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INVENTORY MANAGEMENT IN THE UNITED STATES MARINE CORPS' WAR RESERVE: IMPACT OF MARGINAL COST ANALYSIS THROUGH A MODIFIED NEWSVENDOR MODEL

by

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The United States Marine Corps (USMC) Installation & Logistics Command (I&L) seeks to store appropriate inventory levels of war reserve materiel (WRM) to meet future operational needs under surge demands of uncertain environments. The research of this capstone sought to understand the factors affecting appropriate inventory level for USMC WRM under the premise of using the newsvendor model framework. Through a systems engineering approach, the classic newsvendor model was modified to analyze the appropriate inventory levels using marginal cost and marginal benefit concepts. The modified model is demonstrated through a developed tool called the WRM marginal cost analysis tool (WRMMCAT). The WRMMCAT considers equipment, cost of materiel, storage and maintenance costs, materiel intrinsic value parameter, and conflict intensity factor for one Marine Expeditionary Unit (MEU) with an option to customize results for multiple MEUs. The modified variables in the model provide USMC planners with an output of predicted appropriate quantity of the specified materiel, the expected marginal cost of shortage/overage, and a probability of shortage/overage given a set of user-defined cost and demand data. The WRMMCAT enables a repeatable model for anticipating demand that will add value to the USMC in managing appropriate WRM inventory levels as well as future acquisition and pre-positioning decisions.

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ABSTRACT

The United States Marine Corps (USMC) Installation & Logistics Command (I&L) seeks to store appropriate inventory levels of war reserve materiel (WRM) to meet future operational needs under surge demands of uncertain environments. The research of this capstone sought to understand the factors affecting appropriate inventory level for USMC WRM under the premise of using the newsvendor model framework. Through a systems engineering approach, the classic newsvendor model was modified to analyze the appropriate inventory levels using marginal cost and marginal benefit concepts. The modified model is demonstrated through a developed tool called the WRM marginal cost analysis tool (WRMMCAT). The WRMMCAT considers equipment, cost of materiel, storage and maintenance costs, materiel intrinsic value parameter, and conflict intensity factor for one Marine Expeditionary Unit (MEU) with an option to customize results for multiple MEUs. The modified variables in the model provide USMC planners with an output of predicted appropriate quantity of the specified materiel, the expected marginal cost of shortage/overage, and a probability of shortage/overage given a set of user-defined cost and demand data. The WRMMCAT enables a repeatable model for anticipating demand that will add value to the USMC in managing appropriate WRM inventory levels as well as future acquisition and pre-positioning decisions.

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LIST OF ACRONYMS AND ABBREVIATIONS

AAO	authorized acquisition objective
CARF	combat active replacement factor
CDF	cumulative density function
CI	configuration item
CONPLAN	concept of operations plan
CoS	classes of supply
DLA	Defense Logistics Agency
DOD	Department of Defense
DODI	Department of Defense instruction
DRM	design reference mission
GCSS-MC	Global Combat Support System-Marine Corps
HADR	humanitarian aid and disaster relief
HQMC	Headquarters, United States Marine Corps
ID/IQ	indefinite delivery/indefinite quantity
I&L	Installations and Logistics Command
IOT	in order to
LOGCOM	Logistics Command
LPO-2	Logistics Plans and Operations (Maritime and Geo-Prepositioning Programs)
MAGTF	Marine air-ground task force
MARFOR	Marine forces
MCO	Marine Corps order
MCWP	Marine Corps warfighting publication
MEF	Marine expeditionary force
MEU	Marine expeditionary unit
OEF	Operation ENDURING FREEDOM
OIF	Operation IRAQI FREEDOM
OPLAN	operation plan

PDF	probability density function
STORM-E	synthetic operations research model-enhanced
TFSMS	total force management system
TLCM	total life cycle management
TTDSE	traditional, top-down systems engineering
USMC	United States Marine Corps
WRM	war reserve materiel
WRMMCAT	WRM marginal cost analysis tool
WRMR	war reserve materiel requirement
WRP	war reserve program
WRS	war reserve system
WRSA	war reserve suite of applications

EXECUTIVE SUMMARY

The United States Marine Corps (USMC) has been America's expeditionary force since 1775 capable of fighting on land, sea, and air. The battles that the Marines fight range from traditional peer-to-peer warfare to humanitarian and disaster relief missions (HADR). However, the wide range of conflict and the long history of developing expeditionary doctrine and innovations are not absent from challenges of materiel readiness where balance of winning battles and stewardship of taxpayers' money is often the acquisition decision factor.

This capstone report presents the development of a modified newsvendor model designed to assist the USMC Logistics Command (LOGCOM) and Installations and Logistics Command (I&L) in the USMC War Reserve Planning process by exploring expected marginal costs of inventory understock and overstock. Among the challenges that USMC faces is the uncertainty of the conflict environment as it relates to materiel demand. The current USMC model known as the War Reserve System (WRS) produces results that include obsolete materiel in the USMC inventory. Due to the age and the niche nature of WRS, USMC is searching for alternative methods for its war reserve inventory management. In addition to USMC contracting the efforts to develop new software to address the inventory management problem, the Naval Postgraduate School 522 program uniquely provides an opportunity to apply systems engineering management processes to ignite a potential solution from perspectives of academic research and operational experience.

Starting with an initial stakeholder analysis to define the problem statement, this capstone project seeks to decompose the challenges surrounding the USMC war reserve inventory management. The capstone team's initial research into inventory management and the newsvendor model revealed that applying economic business model to military or government scenarios in the absence of profit led to introduction of scenario-unique factors such as the intrinsic value of materiel and conflict intensity-driven demand distribution. Nonetheless, by modifying the structure of the newsvendor model while preserving its

inventory management framework, the capstone team was able to describe optimal inventory level in terms of expected marginal costs of inventory overstock and understock.

Foundational to this capstone project, we developed a model represented by a tool called War Reserve Materiel-Marginal Cost Analysis Tool (WRMMCAT). This model was informed through literature reviews on the classic newsvendor model, and requirements decomposition activities aided through extensive stakeholder communication. Essentially, WRMMCAT provides expected marginal costs when inventory is expected to be overstocked or understocked. The point at which the two expected marginal costs intersect is associated with the optimal inventory level as shown in Figure 1. Regardless of whether or not decision makers accept the model's results for optimal inventory level, the expected marginal costs alone provide risk and decision factors for war reserve planning.

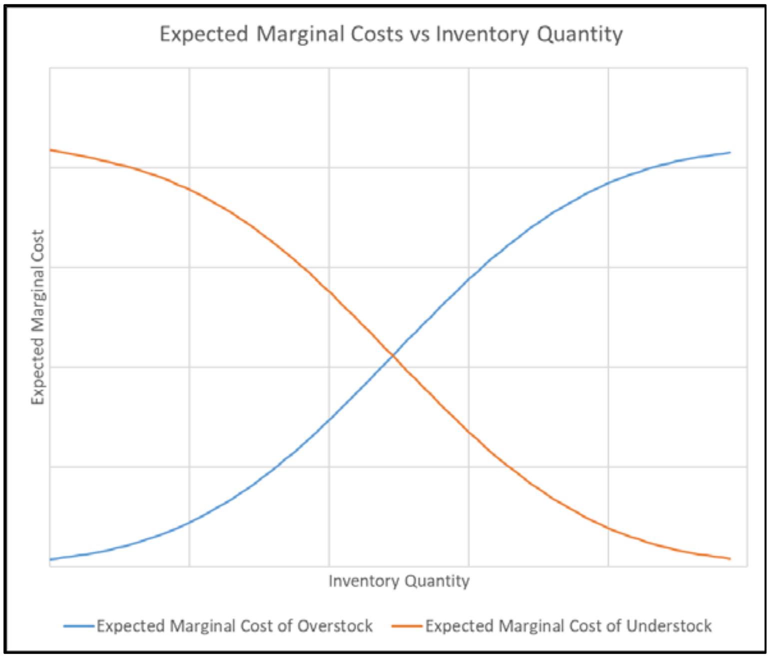

Figure 1. Graphical representation of expected marginal costs vs. inventory quantity

As one of the first activities following the systems engineering process, the capstone team identified the required components of the WRMMCAT. Furthermore, the capstone team ensured traceability of the requirements by developing a hierarchical model of the war reserve inventory problem as depicted in Figure 2.

