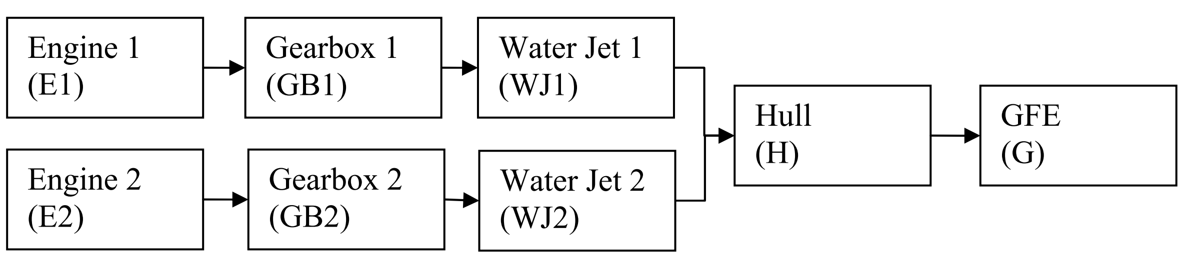

Figure 5. SOCR System Diagram

The formula for system reliability that we used in our data analysis is depicted in Equation 5 and is derived from the data in Figure 5.

$$R = \left\{1 - \left[1-(WJ1)(GB1)(E1)\right]\left[(1-(WJ2)(GB2)(E2)\right]\right\}(H)(G) \quad (5)$$

2. Operation Availability

What A_O is being achieved for the SOCR is a key question we sought to answer through our data collection. By answering this question, we were able to establish a model that will enable logistics managers to make the decisions needed to achieve any given objective availability.

The formula for A_O is depicted in Equation 6. By focusing our data collection on the elements in the A_O formula, we were able to detail the levers that management has available in order to meet their objective availability. For the SOCR, USMI has not calculated or tabulated MTBF for the SOCR and the major components; however, there is a maintenance schedule, which is based on industry standards set by manufacturers of the engines and jet propulsion systems. Through our data collection, we were able to get data on historical A_O based on maintenance records, CM times, and PM times. PM is split between O-level and D-level. USMI conducts all D-level maintenance.

$$A_o = \frac{MTBM}{MTBM + (MCT + MPT + ALDT)} \quad (6)$$

Based on this data, during our analysis, we were able to extrapolate the MTBM based on the known values from our data. We also conducted a what-if analysis to determine the sensitivity for each of the manageable elements within this model.

3. Inventory Service Level

One of the main elements that can be managed in the A_O formula to meet a desired availability is the ALDT. This is the time spent waiting for administrative logistics processes to be completed and the shipping of materials needed for completion of maintenance. One way to mitigate the impact of ALDT is to pre-stage the parts needed for maintenance, as proposed by Mamer and Smith (1985). As part of the SOCR weapon system, a pre-staged inventory is included in the form of SBS and DDPs.

Our data collection enabled us to get a listing of all retail parts ordered for the SOCR for a two-year period. During our analysis, we used analytical statistics to find the service level provided by the SBS and DDPs. In addition, we determined an objective inventory amount for a given service level.

Given that specific service level, we make recommendations that will bring the ALDT closer to zero. For example, if there is a 90% service level, nine out of 10 maintenance jobs can be immediately completed without any ALDT. One job in 10 would not have needed parts, and the ALDT would be the mean lead-time for those parts. When put together, the ALDT would be weighted between the completed jobs and the broken jobs.

D. ANALYTICAL PROCESS

In Chapter IV, we use inferential statistics to make a determination of service level for inventories. We conversely use analytical methods to determine inventory levels required to meet desired service levels. Finally, we present a model that will enable decision-makers to adjust their inventory policy based on historical data.

We use analytical methods to analyze the A_O for the SOCR. We explore the levers of control that decision-makers have available to affect the A_O. We also conduct a sensitivity analysis on those levers to demonstrate the impact they have on A_O. This sensitivity analysis is useful in gauging the effort required to achieve objective A_O.

We analyze the SOCR as a system to create a model used to analyze sensitivity and identify which components have the greatest impact on A_O.

Finally, we analyze all these areas in relation to deployment of the SOCR. The unique nature of a deployment means a vast increase in ALDT for material support and the possibility that there will be no means of distribution to deployed SOCR.

E. SUMMARY

In these first three chapters, we have discussed the existing SOCR system, the TLC support being provided for the SOCR, and the data we have gathered to support our research. This discussion has provided a background understanding and vision for our research analysis. In the final two chapters, we conduct an analysis based on the data we have gathered and provide recommendations for logistics support to the SOCR, as well as potential further research.

IV. RESULTS AND ANALYSIS

A. INTRODUCTION

In this chapter, we describe the results of our analysis. We focused on the service level found in prepositioned inventory and the protection level they provide SBT-22 for maintenance procedures. We did this by calculating the objective inventory level required to meet desired service levels set by management.

We analyzed the A_O of the SOCR craft based on actual historical availability data. We used the parameters of the reliability computation to analyze the impact each of these has on availability. We simulated availability based on known variations in the parameters.

B. SBS AND DDP

1. Overview

The SBS and DDP both serve as prepositioned inventory with the intent of reducing administrative logistics downtime for maintenance procedures. The inventories for both the SBS and DDP were developed by USMI and are updated on an annual basis. The main difference between the SBS and DDP is their intended use.

The SBS is used for garrison maintenance operations and is never deployed. The SBS was purchased as an initial spares requisition during procurement and is intended to support 10 craft. There are two SBS, and each SBS is maintained in a separate container, co-located at SBT-22. The SBS inventories are consolidated inventories supporting a demand from 24 craft.

The DDP is used only for deployment purposes. One DDPs inventory is designed to support two craft for 90 days because the SOCR is deployed in pairs. The use of DDPs is exclusively reserved for deployment, and they do not contribute to garrison maintenance, even if parts required for repairs are present in the DDP but not the SBS.

2. Data Collection

We collected data from SBT-22, which gave us a 24-month history of parts usage for both CM and PM. This data included quantities of parts procured and the year in which they were procured. What was not differentiated in the data was whether the parts were used for CM or PM.

We received data on objective inventory levels for both the SBS and DDPs. These inventories were listed in the same part number format as the parts requisitions data. In addition, we received the latest PIO, which included all the parts necessary to maintain the SOCR, regardless of whether they had been procured before.

3. Spares Model

To help us understand the data we collected, we created a spares model. With this model, we sought to consolidate and analyze the data to answer the following: (1) what is the mean demand; (2) based on the mean demand, what should the desired inventory quantity be set at; (3) what is the current service level for both the SBS and DDPs; and (4) what is the estimated value of pre-staged inventory with a comparison between current and recommended inventories. A depiction of our spares model is included in the appendix of this report.

4. Objective Inventory Level

Objective inventory is the quantity of spare parts on hand that must be maintained in order to achieve the required service level. To determine the objective inventory, we assumed a Poisson arrival. The time between arrivals for a Poisson process is exponentially distributed. In the model, we set the probability of experiencing a stock-out of inventory, and the model returns a quantity needed in the inventory to achieve the desired probability of not stocking out. Because we do not know what decision-makers at SBT-22 would establish as acceptable risk, we made the model so that any probability can be used as an input, and objective inventory levels are adjusted based on that probability. For our base example, we have set the DDP at 95% and the SBS at 85% service level.

In order to create our model, we first had to calculate the parameters in determination of objective inventory quantity to meet the required service level. These inputs were the average number of failures and the service level required. Management will set the service level. The average number of failures, however, has several components. The formula to determine the average number of failures,μ, is

$$\mu = C \times \left(\frac{1}{MTBF} \right) \times \left(\left(\frac{H}{T} \right) \times L \right) \qquad (7)$$

C: # of craft

H: operating hours over two years

T: time, which is two years' historical data (365 × 2)

L: lead-time or repair turnaround time (in days)

Our sample population of data included parts demand over a two-year period across all craft owned by SBT-22. For this reason, we normalized our other data based on this two-year period. To find the hours of use for each craft, we used the SBT-22 engine hour report. This report lists total accumulated hours of use for each engine installed on SBT-22 craft. By matching this report with the date each craft was put into service, we determined that the average annual usage for each craft was 165.98 hours with a standard deviation of 52.54 hours. Once we calculated average boat hours, we were then able to find the MTBF for parts by dividing two years' boat hours by two years' average demand per craft for each part.

Because the DDP was for a 90-day deployment without resupply, we used a 90-day lead-time. The DDP is designed to support two craft. By using a Poisson table, we were able to determine the objective inventory level needed to maintain the desired service level. Our model includes a macro to make this calculation based on a Poisson distribution table and input parameters (i.e., the average number of failures and the desired service level).

Both the DDP and SBS are reviewed annually. Because we used a sample, the results of our model were more accurate when the sample size was larger. Each year's demand can be added to the database, resulting in outputs that are more accurate over time. These outputs can then be used to make adjustments during the annual review. In order to conduct a proper review, however, it is also important to know what protection the current inventory level (also referred to as the current service level) provides.

5. Service Level

The service levels provided by parts maintained in the DDP and SBS inventories are calculated through Poisson distribution. Our model used the Cumulative Poisson Distribution Table to look up the probability of having more demand than inventory levels will support. If there is more demand than can be supported with inventory, a stock-out will result.

To use our model, the input parameters that will be needed are the failure rate for each part over lead-time and the quantity of parts on hand in inventory. We used the mean demand over lead-time calculated in our previous section as the failure rate, λ, and the inventory levels from the data we collected as our number of parts on hand. With these two values, our model returned the probability of greater demand than our inventory could withstand. Because there are requisitions for parts that are not included in the DDP or SBS, there is no protection level for these parts, so we created a logical argument in our model to indicate this status by returning a “No-Protection” status in the service level field. We also created a logical argument that returned a status of “None” when parts had no demand and lacked on-hand inventory. Further, our model did not distinguish between critical and non-critical parts. There may be some parts listed as having “No Protection” that are not critical to the readiness of the SOCR. An example of our model outputs is seen in the appendix of this report.

6. Inventory Consolidation

The SOCR program designates two craft per DDP and 10 craft per SBS. For the purpose of setting up our model, we made the assumption that there would not be any inventory consolidation. This is not the case functionally because the SBS are co-located and all of the SOCR are in the same location. For this reason, the actual coverage level realized by SBT-22 is the same as having two consolidated SBS inventories servicing 24

SOCR. It is useful to realize that the actual service level will be higher than our model showed, but we built our model based on two independent flights of 10 SOCR in order to model the system as the SOCR program is designed.

We did not calculate the impact of consolidating the DDPs in our model. The reason for this is because of the nature of DDP inventories. DDPs are not used unless a craft is deployed, and typically, the craft are deployed in pairs. For this reason, the most likely scenario would be that of an unconsolidated inventory.

7. Effects of Lead-Time

In our model, it was imperative that we consider the impact of lead-time on our service level. When setting up our model, we determined that all parts in the DDP would have a lead-time of 90 days. The reason for this is the 90-day deployment period that the DDP is designed to support. In reality, the lead-time would be, at most, 90 days assuming an order was placed on the first day of a deployment. With the SBS, we assumed a 30-day lead-time, but this was an arbitrary number that we picked. Currently, USMI has an active production line for the SOCR and allows SBT-22 to order parts from their inventory. Because USMI is located less than a two-hour drive from SBT-22 and maintains the SBS inventories for SBT-22, there is, at most, a seven-day lead-time for parts. This lead-time is only achieved because USMI allows SBT-22 to use their inventory. When the production line is no longer active for the SOCR, it can be expected that the lead-time for replacement parts will increase.

Lead-time has a large effect on the service level for repair parts. Our model allows users of the model to change the parameters of lead-time and desired service level. As an example, when we lowered the lead-time for SBS items to seven days, we found that there are no parts that are not within an 85% required service level. Likewise, for this same service level of 85%, the required spares for all parts included in the SBS were reduced from 912 to 213 when lead-time was reduced to seven days. The current inventory for SBS spares includes 2,456 parts.

8. Job Completion

To this point, we have discussed the service level based on the need for individual parts. Mamer and Smith (1982) discussed the optimization of field kits based on job completion. With repair jobs, we know that there is a low likelihood that only one part will be required. Instead, there are a series of parts needed to complete the job, and each one of these parts has its own service level. In addition, some parts are common to more than one type of job. Our data did not differentiate between demands based on the type of job that was being completed, so we can assume that the failure rate for each individual part is the sum of the failure rates for all completed jobs requiring that part.

When looking at service level from the perspective of job completion, it is the product of all the individual parts' service levels needed to complete the repair job that determines the overall job service level. This is because the job will have to wait until the last part arrives before it can be completed. The service level (SL) for the job is

$$SL = P_1 \times P_2 \ldots P_n, \qquad (8)$$

where P_n is service level of the *n*th part required in a repair kit.