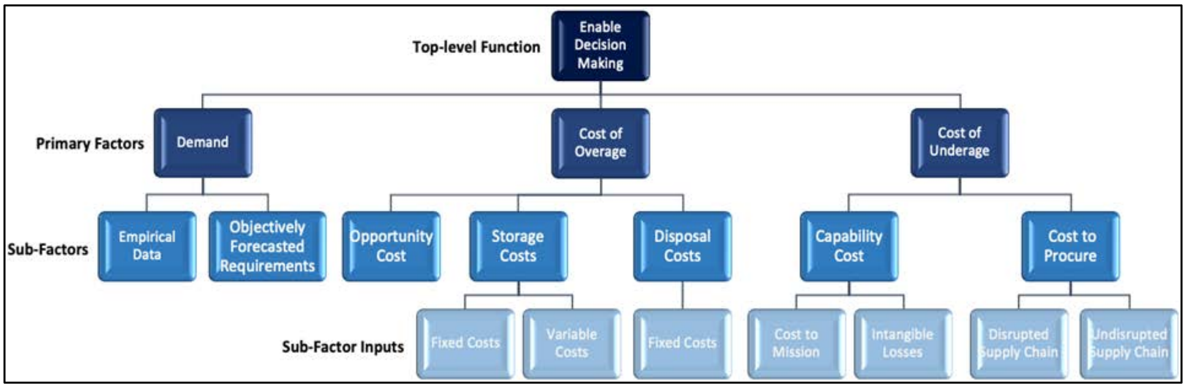

Figure 2. Systems engineering hierarchy

Given that the aim of the WRMMCAT is to determine the optimal stock level, Figure 2 categorizes required functions and tasks into the following three major components of the classic newsvendor model, which are: demand, cost of overage (overstock), and cost of underage (understock). A keynote in the project’s hierarchical model is that it includes both quantitative and qualitative attributes to describe the relationship between the three major model components.

Based on literature reviews, followed by stakeholder confirmation, the requirement for demand is decomposed into two sub-factors. The subfactors are empirical data and objectively forecasted requirements. Currently, the USMC forecasts future demand by referencing policy goals and available empirical data. When applicable and available, empirical data derived from historic consumption is the preferred method for establishing a demand distribution. Policy goals for the USMC is to ensure the proper decisions are made to attain a desired level of War Reserve Materiel (WRM). While policy goals drive the readiness requirement, it is important to note that empirical data may not accurately represent the evolving and emerging threat. This makes the task of predicting future demand almost impossible.

Nonetheless, current doctrinal practices based on policy goals represent future readiness. At the operational level, policy goals are translated into authorized quantity of an item for any USMC operational element. The authorized quantities are results of high-level policy assessment activities such as the doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy (DOTMLPFP) assessment. Additionally, the USMC conducts forecasted requirements analysis using national-level operational plans (OPLANs) to forecast future demand within the constraints of DOD WRM Policy. To inform future forecast, a collection of empirical demand data is required to generate a sample demand distribution across the USMC's organizational structure.

Figure 3 shows a representation of a general demand distribution used in newsvendor models. Since demand varies between items, each particular item of interest would have its own demand distribution curve. In terms of military operations, the distribution describes the likelihood of needing a certain quantity or amount of the interested item. Consequently, the range of conflict intensities is the driving factor for the PDFs since it influences the likelihood and the amount of items needed.

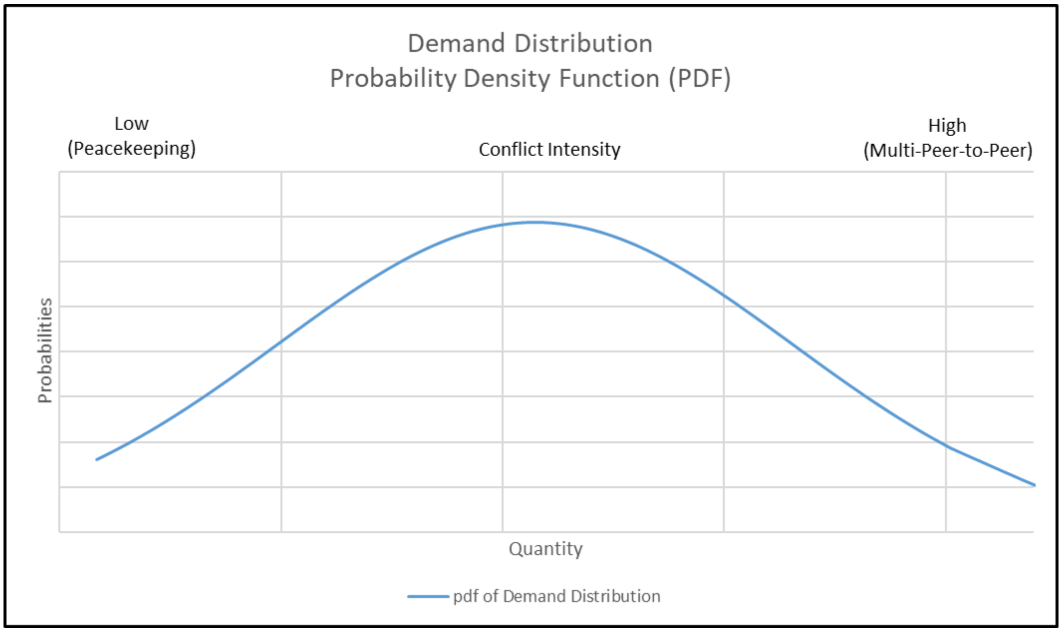

Figure 3. Representation of a general demand distribution

This capstone report presents the findings through the use of BA-5590/U non-rechargeable battery as our sample materiel for model validation. The WRMMCAT is used to generate the expected marginal costs of understock and overstock. As the hierarchical diagram in Figure 2 shows, cost of overage and cost of underage is decomposed into several cost factors that are mathematically described as independent variables. Based on requirements decomposition activities, the capstone team recognized that in order to capture the cost of lost military capability in monetary terms, the modified newsvendor model must introduce variables that represent military inventory management quantitatively and qualitatively.

Our findings of this report discuss the three variables introduced to the classic newsvendor model which are relative capability factor (β), materiel intrinsic value parameter (α), and conflict intensity factor (γ). Figure 4 shows the effects of the variables to the penalty cost function across wide range of values.

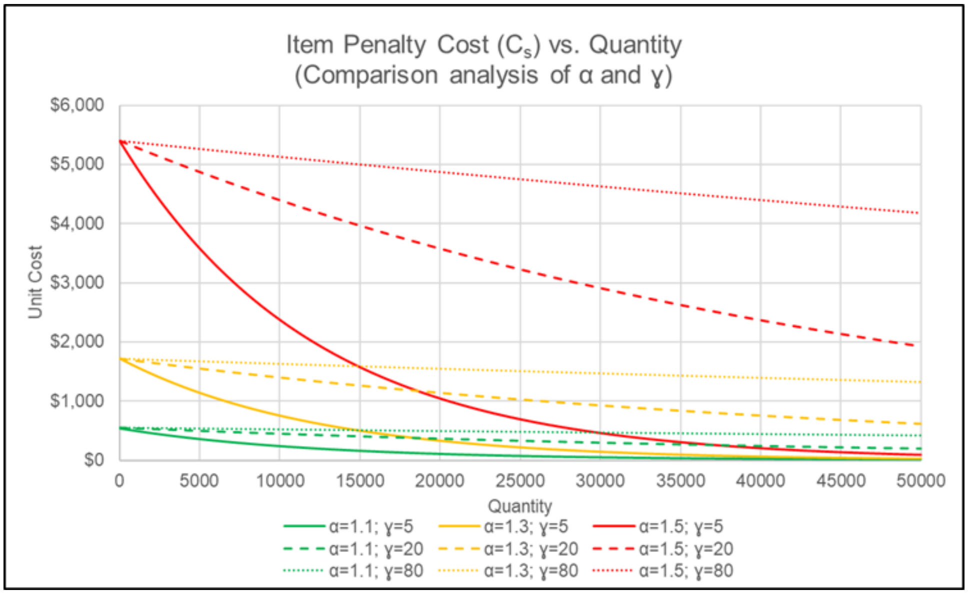

Figure 4. Item penalty cost vs. quantity

The relative capability factor is a ratio of any given inventory level and the doctrinally authorized quantity of an item that represents the value of an item to meet policy goals as a percentage. While the relative capability factor alone does not provide significant insight to the optimal quantity, it is an important variable to consider in terms of the potential magnitude of inventory level required to meet any of the existing OPLANs.