Mamer and Smith (1982) identified a job that cannot be completed with pre-staged inventory as a broken job. For the SOCR, the pre-staged inventory is the SBS or the DDP. If a job cannot be completed and is broken, there is an additional cost incurred by having to wait the entire period of the lead-time in addition to the extra time spent returning to the job. When making quantity decisions on pre-staged inventory, each of the critical repair jobs must be identified as well as the kit of parts needed to complete the job. The required spares level for each of the parts must then be set to enable an acceptable service level for the entire job.

C. OPERATIONAL READINESS AND RELIABILITY

1. Overview

The purchasing contract for the SOCR is for 48 craft, which were scheduled to be delivered over 15 years; however, SBT-22 is only entitled to maintain an inventory of 20 craft according to their table of organization and equipment. In addition to the 20 craft required, SBT-22 expanded the allowable inventory of the SOCR to 24 with the intent of increasing the quantity of fully mission-ready craft. Without any service life extension, each craft has a service life of seven years. The weapon system program is scheduled for 15 years (2002–2017).

The objective for this section is to analyze the factors affecting the operational availability for the SOCR in order to enable management to make decisions regarding readiness. We will use a decision support tool to conduct what-if analysis, and then we will apply a Monte Carlo simulation to the readiness formulation in order to determine the parameters within which actual operational readiness may occur.

2. Data Collection

SBT-22 provided an "SOCR Monthly Engine Hour Report" dated July 2012, which showed the hours used per engine for all craft currently in service. Further, SBT-22 provided a "Progress, Status and Management Report (Covering Period July 01–31, 2012)," which stated the in-service date for the SOCR, by which we could calculate the number of days that the craft have been in service. We matched that data with engine hours per craft to find average engine hours used.

3. Readiness: Operational Availability

For the SOCR, we evaluated readiness using A_O. A_O can also be expressed as a relationship between total hours, CM downtime, and PM downtime:

$$Ao = \frac{\text{Total Time - CM downtime - PM downtime}}{\text{Total Time}} \tag{9}$$

Equation 9 states the ratio between how often, in terms of days, the weapon system is serviceable, and the total number of days in a given time period. For the SOCR, the total time for the weapon system is the average operational hours per craft per year, which is calculated in Table 2.

Table 2. Engine Hours Report

Craft	Date in Svc	Date of Rpt	Days of Svc	Yrs of Svc	Hrs	Annual Hrs
SOCR 01	8-Feb-02	31-Dec-07	2152	5.896	518	87.86
SOCR 02	27-Mar-02	31-Dec-07	2105	5.767	799.3	138.60
SOCR 03	11-Oct-02	31-Dec-07	1907	5.225	941.8	180.26
SOCR 04	11-Oct-02	31-Dec-07	1907	5.225	956.6	183.09
SOCR 07	22-Feb-03	31-Dec-07	1773	4.858	748.3	154.05
SOCR 08	22-Feb-03	31-Dec-07	1773	4.858	889.4	183.10
SOCR 09	11-Jul-03	31-Dec-07	1634	4.477	749.2	167.35
SOCR 10	11-Jul-03	31-Dec-07	1634	4.477	749.8	167.49
SOCR 11	27-Feb-04	31-Dec-07	1403	3.844	590.3	153.57
SOCR 12	27-Feb-04	31-Dec-07	1403	3.844	417.7	108.67
SOCR 13	11-Jun-04	31-Dec-07	1298	3.556	744.1	209.24
SOCR 14	11-Jun-04	31-Dec-07	1298	3.556	769.7	216.44
SOCR 15	17-Sep-04	31-Dec-07	1200	3.288	460	139.92
SOCR 16	17-Sep-04	31-Dec-07	1200	3.288	578	175.81
SOCR 17	14-Jan-05	31-Dec-07	1081	2.962	366	123.58
SOCR 18	14-Jan-05	31-Dec-07	1081	2.962	306	103.32
SOCR 19	6-May-05	31-Dec-07	969	2.655	347	130.71
SOCR 20	6-May-05	31-Dec-07	969	2.655	250	94.17
SOCR 21	16-Feb-07	31-Jul-12	1992	5.458	1092.6	200.20
SOCR 22	16-Feb-07	31-Jul-12	1992	5.458	565	103.53
SOCR 23	17-Oct-08	31-Jul-12	1383	3.789	924.7	244.05
SOCR 24	17-Oct-08	31-Jul-12	1383	3.789	1116.2	294.59
SOCR 25	6-Mar-09	31-Jul-12	1243	3.405	652.3	191.54
SOCR 26	6-Mar-09	31-Jul-12	1243	3.405	406.5	119.37
SOCR 27	20-Jul-09	31-Jul-12	1107	3.033	369.9	121.96
SOCR 28	20-Jul-09	31-Jul-12	1107	3.033	647.4	213.46
SOCR 29	18-Dec-09	31-Jul-12	956	2.619	385.3	147.11
SOCR 30	12-Feb-10	31-Jul-12	900	2.466	496.6	201.40
SOCR 31	2-Jul-10	31-Jul-12	760	2.082	428.7	205.89
SOCR 32	2-Jul-10	31-Jul-12	760	2.082	297.5	142.88
SOCR 33	19-Nov-10	31-Jul-12	620	1.699	402.1	236.72
SOCR 34	19-Nov-10	31-Jul-12	620	1.699	448	263.74
SOCR 35	15-Apr-11	31-Jul-12	473	1.296	325.1	250.87
SOCR 36	15-Apr-11	31-Jul-12	473	1.296	238.8	184.27
SOCR 37	26-Aug-11	31-Jul-12	340	0.932	174	186.79
SOCR 38	26-Aug-11	31-Jul-12	340	0.932	166.3	178.53
SOCR 39	20-Jan-12	31-Jul-12	193	0.529	41.4	78.30
SOCR 40	20-Jan-12	31-Jul-12	193	0.529	41.7	78.86
			Weighted Avg Eng Hrs			**165.98**
			Standard deviation			**52.54**
			Median			**171.65**
			Q1			**125.36**
			Q2			**201.10**
			Inter Quartile			**75.74**
			Max			**285.25**
			Min			**58.04**

a. Total Time: Average Sailing Hours per Craft per Year

To calculate the average annual operating hours for each craft, we used SBT-22's engine hour report, which showed the number of hours per engine per craft on July 31, 2012. Because each craft has two engines, we were able to approximate the hours of use for the craft based on the engine with the most hours. Even if one of the engines was replaced, it would be evident through a large differential in recorded hours for the craft. We assumed that boat usage was based on a normal distribution, so we were able to find the average hours of use and the standard deviation. To ensure that none of the craft were outliers, we used the boxplot method of determination. In this determination, the top and bottom quartile of engine hours use are calculated. The difference between these two quartiles is the inter-quartile range which we calculated at about 75.7 hours. We set our threshold for a minor outlier at 1.5 times the inter-quartile range added to the median and a major outlier at three times the inter-quartile range added to the median. This meant that any craft with engine hours greater than 285.3 hours or a lower than 58 hours annually would be treated as a minor outlier, and any craft with over 398.9 hours would be a major outlier. One of the craft fell outside this range, and it is considered a minor outlier. Because only one of the craft was in the minor outlier range, and none of the craft were in the major outlier range of three times the inter-quartile range, we determined that all craft engine hour usage was representative of the SOCR population and accepted them in the determination of average engine hour usage.

In order to standardize our units of measurement for A_O, we used engine hours. For example, we converted time into operational hours by dividing annual hours by the number of time units in a year (e.g., weekly hours would be expressed as annual hours divided by 52).

b. Operation Availability

From *Special Operations Craft Riverine (SOCR) Quarterly Program Management Review & Configuration Control Board, 11 February 2008* (USMI, 2008), we were given readiness data for 20 SOCR from April 2005 to June 2008. This report set the A_O at 89.5% for all craft.

Because this A_O was based on all craft currently in service beginning with each craft's in-service date, we accepted it as a representative sample of the distribution of craft we would find at any given time in the fleet. This percentage would not be accurate if it were based only on craft recently fielded or craft that were about to be decommissioned because it would bias to one of the extremes of the SOCR's useful service life.

c. PM Downtime

From our interviews with the government representative at USMI, we knew that the semiannual scheduled PM takes place about seven days twice a year. In addition, we observed that USMI maintenance periods are most commonly in multiples of seven days, which is indicative of a weekly cycle time. For this reason, we normalize operational hours to weeks:

$$\text{Weekly Operating Hours: } \frac{166 \text{ Annual Hours}}{52 \text{ Weeks}} = 3.19 \text{ Hours} \tag{10}$$

Equation 10 indicates that the duration of each scheduled semiannual PM (one week) is equivalent to 3.19 operational hours, for a total of 6.38 operational hours annually for both scheduled PMs.

In addition, SLEP maintenance is done once between years three and four of the SOCR life cycle and takes 60 days on average; however, SLEP displaces one of the scheduled semiannual PMs so it accounts for an additional 53 days of maintenance over seven years of useful craft life. The number of hours of SLEP maintenance per year is therefore 53 days divided by seven years, which gives 7.57 days annually, which is equivalent to 3.45 operating hours:

$$\text{SLEP Hrs} = \frac{7.56}{7} \times 3.19 = 3.45 \text{ Hrs} \tag{11}$$

By including SLEP maintenance downtime in PM downtime, the following number of hours of total PM downtime, in terms of loss of operating hours, per year is

$$\text{Total PM} = \text{SLEP} + \text{Semi Annual PM} \Rightarrow 3.45 + 6.38 = 9.84 \text{ (operating hours)} \tag{12}$$

d. CM Downtime

Because our data gave us actual numbers for all elements of our operational availability equation except for CM, we plugged in all our calculated numbers and solved for CM. To calculate CM downtime, we used the A_O formula discussed previously. Subsequently, we calculated total time and PM downtime, which gave us the following equation:

$$A_o = \frac{TOT - PM - CM}{TOT} \text{ or } \text{CM}=TOT - PM - A_o \times TOT \tag{13}$$

Therefore:

$$CM = 166 - 9.84 - .895 \times 166 = 7.59 \text{ Hrs} \tag{14}$$

When 7.59 operational hours were normalized to weeks, we found that each craft spends 2.38 weeks in the CM cycle.

Further, we analyzed the components of the CM downtime. The CM downtime is a function of total failures and the average repair time of these failures. The repair time, or turnaround time, is based on the actual repair time and ALDT in terms of spares availability. Spares availability is expressed in terms of service level, and for the SOCR, an objective service level is established in the life cycle sustainment management plan as 95% for repair parts with an objective lead-time of five days for parts not on hand. USMI has the responsibility of maintaining inventories of repair parts and ensuring that appropriate lead-times are maintained. If parts are on hand, the cycle-time for CM is estimated at seven days. Converting these numbers in terms of operating hours, we found the following for CM average repair time and supply lead-time:

$$\text{Op Hrs lost to CM} = \frac{\text{Days of Maint}}{\textit{Days} \text{ in a Week}} \times \text{ Weekly Op Hrs} \tag{15}$$

$$\textit{Therefore}: \frac{7}{7} \times 3.19 = 3.19 \text{ Operating Hours}$$

$$\text{Supply Leadtime} = \frac{\text{Days lead time}}{\text{Days in a week}} \times \text{ Weekly Op Hrs} \tag{16}$$

$$\textit{Therefor}: \frac{5}{7} \times 3.19 = 2.28 \text{ Operating Hours}$$

To calculate the number of failures per craft per year—called *F* in Equation 17—we used the following equation:

$$H = F \times ((CM_h \times P_s) + ((S + CM_h) \times P_n))) \tag{17}$$

H: operating hours
F: number of failures
CM_h: operating hours lost to CM
P_s: probability of part in stock
P_n: probability of part not in stock
S: supply lead-time

$$\textit{Therefore}: 7.59 = F \times ((3.19 \times 0.95) + ((2.28 + 3.19) \times .05))) \tag{18}$$

Solving for *F* gives 2.29 failures per craft per year.

e. Full-Mission-Capable Rate

The full-mission-capable (FMC) rate tells how many craft are available on average for any given time and is a function of the number of craft possessed and A_O:

$$FMC = \text{ number of craft } \times \text{ operational availability} \tag{19}$$

In our case, the FMC is therefore as follows: 24 x 89.5% = 21.5 craft. In other words, 2.5 SOCR are not available at any given time, on average. Because operational requirements require only 20 full-mission-capable craft, SBT-22 is maintaining greater than 100% of their operational requirement.