The two remaining factors are qualitative in nature, but they provide an essential quantitative function for the model's behavior. Materiel intrinsic value parameter, ranging from team-defined values of 1.0 to 1.5 characterizes the operational value of an item where increase in value indicates increase in importance. We observed that the materiel intrinsic value significantly affected the overall penalty cost. Likewise, the conflict intensity factor ranges from 1 and 80 to characterize the operational conflict intensity as a planning factor. The conflict intensity parameter affected the slope, or the rate, at which the penalty cost decreases over quantity. Because the capstone team developed the model to represent a relational behavior between demand and cost, the wide range of values are not discretely defined. Since the war reserve planning process is an iterative process requiring continuous risk analysis that is subjective in nature, defining the values restrict the planners to use expert knowledge and experience for the planning process.

With the BA-5590/U non-rechargeable battery as the sample item, Figure 5 depicts a graphical result for three potential scenarios using a materiel intrinsic value parameter of 1.3 and three varying conflict intensity factors. Figure 5 shows three separate intersecting points, or respective optimal inventory quantities, between the expected marginal cost of overstock and the expected marginal costs of understock. The graph provides a visual representation of the slopes of expected marginal costs as planning perception of materiel and demand changes. Table 1 provides sample results for the BA-5590/U non-rechargeable batteries that represents the sensitivity of the introduced variables in the newsvendor framework.

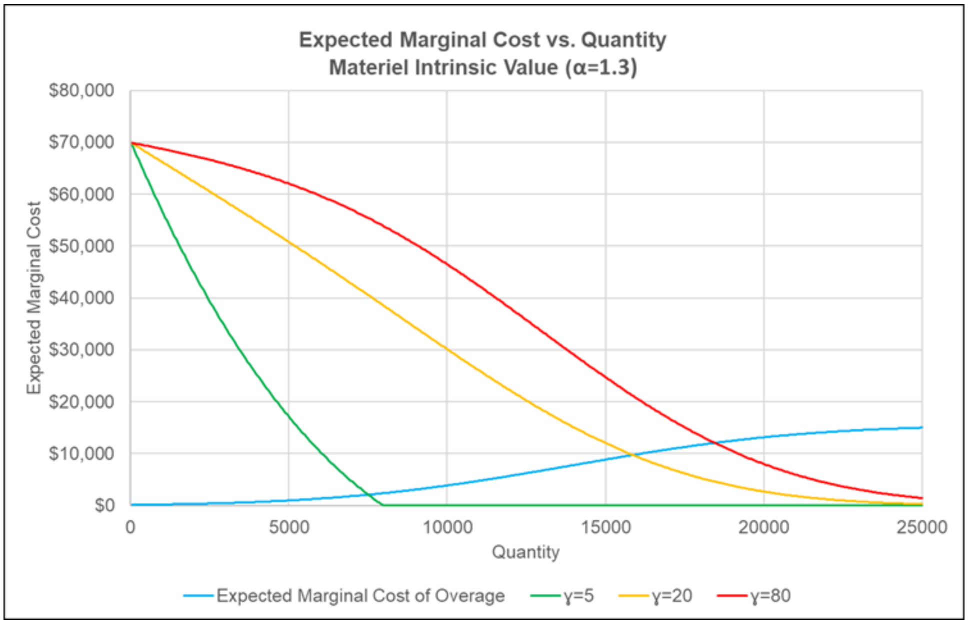

Figure 5. Materiel intrinsic value (α=1.3) vs. various conflict intensity parameters

Table 1. Optimal quantities resulting from sample α vs. ɣ values

	Low Conflict Intensity (ɣ)	Medium Conflict Intensity (ɣ)	High Conflict Intensity (ɣ)
Low Materiel Intrinsic Value (α)	α: 1.1 γ: 5 **Q*=3,100**	α: 1.1 γ: 20 **Q*=8,650**	α: 1.1 γ: 80 **Q*=11,900**
Medium Materiel Intrinsic Value (α)	α: 1.3 γ: 5 **Q*=7,550**	α: 1.3 γ: 20 **Q*=15,900**	α: 1.3 γ: 80 **Q*=18,500**
High Materiel Intrinsic Value (α)	α: 1.5 γ: 5 **Q*=10,100**	α: 1.5 γ: 20 **Q*=20,050**	α: 1.5 γ: 80 **Q*=22,450**

Where the WRMMCAT provides value to the USMC LOGCOM and I&L is the ability to quickly analyze potential scenarios that OPLANs represent. Furthermore, the subjectivity that exists between OPLANs is built into the WRMMCAT to provide planners with the flexibility to maintain the operational expertise required for risk analysis. By presenting the results in terms of expected marginal costs, the planners will have means for comparative analysis with existing fiscal policies for war reserve management. The capstone team's objective was to develop a model that produces an appropriate inventory level for the USMC's WRM. To achieve this objective, the team introduced critical variables that affect inventory stock within a widely applied inventory management framework. The WRMMCAT is specific to the purpose of war reserve inventory management with the flexibility to cover a wide range of materiel types given that existing and historical cost and demand distribution data are available.

The major limitation to the WRMMCAT remains with demand distribution data stemming from the newsvendor model framework. Since the newsvendor model is used for single-period analysis, such as the initial 60-day period of a surge deployment, the probabilities of understock and overstock remains with the accuracy of the demand distribution that best represent similar scenarios. While the WRMMCAT provides analysis for multiple Marine Expeditionary Units (MEUs), the fundamental calculations were developed under demand distribution of a single MEU. Therefore, further research and modification is required to validate the model's behavior for more complex relationship between demand and organizational size for planning.

Overall, the capstone team developed a tool using a systems engineering approach to provide the USMC LOGCOM and I&L an alternative method for war reserve inventory management planning. Instead of replacing an existing war reserve planning system, the sponsor sought different approaches on inventory management. Through the use of a popular inventory management model as the foundational framework, the team was able capture a complex logistics problem to deliver a repeatable analysis tool. WRMMCAT as it is delivered will need refinement to maintain relevancy to current and future war reserve priorities.

The capstone team believes that future research is needed to fully capture the complex network of factors that drive demand for specific materiel analysis. WRMMCAT and this capstone project research, as they stand, require more data collection and feedback from the USMC to understand additional shortfalls of the introduced variables in the model. A future research area related to this capstone project is capturing the wastage of materiel during differing intensities of conflict as WRMMCAT does not capture any waste and requires further refining to truly represent the operational environment. Furthermore, this research area could potentially extend its utility by integrating economic order quantity concepts for determining inventory reordering frequencies for expendable items such as the BA-5590/U non-rechargeable batteries.

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I. INTRODUCTION

A. BACKGROUND

The United States Marine Corps' (USMC) Air-Ground Task Forces (MAGTFs), such as Marine Expeditionary Units (MEUs) and Marine Expeditionary Forces (MEFs), are doctrinally self-sustainable for up to sixty days with authorized supplies and equipment. However, in scenarios of surge deployment, the Marine Corps requires additional supplies from the War Reserve Materiel (WRM) inventory with immediate availability to support theater operations until required long-term sustainment is established. Many factors determine the demand for equipment during surge deployments, which range from Humanitarian Aid and Disaster Relief (HADR) to multi-front war with one or more near-peer state actors. To make informed decisions, the USMC must have a thorough understanding of operational force stock levels, available WRM, and logistical capabilities and capacity for theater-level sustainment to address the operational need. Uncertainty in these factors affect Class VII (major end item) equipment and supplies, such as Class IX (repair parts) to support the required equipment. Further confounding the problem, multiple items critical to any war effort have limited suppliers and/or lengthy production lead times that cannot meet wartime surge demand. Given these many variables, the USMC has significant concerns regarding its ability to accurately predict and store appropriate levels of WRM inventory that can support a myriad of surge demand signals.

The purpose of this project is to generate a model for estimating optimal WRM for a given item using an alternative approach. Exploring variables that may assist USMC Installations and Logistics Command (I&L) in making informed WRM inventory level decisions rather than depending solely on the current USMC model known as the War Reserve System (WRS). Despite the uncertainty of Marine Corps deployment scenarios during surge requirements, our team has developed an inventory model to produce a suggested WRM inventory level for each item examined in the model. Through the input of specific variables such as cost constraints and organizational data, USMC planners may leverage provided deliverables to assist in the determination of appropriate WRM inventory levels.