4. What-If Analysis Scenarios for the SOCR

We conducted a simulation in order to model the effects of variation in boat usage based on operational hours. In order to model operating-hour variation, we needed to hold constant the parameters affected by operating hours.

a. Preventive Maintenance

Because PM takes one week to complete and is done every six months, it has an impact on the number of operational hours that the craft is available. If the average operational hours of use rises, then the operational hours lost during the two weeks of PM will rise. In addition, PM time is scheduled for 14 days; however, there are times when the SOCR are sent to USMI for PM and the craft remain at USMI for more time than expected. The reason for this variation is CM that is discovered during the PM. Based on data and interviews at USMI, we felt that we could make the assumption that scheduled PM does not have significant variation; rather, it is the CM component that creates variation in turnaround time.

b. Service Life Extension Program

SLEP takes 60 days to complete and is completed at USMI on the same manufacturing floor as new craft. We did not model a distribution for SLEP and assumed there is no variation. Because SLEP is conducted once during the useful life of the craft, we spread the SLEP downtime across the seven years of useful life for the craft. SLEP also displaces one of the semiannual PMs. For this reason, we divided 53 days of additional downtime by seven years to find that SLEP accounts for 1.08 additional weeks of downtime.

c. Corrective Maintenance

We assumed a direct relationship between operating hours and CM. We calculated the CM based on the difference between the realized operational readiness and the operational readiness that would have been reported if only PM had been conducted. We then fixed this ratio of CM tasks and operational hours of use by dividing the number of CM failures per year by the average operational hours in a year. We then multiplied this ratio with the simulated operational hours to model the number of CM jobs expected for each simulation year.

If the SOCR program is running as designed, we estimated a repair turnaround time of seven days when parts are on hand and twelve days when parts are not on hand. This estimation gave us a weighted average of 1.03 weeks of turnaround time for CM. By multiplying this turnaround time by the number of simulated CM repairs, we found the expected total CM downtime for each simulation year.

d. Simulation Results

Using the PM, SLEP, CM, and operational hours parameters, we created a distribution of expected A_O by using Monte Carlo simulation with software Crystal Ball. With a 95% certainty, A_O was greater than 87.1% (see Figure 6). This means that 20.9 SOCR will be operational at least 95% of the time.

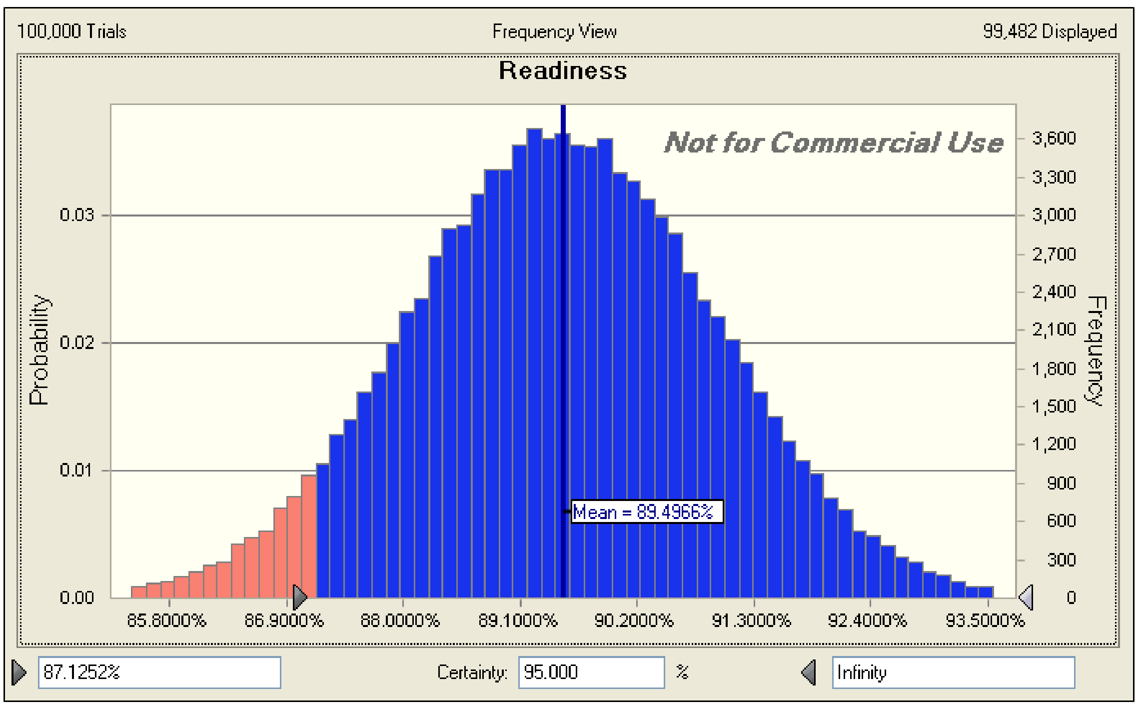

Figure 6. Operational Readiness

Because the SOCR program was designed for 20 operational craft, the A_O exceeds program requirements and there is less than a 0.01% chance that fewer than 20 operational craft will be available (see Figure 7).

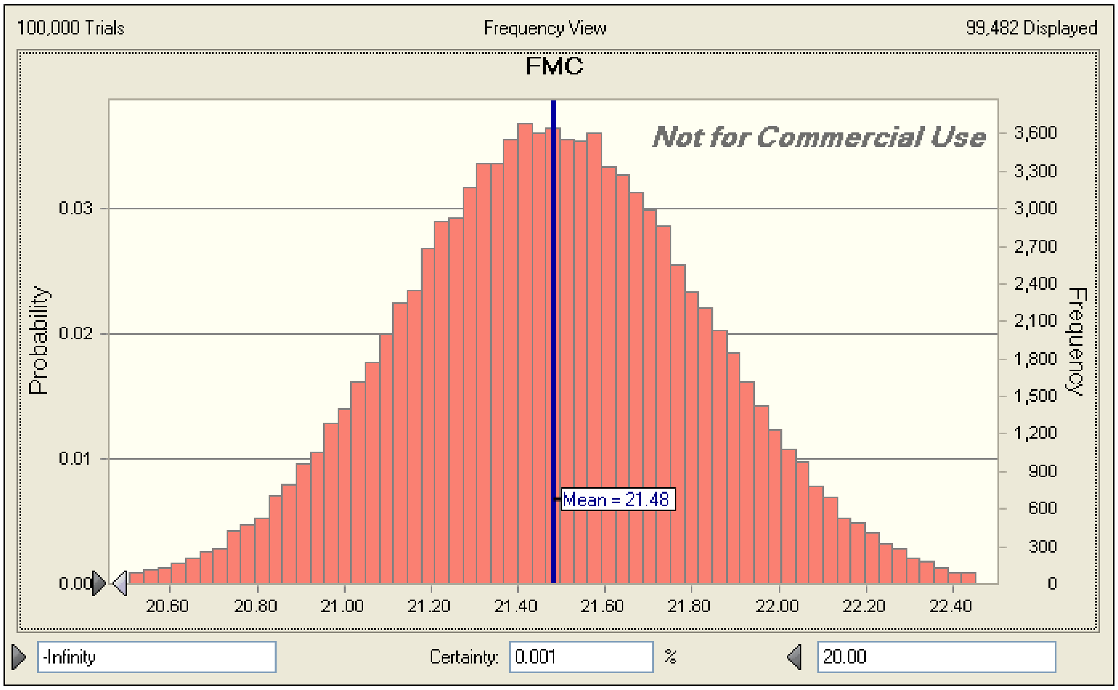

Figure 7. Full Mission Capable

The number of repairs that can be expected will also vary. This is because operational hours have a direct relationship with CM. Based on our simulation, we found that the expected number of repairs per year was 3.49 or fewer for any given craft in the SOCR inventory given a 95% confidence interval (see Figure 8).

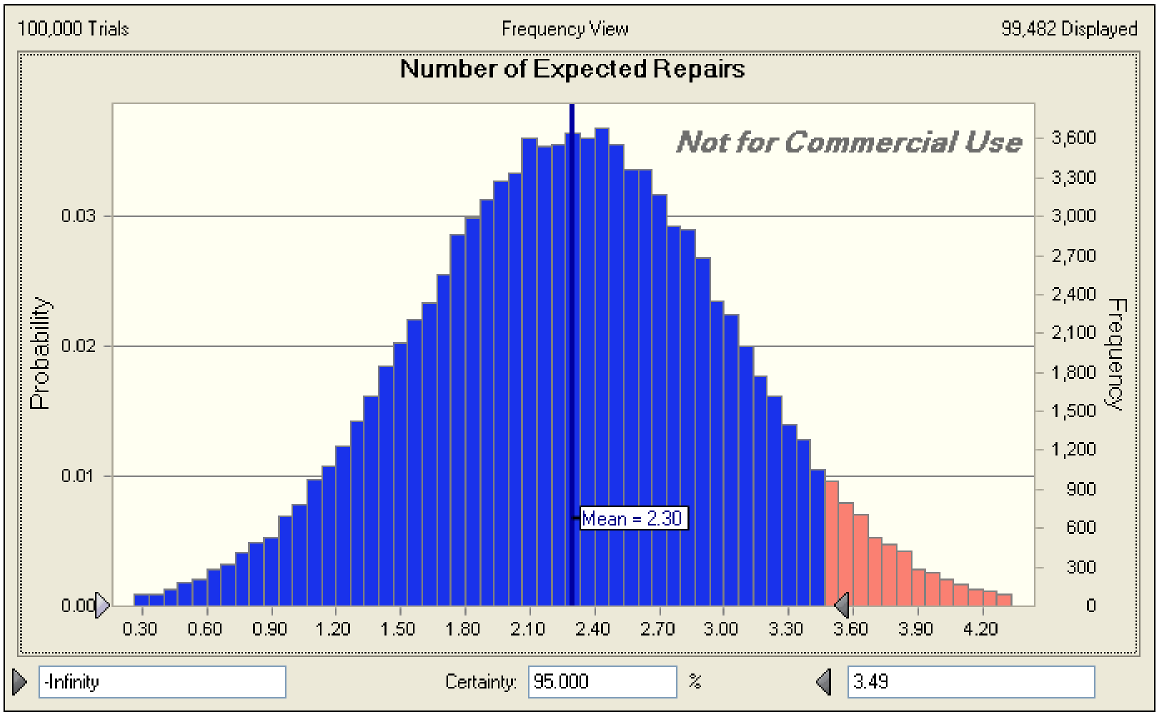

Figure 8. Number of Expected Repairs

D. SUMMARY

In this chapter, we have used the data we collected to analyze the SBS and DDPs ability to provide spare parts for required maintenance in order to reduce the administrative downtime associated with ordering parts. We looked at the service level currently provided by the pre-staged inventories and created a model to enable decision-makers to plan on-hand quantities required to meet their desired service level. In the next section, we will make recommendations for improvements in the SBS and DDPs based on the model we developed.

We also analyzed the operational readiness of SOCR. This analysis enabled us to simulate changes in the parameters affecting operational readiness. Through this analysis and simulation, we make recommendations which management can consider for attaining the highest operational readiness at the most economic cost.

V. RECOMMENDATIONS

A. SBS AND DDP SERVICE LEVELS

The SBS and DDP are both pre-staged inventories that serve the purpose of decreasing administrative downtime for SOCR requiring maintenance. They do this through maintaining a protective inventory for parts. By making a determination on what A_O is required for the craft supported by these inventories, SBT-22 managers can use the model presented in Chapter IV of this report to hold the A_O constant while making adjustments to the quantities of parts maintained in the SBS and DDPs.

Because maintenance repairs often require a variety of repair parts, maintenance managers will need to determine which critical maintenance jobs will be necessary to keep the SOCR operational. A critical maintenance job is any PM or CM job that will prevent the operational use of the SOCR. Each of the parts needed to complete these jobs needs to be identified by maintenance personnel; this listing of parts will be classified as a parts kit. With our current data, we did not have the ability to calculate the average occurrence for these jobs; however, once the job kits needed for critical maintenance are identified, the protection level for each of the parts contained in the job can be used to indicate the current protection level for the kit given the SBS and DDP inventories.

Further research will be useful for determining a more accurate estimate of average occurrence for critical maintenance jobs. By developing a history of completed jobs, orders for parts not required in critical maintenance will be identified as well as the identification of parts used in critical maintenance jobs but that were ordered independently of a critical maintenance job.

These recommendations will not change the concept of the SBS and DDP but will enable managers to quantify the impact that decisions will have on inventory protection levels and readiness.

B. AVAILABILITY

Based on the data we collected, we were given the availability of the SOCR. In this report, we used the data to separate that availability into its components and estimate how much each component contributed to the system availability. Once management at SBT-22 makes a determination on what the desired availability target should be, decisions affecting the components of availability can be made to achieve that desired availability level.