USMC WRM is not a complete set of equipment and supplies for a particular unit size but is instead the difference in equipment and supplies that a unit currently has on hand to deploy with and what they require to fulfill their mission requirements. The USMC Warfighting Publication states,

> The WRM requirement is that portion of the war materiel requirement required to be onhand on (D-day) or after the day an operation commences. This level consists of the war materiel requirement less the sum of the peacetime assets assumed available on D-day and the war materiel procurement capability. It includes the depth of support required (supplies and equipment needed to sustain MAGTFs) for a distinct period of time and is based on projected employment scenarios to support either operational requirements or budgetary planning. (Logistics Operations [MCWP 4 –1] 1999, 2)

We can, therefore, surmise that the Marine Corps WRM stockage is tailorable to the prevailing Operational Plans (OPLANs) that are in effect at any given time. Given these plans change based on prevailing global threats and are also classified, we presume the USMC stores an inventory level in the WRM sufficient to meet a worst case and maximum intensity scenario.

1. Relevant Policy to USMC WRM Program

To establish a foundation of policy and doctrinal knowledge and to develop an adequate model with which to estimate optimal WRM levels, our team examined the current Department of Defense (DOD) WRM Policy and USMC WRM Doctrinal Standards. The USMC's, "war materiel requirement has two components: peacetime force and war WRM requirements" (Logistics Operations [MCWP 4 –1] 1999, 2–19). *The Marine Corps Warfighting Publication* (MCWP 4-1) states that USMC WRM stocks are held in two portions: field, or starter stocks, and inventory control, or swing stocks. Additionally, field stocks are materiel held by operating forces and are distributed around the globe to support initial operating force efforts, while inventory control stocks are centrally held and controlled at the wholesale level at USMC logistics bases, or within the DOD supply system, and are positioned around the globe, either afloat or ashore, and can support multiple operations. For this study, we are only concerned with the war WRM requirements and inventory control, or swing stocks. The USMC states, "The manner in which materiel support is planned and positioned considers both the organizational structure and employment doctrine of the MAGTF and the availability and responsiveness of access to stocks of war reserve materiel (WRM), which is maintained in accordance with DOD policy" (Logistics Operations [MCWP 4-1] 1999, 2–18). Department of Defense Instruction (DODI) 3110.06 WAR RESERVE MATERIEL (2019), published by the Under Secretary of Defense, Acquisitions and Sustainment, provides concise guidance to Military Departments for computing WRM requirements (levels of stockage). This policy guidance provides the USMC a great deal of latitude in determining their WRM requirements with the intent that the USMC provides adequate capabilities within their WRM inventory. Policy is significant as it is difficult to predict what the USMC determines an adequate mixture of objective and subjective measurements will be.

2. Current Efforts to Address WRM Concerns

According to the capstone project description provided by USMC I&L, Logistics Plans and Operations (Maritime and Geo-Prepositioning Programs) (LPO-2), the Marine Corps utilizes the legacy WRS software program to predict WRM demand. WRS uses inputs such as unit size, OPLAN, temperature zone, tempo of combat, total number of days for the plan, classes of supply needed and several others to enable withdrawal plan development. However, approximately forty percent of the projected demand generated by the WRS software is obsolete materiel in the USMC inventory. Due to the age and niche nature of the software, the organization is unsure how the software determines the demand. Currently, there is an effort to modernize the software through a War Reserve Suite of Applications (WRSA). An existing contract develops WRSA software (along with algorithm). The WRSA's goal is to allow a user to select desired classes of supply and the WRSA will generate the required quantity.

Modeling and simulation is also being leveraged to address WRM concerns through the Synthetic Operations Research Model-Enhanced (STORM-E) modeling platform via incorporation of energy-related features and modules to address operational energy issues. STORM-E provides Combat Active Replacement Factors (CARFs) to aid estimation of the USMC's War Reserve Materiel Requirements (WRMR) and inform the Authorized

Acquisition Objective (AAO). Specifically, a CARF is a planning factor used to forecast equipment attrition rates, and thus combat replacements, for Class VII and select Class II (Individual Clothing and Equipment). CARFs are currently calculated based on historical data from Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF), which limits their range of reliable application to High Intensity / Peer-to-Peer conflicts (SEED Center for Data Farming 2019).

B. PROBLEM DESCRIPTION

The primary research question to answer for this problem is what is the predicted appropriate inventory level for a given USMC WRM item, when considering marginal cost and the probability of various levels of item demand?

1. Problem Statement

Given surge requirement for uncertain environments, USMC I&L seeks alternative methods for selecting WRM inventory levels.

2. Scope

The research for this capstone seeks to understand what an appropriate inventory level for USMC WRM is when considering marginal cost and marginal benefit concepts as described in various inventory frameworks. We will construct a modified newsvendor framework model and demonstrate it through a sample application of the BA-5590/U non-rechargeable battery.

3. Project Key Assumptions

a. Model Driving Assumptions

1) WRM inventory requirement is to meet the initial sixty days of deployment need.

2) Inventory reorder is not feasible within a sixty-day timeframe of unit deployment surge.

3) An unlimited transportation capacity to deliver WRM items.

4) ***Project does not account for Combat Active Replacement Factors.***

b. Sample Driving Assumptions

1) ***Marines will demand BA-5590/U batteries at the start of mission (batteries at <100% capacity are assumed thrown away).***

2) ***Energy infrastructure to use rechargeable batteries are not established in the sixty-day timeframe.***

C. PROJECT OBJECTIVES

The overall objective of this capstone project is to develop a model that uses the concepts of expected marginal cost of item shortage and excess to provide an optimal inventory level for any given item of interest. Inventory levels are based on multiple factors described in the applicable OPLAN. Particularly, this project has the following sub-objectives:

1. To determine the key/critical variables for the model that affect the resulting inventory stock.

2. To consider the BA-5590/U battery to observe the value of our inventory model to aid the WRM decision-making process.

D. LITERATURE REVIEW

Marine Corps WRM process flow, the newsvendor (problem) model, and conflict trends (demand) were examined. In addition to examining existing Marine Corps doctrine and policy, models, historical case studies, and related logistical optimization, efforts were directed to journals, theses, books, and research databases to categorize according to the knowledge base in relation to the Marine Corps War Reserve Materiel: doctrine, current operational practices, optimization models, and conflict intensity factors. An objective focus on gathering information and knowledge of the variables and various process and mathematical models that affect inventory optimization given an uncertain Marine Corps surge demand were focused on.

1. WRM Process Flow

The 2016 Naval Postgraduate School MBA professional report titled *Performance Analysis of the United States Marine Corps War Reserve Materiel Program Process Flow*, by Campbell, Helwig, and Sweet, provided an exploration of the historical performance of the USMC WRM Process Flow, focusing on the OIF force build up prior to the 2003 invasion of Iraq. The report also, "focused on the processes and procedures that take place within LOGCOM to identify, procure, package and ship when an item is requested but not maintained in the WRM inventory" (Campbell, Helwig, and Sweet 2016). Through both computer modeling and process analysis, the report recommended efficiency improvements and reduction of lead time to better support future surge demand. This report, along with multiple Marine Corps doctrine and policy documents, helps us to understand the current USMC WRM order and re-order process and how these procedures might influence our quantitative approach to improving USMC WRM (Campbell, Helwig, and Sweet 2016).

2. Newsvendor (problem) model

Evan L. Porteus, of Stanford University, indicated in his work, "The Newsvendor Problem," that the newsvendor model can be tailored and applied to a variety of predictive problems. He states that, "It occurs whenever the amount needed of a given resource is random, a decision must be made regarding the amount of the resource to have available prior to finding out how much is needed, and the economic consequences of having 'too much' and 'too little' are known" (Porteus 2008, 115). The newsvendor model seeks to optimize inventories to maximize profit. Traditionally, the problem involves uncertain demand, a perishable product, fixed prices, and a single selling period. Actual demand at any given time is unknown, and its underlying probability distribution is known, typically from historic empirical data. The cost of an unsold paper is a known variable. Customer satisfaction, or lost profit costs is also a known variable. Porteus's work helps us to understand the newsvendor model and how we might apply it to the USMC WRM problem.

3. Conflict Trends (Demand)

The RAND Corporation study entitled, *Conflict Trends and Conflict Drivers: An Empirical Assessment of Historical Conflict Patterns and Future Conflict Projections*, by Thomas Szayna, sought to answer the research question, "What have the trends in conflict been, why they have changed, and what can we expect in the future?" RAND Corporation's typology used in the study served to assist the researchers, not only in the organization of data, but also, in the determination of which data points were worthy of inclusion in a formula with which to anticipate future conflict trends. This capstone project will consider the typology used by RAND Corporation as a model to aid in our variable identification and appropriate inventory model development.

E. STAKEHOLDER ANALYSIS

The value stakeholders can expect from the project is an appropriate inventory model that recommends the optimal quantities of WRM inventory in order to meet surge demand. An appropriate inventory model will help to determine the highest return on investment, given the variability of surge demand, to meet WRM requirements. Appropriate inventory model will support follow-on implementation of value model optimizations in order to assist the USMC in the quantitative analysis to support current WRM requirements, WRM forecasting, and the prioritization of WRM as determined by surge demand. The USMC currently stores vast amounts of materiel in WRM; however, our sponsors believe these quantities could be tailored to meet surge demand. The project aims to provide USMC stakeholders a model to improve WRM to either validate or invalidate the current WRM inventory.

1. I&L, LOGCOM, LPO-2

The War Reserve and Maritime Pre-Positioning Team at LPO-2, Installations & Logistics Command, desires alternative methods for determining WRM requirements. The research presented in this capstone project will provide the stakeholder information to consider for its future WRM stocks, or stock aboard Maritime Pre-Positioning Ships modernization efforts. The output from this capstone inventory model will provide an additional tool for consideration by LPO-2 to aid in acquisition and positioning decisions, as indicated in Figure 1.

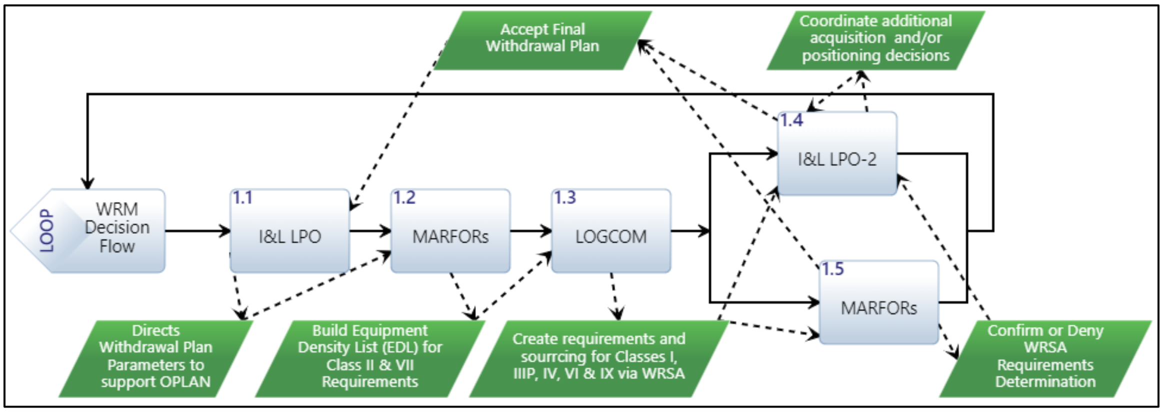

Figure 1. War reserve materiel planning process

2. Defense Logistics Agency (DLA)

The Defense Logistics Agency (DLA) supports warfighter readiness as the DOD agency responsible for procurement and storage of WRM items, such as the BA-5590/U battery. Additionally, DLA is responsible for other items that may not be required in peace time but do require an industrial investment to ensure adequate stocks are on hand to meet surge demands. Defense Logistics Agency's stake is in understanding the need of all military departments to manage the supply chain and industrial base to adequately procure and store items to meet specific operational demands.

F. DESIGN REFERENCE MISSION (DRM)

The DRM provides the operational context of how our modified newsvendor model enables USMC LOGCOM and I&L to consider an appropriate level of USMC WRM inventory. Unlike DRMs for technical systems that provide operational context in support of combat operations, the DRM for inventory optimization problem that we face is in support of several risk-based decision-making processes to understand the effects of inventory in terms of marginal costs.

The currently used legacy WRS, noted as outputs of actions 1.2 and 1.3 in Figure 1, is antiquated and does not meet today's logistics planning needs due to untrustworthy / untimely data results, does not follow current planning processes in a resource constrained joint logistics environment, and does not provide decision makers with risk analysis that prioritizes limited resources to meet requirements (T. Hagen, email to author, April 8, 2020). Provided that existing systems and processes may be omitting information that would otherwise better inform resulting inventory decisions, our model seeks to assist the decision-making process as an additional decision factor to action 1.4 of Figure 1. To develop a viable DRM, we assume that military objectives are generally affected by materiel availability. If materiel availability is affected by inventory management decisions, then one of the major decision factors is the cost to maintain the inventory. Converse to the cost of maintaining the inventory is the "cost" of not having the inventory. In terms of cost, it is relatively easier to conceptualize the adverse military effects of not developing a technical system at all than the effects of not having *enough* of existing materiel or systems.

Therefore, development of inventory management models within a decision-making process framework aids in selection of appropriate inventory level of commodity items. Our DRM is bounded by how USMC LOGCOM and I&L would potentially use a modified newsvendor model to affect the existing decision-making process by highlighting the feasibility and fidelity of using marginal costs as a major decision driver. This DRM is an additional, but an essential data point in attempting to capture the complex nature of balancing various military scenarios and budget constraints.

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II. METHODOLOGY

A. SYSTEMS ENGINEERING APPROACH (REQUIREMENTS ANALYSIS)

This chapter outlines the methodology used to define the problem and the requirements of the mathematical model. LPO-2 must support the future materiel requirements of multiple MAGTFs; however, missions, threats, and locations are all unknown. This unknown nature and inherent variability magnify the need for a methodical and systematic approach. While an informative mathematical model is not a traditional physical system, the team chose to apply a traditional, top-down systems engineering (TTDSE) approach to the problem requirements analysis (Buede 2009, 19). “A top-down approach views the system as a whole” (Blanchard and Fabrycky 2014, 18). This systems engineering approach provides a framework to understand the variables, their relationships, inherent conflicts, and required tradeoffs. The systems engineering approach also allows us “to translate operational needs and requirements into operationally suitable blocks of systems” (Blanchard and Fabrycky 2014, 18).

We performed the following steps: mission requirements; stakeholder requirements analysis; system requirements overview; and component and configuration item (CI) requirements overview. These steps align with the process described in The Engineering Design of Systems by Dennis M. Buede. According to Buede, requirements are decomposed via a top-down decomposition process consisting of two hierarchies (Buede 2009, 20). The first, or top-level requirements include the overall “supersystem” mission and the stakeholder requirements of the “supersystem.” In our case, the “supersystem” is the entirety of the LPO-2 war reserve program. The lower hierarchy includes the “sub-system” or system to be developed, the component requirements, and the configuration item requirements. (Buede 2009, 154). The sub-system is the requested mathematical model. Figure 2 illustrates the requirements hierarchy.

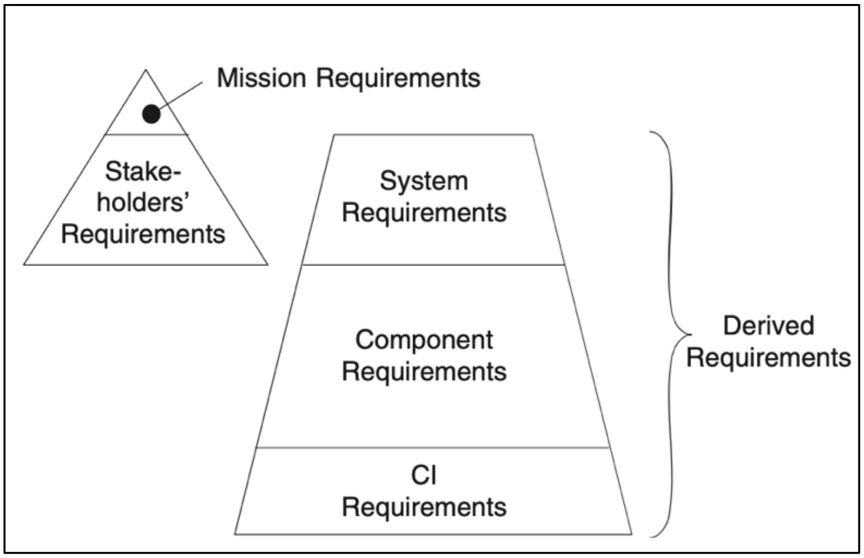

Figure 2. Requirements hierarchies. Source: Buede (2009).

In applying a systems engineering framework our requirements must be defined and traceable. In *Systems Engineering and Analysis*, Blanchard and Fabrycky state, "The true system requirements need to be well defined and specified and the traceability of these requirements from the system level downward needs to be visible" (Blanchard and Fabrycky 2014, 18). Utilizing this systems engineering approach, we can decompose the requirement, identify critical factors and functional relationships to facilitate the development of a tool that recommends a balanced solution that is traceable to the stakeholders' needs.