1. Service Life Extension Program

SLEP is the largest contributor to the reduction in availability. Because SLEP is a PM function, there is an inherent relationship with CM. In order for SLEP to be worth doing, it must reduce CM downtime by at least the same amount of time that it takes to complete SLEP. In the case of the SOCR, this would mean reducing annual maintenance by almost exactly one extra week of CM annually per craft, which is equivalent to about one additional CM job annually.

In addition to the impact that SLEP has on availability, SLEP should be considered in terms of cost. Currently, a new SOCR with all engineering changes costs $1,365,155 to replace and SLEP costs about $200,000. Based on the cost of the craft and the expected hours of use, we found that the cost of each operational hour is about $1,175. By using this cost per operational hour, we found that each craft's life must be extended by about 170 operational hours for SLEP to be effective; we can expect SBT-22 to accumulate this many hours in just over one year. SLEP is only cost effective if it extends the life of the craft by greater than one year.

Under the current procurement schedule, four craft per year were delivered over 12 years. Only 24 craft were authorized. This means that the authorized craft limit was achieved in six years. In order to maintain 24 craft, SBT-22 had to dispose of excess craft when new craft were delivered, which resulted in a six-year effective life. As a result, the oldest craft in service as of July 2012 is only 5.46 years old. USMI has specified a seven-year service life for their craft when a SLEP is conducted; therefore, we can see that SBT-22 does not get the benefit of the full service life of the craft. In fact, the data we collected indicates that disposing of craft based on the established procurement schedule actually reduces the useful life that SBT-22 gets out of their SOCR by at least one year.

2. Scheduled Maintenance

Currently, SOCR PM checks and services are scheduled every six months. They are conducted regardless of the number of operational hours that the craft is used.

For components that give an indication of wear prior to failure or are of low criticality, conducting checks is an economical way of maintaining a high readiness level. This process is referred to as conditions-based maintenance (CBM; Golmakani, 2012). An example of a PM item for which a CBM check would be appropriate could be a load test on an alternator. Rather than automatically servicing or replacing an alternator, which is an expensive repairable component, a load test would indicate if an alternator has decreased voltage output, which indicates that it will fail soon. Either an inspection can be performed manually during scheduled checks and service intervals, or it can be built into the system through sensors, which indicate when conditions have been met that requires maintenance activities. CBM enables maintainers either to detect defective components prior to failure or anticipate failure based on the increased risk as known conditions are met (Golmakani, 2012).

Services are conducted during the PM cycle regardless of the condition of the craft. For parts or materials that fail often, are inexpensive, are easy to replace, do not give indications that they will fail soon, have a predictable failure pattern, or are of high criticality, a service may be more economical. An example of a part that would be serviced could be a thermostat. Because a thermostat gives no indication it is about to fail, and when it does fail, causes the engine to overheat and become inoperable, it may be more economical to replace it during scheduled service rather than run it to failure.

Many checks are easily conducted, and those that require a lot of disassembly oftentimes are better completed with a service. Even if some checks are done more often than needed, because they are easily completed, it is still economical. The decision to accomplish an unneeded PM task should be cautiously considered and analyzed from the perspective of risk of accidental damage from the maintenance action itself. For this reason, a calendar-based schedule is appropriate for many checks, but would deserve analysis of the checks being performed to determine if there is a risk of generating more maintenance requirements through accidental damage. Because SBT-22 has mechanics that are capable of all operational levels of maintenance on the SOCR, we recommend that these checks and any associated maintenance service as a result of conditions discovered during the checks should be conducted on their current schedule by SBT-22.

Many services for the SOCR are based on the wear that is put on the craft in terms of operating hours. With the current contract-based PM schedule, these services are conducted regardless of the operational hours, resulting in some unnecessary maintenance. We recommend that maintenance personnel at SBT-22 review the current maintenance schedule to determine which maintenance tasks could be converted to an operational hours–based schedule. This may result in less cost in maintenance and a higher operational readiness level.

C. FURTHER RESEARCH

Both the SOCR and RAB are manufactured by USMI and are almost identical in logistics support requirements. The RAB is not supported with a logistics support agreement with USMI. Further research could be focused on integration of best practices from both logistics support structures to better support both craft. This could result in further efficiencies because of standardization of procedures or spare parts, as well as pooling of spares.

With the SOCR program approaching its end, a next generation of riverine craft will need to be procured. Further research might look at the best practices from the SOCR and areas for improvement in order to help develop a program with an efficient life cycle cost, specifically when it comes to operating costs.

With the data we collected, we were able to calculate and model availability for the SOCR. Availability indicates an expected percentage of craft that will be available at any given point in time. Reliability indicates the probability of availability over time. For example, reliability will indicate what percentage of craft will stay operational over a defined time period for a mission. In order to determine reliability, data would have to be collected for overall craft failure rates. Maintenance tasks would need to be analyzed to determine what tasks are truly critical and which maintenance tasks are PM or minor repairs.

Finally, the SOCR model is not exclusive to this program. Further research could identify other low-density items and apply best practices from the SOCR program.