B. MISSION REQUIREMENTS

LPO-2's mission statement is, "To provide worldwide, integrated logistics/supply chain and distribution management; maintenance management; and strategic prepositioning capability in support of the Operating Forces and other supported units in order to maximize their readiness and sustainability and to support enterprise and program level Total Life Cycle Management (TLCM)" (Marine Corps Logistics Command 2015). The operational need is for an additional tool that provides an alternative method of informing sourcing and stocking decisions. The purpose of this tool is to provide an additional method of approaching difficult sourcing and stocking decisions. The consideration of multiple informative tools and methods allows decision makers to better assess risk.

Specifically, there is a requirement for a tool that considers the WRM Stakeholders' needs, marginal cost, marginal benefit, and the potential impact on the mission. The projected use of this model is to better inform sourcing decisions or war reserve materiel stock levels.

C. STAKEHOLDER REQUIREMENTS ANALYSIS

We utilized Marine Corps Doctrine, Marine Corps Logistics Command Strategic Plan (2015-2025), and correspondence with our sponsors to identify the stakeholders, their roles, interest and influence for the War Reserve Materiel program. The stakeholders are the organizations and individuals that affect and/or are affected by the WRM program "supersystem." The supersystem is the Marine Corps WRM program. As such we considered the needs of the WRM program stakeholders. Table 1 identifies the stakeholders, type, interest and influence.

Table 1. Stakeholder analysis table. Adapted from Marine Corps Logistics Command (2015).

Stakeholder	Type	Interest	Influence / Impact (to project)
I&L, LOGCOM, LPO-2	Acquirers / Maintainers / Developers / Administrators	Success is a tool that informs sourcing decisions, quantifies and weights WRM objectives, stakeholder needs, IOT deliver capabilities and increase readiness	Primary Stakeholder; Funding Requests and Sourcing Decisions; Manage and Maintain Materiel (Storage Costs); Pre-positioning Decisions
Marine Corps Logistics Command	Assessors / Communicators	WRM program that supports the accomplishment of assigned support mission; readiness and capability	Policy for WRM; protection level guidance.
Operating Force	Customer / Users	Operational needs met; Right equipment at right time; readiness	Operational need and value; empirical data influences demand; opportunity costs
Combatant Commands	Customer / Users / Support Staff	WRM to meet OPLAN requirements; Equipment for successful mission accomplishment	OPLANs influence Demand; Protection level/planning considerations
Congress	External Organization	Funding / Political Objectives / prudent spending; mission accomplishment	Funding approval; policies
Taxpayer	External Stakeholder	Expected protection level / insurance; Operational mission success; Prudent spending / reduce or avoid waste	Return on investment; Military protection / mission accomplishment
Manufacturer / Industrial Base	Suppliers	Business Profit	Surge Capacity / Availability of item during conflict; warm/cold industrial base
Defense Logistics Agency (DLA)	External Support Organization	Industrial base investment programs; WRM supply support; Cooperative agreements with USMC LOGCOM	Procurement Costs; IDIQ Contracts / BPA Agreements; Supply chain disruption considerations

Our analysis shows inherent conflict among the needs of the shareholders, specifically cost and funding constraints, and the materiel cost of achieving a greater level of readiness. The need to balance cost and readiness is a fundamental aspect of the problem and a requirement of our model.

D. SYSTEM REQUIREMENTS OVERVIEW

Any model that aims to successfully meet stakeholder needs and inform decisions must identify, evaluate, and substantiate the requirements, or factors, that inform the model. As Buede states, “Developing a good and complete set of requirements is very difficult” (Buede 2009, 157). To address this challenge, the team employed a modified systems engineering approach to rigorously identify and define which components, or factors, should be used in the model and to substantiate their use in the model. Furthermore, the systems engineering approach requires traceability. The team accomplished this traceability via the creation of a hierarchical model. This decision was consistent with Buede (2009, 153) as he indicates,

> The requirements for a system set up standards and measurement tools for judging the success of the system design. These requirements should be viewed hierarchically. At the top are mission-level requirements that establish how the stakeholders will benefit by introducing the system in question into the supersystem of the system. These mission requirements relate to objectives of the stakeholders that are defined in the context of the supersystem, not the system itself. (Buede 2009, 153)

Therefore, the team had to determine what factors, or requirements functions, need to be considered in the model to successfully meet the fundamental objective of enabling decision makers (stakeholders). Our model is a system, which is defined by Buede (2009) as, “a set of components (subsystems, segments) acting together to achieve a set of common objectives via the accomplishment of a set of tasks” (Buede 2009, 157). Thus, the factors within the model must consider the needs and objectives of the stakeholders, and the consideration of these objectives are the primary factors. Sub-factor considerations are inputs that determine the values of the primary factors. The model is a system that converts objectives into a common currency and allocates a weight or mathematical relationship to them in order to inform decisions.

The aim of the team’s model is to determine stockage levels. War Reserve Materiel stockage levels are driven by factors such as policy, planning, empirical demand data, industrial base considerations, and funding levels, which must sufficiently support the future materiel requirements of USMC forces. The systems engineering process for designing a system requires many decisions, thorough analysis, and experience to find a very good solution that satisfies mandatory stakeholder requirements and provides a high-level of performance (Buede 2009, 155). Figure 3 consists of the model’s requirements (factors) in a hierarchical view that satisfies stakeholder requirements.

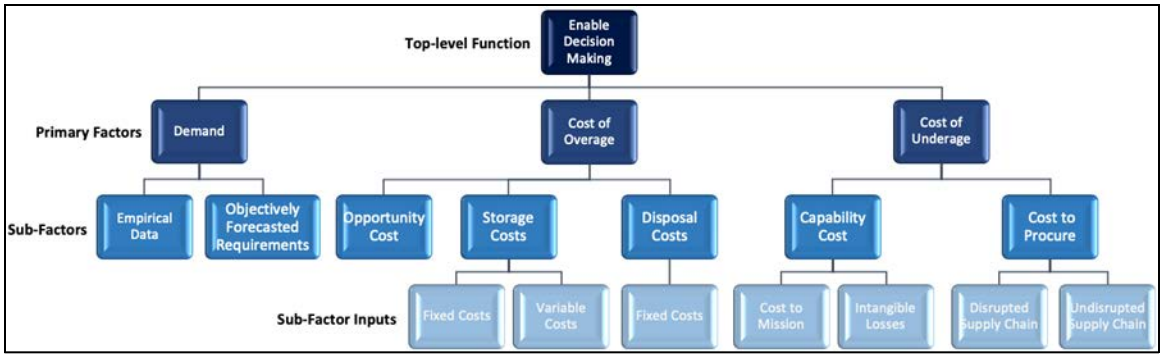

Figure 3. Systems engineering hierarchy

According to Figure 3, the top-level function of the model is to enable decision making, which is what the model must do in order to meet the system’s objectives and stakeholder requirements. Within the model, three primary (required) factors exist, which are demand, cost of overage, and cost of underage. These primary factors, when leveraged within the model, enable decision making. Furthermore, the primary factors consist of inputs from sub-factors that enable them to generate outputs for the model. The primary factors are viewed as systems within the model. To facilitate decision making, the primary factors and sub-factors must be traced to stakeholder needs.

The model is an easy to use, customizable computer-based system that informs stakeholders in making sourcing decisions via a number (system’s output) that provides a marginal cost and marginal benefit regarding the stockage level of WRM.

E. COMPONENT REQUIREMENTS OVERVIEW

To scope the problem within defined constraints, the team, along with stakeholders, narrowed the required functions and sub-functions of the model to ensure a viable output. The team analyzed several variables for consideration as functions, or factors, within the model and selected those best suited to meet stakeholder requirements and objectives. As previously stated, the primary functions are demand, cost of overage, and cost of underage; however, these factors consist of multiple sub-factors that influence their effects on the model and the decisions made that rely on the model's output. These sub-factors are external systems that impact the system (model) and its outputs. As discussed by Buede, "the external systems, many or all of which may be legacy (existing) systems, play a major role in establishing the stakeholder's requirements" (Buede 2009, 157). This holds true for the team's model as all of the primary factors receive input from legacy systems, which are sub-systems in the model and are discussed below.

1. DEMAND

Demand is the most critical requirement, or factor, in the model. A single demand distribution that is a random continuous variable with a known distribution curve nature. Within the scope of the project, the team considered the following inputs to the primary function of demand within the model: empirical data and objectively forecasted requirements, which consists of policy goals and protection measures (service level).

Empirical Demand Data

This is perceived demand for an item from the warfighter that is derived from historical usage data.

Objectively Forecasted Requirements

The USMC relies on DOD OPLANs to forecast future demand within the constraints of DOD WRM Policy, which influences the level of WRM that the USMC can procure and store. The DOD provides guidance to the USMC regarding the Service Level of WRM. The policy states:

> the goal of the WRP will be to establish a standard service level WRMR. The war reserve program framework is bounded by the most stressing contingency response plan and existing OPLANS / CONPLANS to shape our service and operational level WRMR that informs our enterprise investment and positioning strategies to maximize WRMR responsiveness to future combat operations and Marine Corps Operating Concepts. (United States Marine Corps 2019)

DOD Policy aims to serve as “insurance” to attain a desired level of coverage, or stockage level, in WRM to meet contingency plans. Currently, the DOD plans for the worst-case scenario based on staff estimates, intelligence reports, and experience. While this has proven to be successful, it does not adequately measure demand and the variable that affect it.

The team considered the authorized quantity of an item at the MEU level as the basis for this constraint. The team interpreted this authorized quantity in a manner that provides a base, or minimum service level, and potentially a maximum service level tied to the authorized quantity and operational requirements of a MEU. Operational requirements establish the frequency of use for an item, which either increases or decreases the demand for an item.

Operational requirements are linked to the type of operation environment expected. This ranges from low to medium frequency use for humanitarian like operations to high frequency use for large scale force-on-force operations.

2. COST OF OVERAGE

The function of cost of overage is to avoid waste. Within the scope of the project, the team considered the following inputs to the model: opportunity, storage, and disposal costs. In order to ensure the model’s output is viable, the team must know what the Cost of Overage for an item will be and what the probability of being over is and by how much.

Opportunity Costs (Procurement Costs)

This is the cost to the USMC to procure an item for storage in WRM inventory that is not used or needed to support operations. This should consider the lost opportunity costs to procure other materiels that are or may be required.

Storage Costs

This is the cost to the USMC to store an item in WRM inventory. This is a fixed cost within the model. The model considers fixed and variable costs to include maintenance costs.

Disposal Costs

This is the cost to the USMC to dispose of an unused or expired item in WRM inventory. These costs may be accounted for in an item's total life cycle costs at the time of procurement. This is a fixed cost within the model.

3. COST OF UNDERAGE

The function of cost of underage is to determine the cost to capability and cost to procure an item that is not available in WRM inventory when there is a demand for the item. In order to ensure the model's output is viable, the team must know what the cost of underage for an item will be, what the probability of being under is, and by how much.

Capability Cost

Given the USMC does not operate as a business; it is difficult to determine the cost of a capability. The team must identify a method in which to convert and intangible value into a common currency for use in the model. This will facilitate the comparison between the cost of overage and cost of underage.

To determine the Cost to Mission an item is assigned a value based on its impact to the USMC's ability to accomplish a mission. This value will vary depending on the item's criticality within the USMC and the Protection Measure for a specific type of mission.

Cost to Procure

This is the same Procurement Cost addressed in the Cost of Overage, but with a premium placed on an item with the understanding that it will cost the USMC more to procure the item if not available in WRM inventory when there is a demand for the item.

This sub-factor’s inputs are Indefinite-Delivery, Indefinite-Quantity (IDIQ) contracts, which have contingencies for both wartime and peacetime.

It is important to note that Wartime IDIQ contracts my not be able to meet the surge in demand required by a specified Protection Measure due to shortfalls in the industrial base, availability of materiels, and or disruptions to supply chains. Disruptions in the supply chain may make the employment of these contracts infeasible.

F. CHAPTER SUMMARY

This chapter discussed the methodology used to define the problem and the model’s requirements. The variables, or factors, and their relationships within the model were described to provide context to the team’s approach. Our modified systems engineering approach was taken to provide LPO-2 with a reliable model to determine the required quantity of WRM to store for any operation. The following chapter will provide a detailed review of precisely how the team built the model, its specific inputs, outputs, and how they are used to provide value to the stakeholders.

III. MODEL DEVELOPMENT

In this chapter, we describe our model development efforts centered on adapting the classic single-period (newsvendor) model to determine an optimal inventory level. We extend the classic newsvendor model by providing relational logic between the out-of-stock probabilities and operational impact by introducing three new variables called the “relative capability factor,” the “materiel intrinsic value,” and the “conflict intensity parameter.” We use the demand and cost data of the BA-5590/U non-rechargeable battery to provide numerical examples and application. We expand on the interpretation of the model using results from a Microsoft Excel-based tool called the War Reserve Materiel Marginal Cost Analysis Tool (WRMMCAT). While we focus our example on batteries, the analysis tool allows for examination of other materiels as long as demand and cost data is available. Interestingly, using expendable materiel, such as BA-5590/U non-rechargeable batteries presented unique inventory management challenges that highlight the limitations of our model and the classic newsvendor model in general.

A. THE MODEL FRAMEWORK

In this section, we discuss the model framework around the classic newsvendor model. We first discuss the general concept of a newsvendor model as applied to inventory management followed by identification of dependent variables and how we modified the variables while maintaining the integrity of the class newsvendor model to fulfill stakeholder objectives identified in Chapter II.

1. Newsvendor Model Overview

The classic newsvendor model uses cost variables and demand distributions to determine inventory levels. Cost variables describe the costs that a decision maker faces such as purchase price of the item, the selling price, any salvage, and storage costs for excess items. Demand distributions describe the probabilities of inventory being either over or under the real demand. Zhai, Yu, and Sun (2018) in *Robust Optimization for the Newsvendor Problem with Discrete Demand* showed that the assumption behind a classic newsvendor model is that demand is normally a continuous random variable for many situations that is used to determine service levels. In turn, the service levels are used to determine the optimal quantity to meet or exceed the service level. While we do not use service levels to calculate for the optimal quantity, we combine the demand distribution with cost profile of a particular item to generate a closed-form formula that calculates the optimal inventory by comparing expected marginal costs.

Furthermore, the use of expected marginal costs to obtain the optimal quantity provides an insight to the overall net contributions, which is a large focus on for-profit businesses. Adelman, Barnes-Schuster, and Eisenstein (1999) in their course notes, *The Operations Quadrangle: Business Process Fundamentals*, provides the mathematical approach using marginal costs to calculate the “expected” net contribution. While net contribution is defined as the monetary value remaining after all costs and profits are considered, “expected” net contribution describes the relationship between demand and inventory level. Therefore, the newsvendor model analysis using both cost and demand profiles seeks to maximize the expected net contribution. Table 2 describes the common variables in a classic newsvendor model that we also adopt to develop the WRMMCAT.

Table 2. Common variables in a classic newsvendor model

Variable Notation	Terms
Q	Inventory Quantity
c	Purchase Price / Acquisition Cost
D	Forecasted Demand
$F(d)$	Cumulative Distribution Function of Demand
$Q*$	Optimal Inventory Quantity
C_o	Cost of Inventory Overage
C_s	Cost of Inventory Shortage
h	Holding Costs
r	Revenue Received for Sale
p	Penalty for Lost Sales
c_a	Cost of an Item from Alternate Source
s	Salvage or Disposal Cost for Excess Inventory

The classic newsvendor model depends on two cost functions: the cost of inventory overage and the cost of inventory shortage. The inventory overage cost, or for any given item that is not sold or used, the variables include cost of holding or storage, the procurement cost of the item, and any salvage costs.

$$C_o = h + c - s$$

The cost of inventory shortage comprises cost variables when the inventory is lower than the demand. The shortage inventory cost variables are revenue from sales, the procurement cost of the item, alternative source cost and any applicable penalty costs. In this capstone, the penalty costs are associated with not having an item when needed to accomplish military objectives.

$$C_s = (r - c) - (r - c_a) + p$$

The mathematical formula for the cost of inventory shortage describes the cost to the vendor due to lost sales. Lost contribution, or potential profit by lost sale is described by $(r - c)$. When an item is out of stock, a vendor has the potential to acquire an item from an alternate source is described by $(r - c_a)$. The $(r - c_a)$ is subtracted from the potential profit because while the availability of items from an alternative source decreases the amount of lost sales, there still exists a cost that is higher than the initial procurement cost. While the penalty variable describes the additional cost of sales losses, the defining characteristics of the penalty depends on how newsvendor model is applied in various situations. Moreover, the penalty variable can have the most influence when calculating the net contribution. In this capstone, we make an assumption that there is no option to procure an item from an alternate source. Given the unknown variables behind the federal acquisition process, elimination of the alternate cost of an item focuses the analysis to existing inventory during the 60-day period. However, we recognize that future work could incorporate alternate source factors to allow the ability to capture other possible supply scenarios.