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APPENDIX. SOCR SPARES MODEL

							2 yr Avg Hrs	331.9503	Protection		0.95	0.85								
							Total Craft	Craft per DDP	Craft Per SBS		DDP Lead Time	SBS Lead Time								
							24	2	10		90	30								
PART #	DESCRIPTION	UOM	Cost	Sum of QTY	Sum of DDP Qty	Sum of SBS Qty	Per Craft	90 Day DDP	MTBF	λ	DDP Mean	DDP Spares	DDP Svc Lvl	Model DDP Vlaue	Current DDP Value	SBS Mean	SBS Spares	SBS Svc Lvl	Model SBS Value	Current SBS Value
233-7658	PLATE, 01-42443	EA	$ 18.60	80	4	1	3.33	0.42	99.59	0.01004	0.82	3	99.84%	$ 55.80	$ 74.40	1.37	3	60.23%		
233-7657	COVER, 01-46285	EA	$ 37.90	74	4	1	3.08	0.39	107.66	0.00929	0.76	2	99.89%	$ 75.80	$ 151.60	1.27	2	63.85%	$ 75.80	$ 37.90
233-7695	CAM	EA	$ 67.50	71	4	1	2.96	0.37	112.21	0.00891	0.73	2	99.91%	$ 135.00	$ 270.00	1.22	2	65.69%	$ 135.00	$ 67.50
311-7098	TERMINAL, NON-INSULATED BUTT, 14-BUTT (100/PK)	EA	$ 0.14	100	12	2	4.17	0.52	79.67	0.01255	1.03	3	100.00%	$ 0.42	$ 1.67	1.71	3	75.40%	$ 0.42	$ 0.28
313-7056	BATTERY, DEEP CYCLE, 12V LEAD ACID	EA	$ 210.09	80	4	2	3.33	0.42	99.59	0.01004	0.82	3	99.84%	$ 630.27	$ 840.36	1.37	3	84.07%	$ 630.27	$ 420.18
313-7023	BATTERY, CRANKING, 12V	EA	$ 153.95	58	4	2	2.42	0.30	137.36	0.00728	0.60	2	99.96%	$ 307.90	$ 615.80	0.99	2	92.10%	$ 307.90	$ 307.90
247-7094	SEAL, JWKZADF/201499	EA	$ 63.11	26	2	1	1.08	0.14	306.42	0.00326	0.27	1	99.74%	$ 63.11	$ 126.22	0.45	1	92.59%	$ 63.11	$ 63.11
854-7295	SEAL, GREASE UNITIZED (HD TRL)	EA	$ 38.45	177	6	6	7.38	0.92	45.01	0.02222	1.82	4	99.73%	$ 153.80	$ 230.70	3.03	5	96.49%	$ 192.25	$ 230.70
256-4513	GASKET, STRAINER TOP CAP, 3/16"THK, 70 DURO NEOPR	EA	$ 7.00	38	2	2	1.58	0.20	209.65	0.00477	0.39	2	99.26%	$ 14.00	$ 14.00	0.65	1	97.16%	$ 7.00	$ 14.00
247-7206	KIT, TAIL PIPE	EA	$ 5,075.30	15	1	1	0.63	0.08	531.12	0.00188	0.15	1	98.93%	$ 5,075.30	$ 5,075.30	0.26	1	97.22%	$ 5,075.30	$ 5,075.30
512-7093	FILTER, STRAIGHT AIR, 7.5" X 5"	EA	$ 119.18	93	2	4	3.88	0.48	85.66	0.01167	0.96	3	92.77%	$ 357.54	$ 238.36	1.59	3	97.67%	$ 357.54	$ 476.72
264-7003	ELEMENT, REPLACEMENT, AQUABLOC (FOR 500MA30)	EA	$ 7.53	92	8	4	3.83	0.48	86.60	0.01155	0.95	3	100.00%	$ 22.59	$ 60.24	1.58	3	97.77%	$ 22.59	$ 30.12
233-7644	V-BELT, ALTERNATOR	EA	$ 18.89	31	2	2	1.29	0.16	256.99	0.00389	0.32	1	99.58%	$ 18.89	$ 37.78	0.53	1	98.32%	$ 18.89	$ 37.78
247-7155	SEAL, HJ 291 WATER	EA	$ 883.85	11	1	1	0.46	0.06	724.26	0.00138	0.11	1	99.41%	$ 883.85	$ 883.85	0.19	1	98.43%	$ 883.85	$ 883.85
303-7027	CIRCUIT BREAKER, W31 SERIES, 15AMP TOGGLE-ACTUATED	EA	$ 27.82	11	2	1	0.46	0.06	724.26	0.00138	0.11	1	99.98%	$ 27.82	$ 55.64	0.19	1	98.43%	$ 27.82	$ 27.82
504-7131	PYROMETER, DUAL, 2" 300-1700 LOW BLACK BEZEL HEAD	EA	$ 97.82	11	2	1	0.46	0.06	724.26	0.00138	0.11	1	99.98%	$ 97.82	$ 195.64	0.19	1	98.43%	$ 97.82	$ 97.82
233-7659	O-RING, 05-06-537	EA	$ 1.73	10		1	0.42	0.05	796.68	0.00126	0.10	1	No Protection	$ 1.73	$ -	0.17	1	98.69%	$ 1.73	$ 1.73
074-7009	PLUNGER, SPRING, SS 5/8"-1TH LOCKING NOSE L-HANDLE	EA	$ 36.66	9	4	1	0.38	0.05	885.20	0.00113	0.09	1	100.00%	$ 36.66	$ 146.64	0.15	0	98.93%	$ -	$ 36.66
311-7046	SWITCH, TOGGLE MINIATURE, 5A AT 125VAC ON-ON SPDT	EA	$ 5.25	8	8	1	0.33	0.04	995.85	0.00100	0.08	1	100.00%	$ 5.25	$ 42.00	0.14	0	99.14%	$ -	$ 5.25
504-7002	GAUGE, ELECTRONC BLK, 100-250F WATER/GEAR OIL TEMP	EA	$ 25.04	8	2	1	0.33	0.04	995.85	0.00100	0.08	1	99.99%	$ 25.04	$ 50.08	0.14	0	99.14%	$ -	$ 25.04
854-7076	PLUG, ELECTRIC, 6-PIN	EA	$ 12.39	2		1	0.08	0.01	3983.40	0.00025	0.02	0	None	$ -	$ -	0.03	0	99.94%	$ -	$ 12.39
247-7109	BEARING, JNODAEV/201447H	EA	$ 409.42	7	1	1	0.29	0.04	1138.12	0.00088	0.07	1	99.75%	$ 409.42	$ 409.42	0.12	0	99.34%	$ -	$ 409.42
247-7091	SCREEN, INTAKE	EA	$ 1,477.76	21	2	2	0.88	0.11	379.37	0.00264	0.22	1	99.86%	$ 1,477.76	$ 2,955.52	0.36	1	99.41%	$ 1,477.76	$ 2,955.52
233-7313	GASKET, EXHAUST	EA	$ 6.02	6	4	1	0.25	0.03	1327.80	0.00075	0.06	1	100.00%	$ 6.02	$ 24.08	0.10	0	99.51%	$ -	$ 6.02
247-7097	O-RING, HAMILTION HJ292 WATERJET, TRANSOM	EA	$ 15.90	6	2	1	0.25	0.03	1327.80	0.00075	0.06	1	100.00%	$ 15.90	$ 31.80	0.10	0	99.51%	$ -	$ 15.90
504-7016	INDICATOR, FUEL LEVEL, 2-TANK TENDER SYSTEM	EA	$ 398.89	6		1	0.25	0.03	1327.80	0.00075	0.06	1	No Protection	$ 398.89	$ -	0.10	0	99.51%	$ -	$ 398.89
613-7325	ROPE, DOUBLE-BRAIDED NYLON 3/16" X 150' BLACK	EA	$ 49.26	6		1	0.25	0.03	1327.80	0.00075	0.06	1	No Protection	$ 49.26	$ -	0.10	0	99.51%	$ -	$ 49.26

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