In our capstone, we recognize no revenue exists since no "sale" happens between the USMC War Reserve and the requesting military organization. In situations where no revenue or penalty exist, the cost of inventory shortage can be simplified to the negative of the procurement cost of the item. The negative procurement cost suggests that the model drives the quantity to always be short because there was no money spent to procure the item, or on "credit." Therefore, a newsvendor situation where there is no revenue nor penalty, the cost of inventory shortage function to be ill-defined, as there is no cost incentive to hold any inventory. In our project, defining the penalty variable was critical to ensure the model remains mathematically defined. Instead of maximizing the expected net contribution and thus maximizing profit at a specific quantity, our model provides the specific quantity that minimizes the cost of having inventory while maximizing the availability of materiel in reserve.

2. Demand Distribution in Newsvendor Models

To conduct analysis using the expected marginal costs, the newsvendor model requires demand distribution data. An example of demand distribution in the classic newsvendor model is demonstrated by Adelman et al. (1999) through normally distributed empirical data. The empirical data shows the naturally occurring lower and upper boundaries of the demand distribution based on historical sales. A simple statistical analysis using probability density functions and cumulative density functions provides probabilities of overstock or understock at a given quantity. Based on our literature reviews, normal distribution is the most practiced distribution type to capture demand. However, the choice for distribution types are scenario-dependent and must be selected upon first analyzing the historical demand patterns.

Characterizing the demand distribution is perhaps the most critical requirement to conduct the "expected" marginal cost analysis. We examined two different approaches to determining the demand for our model. The first approach requires historical USMC requisition data and the RAND Corporation models that estimate the level and number of future conflicts. The second approach is to use available USMC doctrinal resources, such as the table of equipment, that defines materiel requirements along with data on materiel service life.

We chose the second approach to characterize the demand distribution for our model. The criteria used to choose between the two approaches included availability of data and the number of assumptions required to generate a demand. We determined that the demand distribution of the War Reserve accounts for multiple ranges of conflict intensity. Figure 4 demonstrates a general demand distribution that is representative of the War Reserve. Each end of the distribution clearly displays the required quantities to account for low or high intensity conflicts with lower probabilities of demand. However, the highest demand for War Reserve Materiel is likely to represent ongoing conflict such as the surge deployment in support of Operation Iraqi Freedom in 2003 or the 2017 re-surge of troops in Afghanistan.

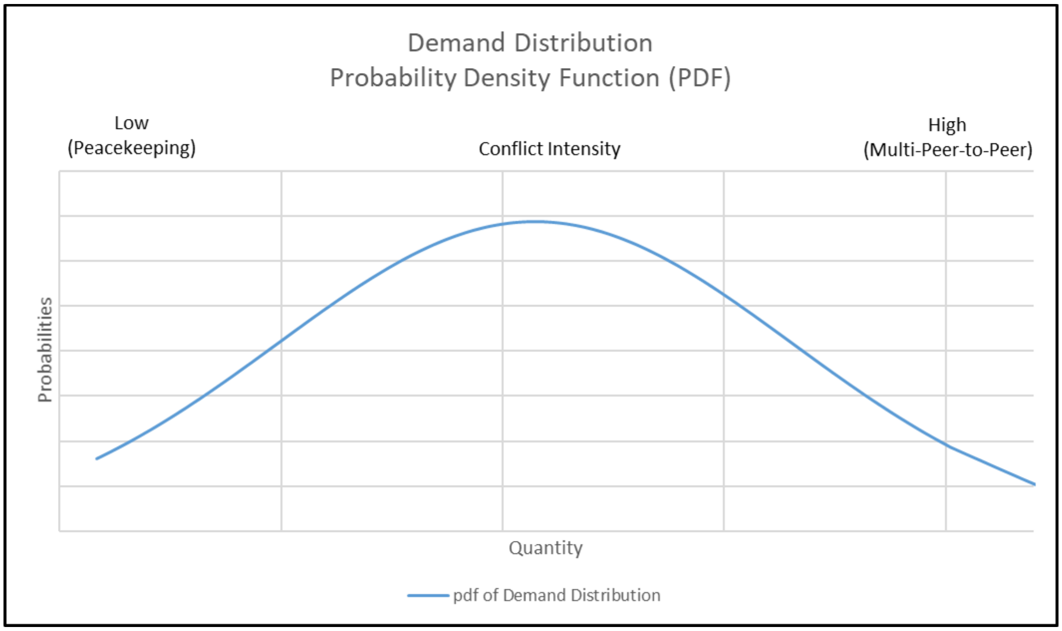

Figure 4. Representation of a general demand distribution

To anticipate future conflicts, the first approach relied on adopting a model from the RAND study, "Conflict Trends and Conflict Drivers: An Empirical Assessment of Historical Conflict Patterns and Future Conflict Projections." This study provided a strong analysis of historical data on conflicts that occurred from 1946 until the 2010s and hypothesized future trends through 2040. However, this analysis of inter- and intrastate actors does not provide any specifically actionable information on USMC War Reserve planning decisions, as conflict participants are not identified. Additionally, finding consistently recorded historical requisitions proved to be a challenge. Policy requirements that supply records be kept for seven years did not allow for a wide enough perspective to make accurate forecasts on operational environments outside of garrison and War on Terror-level conflicts (MCO 4400.150, 2014).

Consequently, the second method considered was based on the known requirements of a given USMC element, the MEU. With the MEU being the lowest military echelon capable of initial self-sustainment for deployments, we used a current table of equipment to determine the number of allocated systems. By using the most up-to-date doctrinal capability and collecting available materiel service-life and usage data, we were able to generate a demand distribution that provides a relational logic for demand across multiple conflict intensities.

Though certainly more feasible to create, the second approach is not without its limitations. Using the USMC energy requirement tools and subject matter expert-driven studies resulted in mean and standard deviation with a near-perfect normal distribution centered on the mean demand (Boyd et al., unpublished data, 2013). Reflecting on the studies by Zhai et al. (2018) on discrete demand and Halkos and Kevork (2012) on effects of coefficient of variation on optimal quantities, our model is limited by the assumption that demand is a continuous random variable and the coefficient of variation is unpredictable across multiple materiels. While each OPLAN, both previously executed and planned, can be considered as discrete demand points, the probabilities of OPLAN execution introduces another level of stochastic demand to determine inventory level. However, if enough data is gathered on OPLAN planning and execution, the discrete demand points could potentially be integrated in a newsvendor model.

3. Classic Expected Marginal Cost and Marginal Profit

Once the demand distribution was characterized, it was applied to the cost variables to calculate the expected marginal costs. The expected marginal cost and marginal profit is different from the actual cost and profit because it accounts for the probabilities of the inventory level as either over or short. The expected marginal cost and profit is used to examine the cost effects of ordering one more unit (Adelman et al. 1999). As more units are ordered, the expected marginal profit from ordering one more unit decreases since the likelihood of actual demand reaching each increased unit decreases. Subsequently, the expected marginal cost of ordering one more unit increases.

Given a demand distribution, whether it be empirical or theoretical, a vendor is able to determine the probabilities of inventory shortage or overage at any given forecast quantity, Q. Once vendors select a forecast quantity, the vendors can apply the cost functions to determine the expected marginal cost and profit. The classic newsvendor model represents the expected values as

$$Expected\ Marginal\ Cost =$$

$$P(Demand \leq Q) \times marginal\ cost\ of\ inventory\ overage,$$

$$Expected\ Marginal\ Profit =$$

$$P(Demand > Q) \times marginal\ cost\ of\ inventory\ shortage.$$

The relationship between the two expected marginal cost calculations suggest that a vendor would increase inventory levels that is expressed as.

$$Expected\ Marginal\ Cost < Expected\ Marginal\ Profit.$$

Here, we observe that expected marginal profit is better described as the expected marginal 'lost' profit because the profit has not been realized by the vendor. Instead, the vendor recognizes this as the potential profit lost by not having enough inventory.

The optimal quantity, $Q*$, then is expressed as

$$P(Demand \leq Q)C_o = P(Demand > Q)C_s.$$

However, recalling that the USMC does not recognize profit, we began defining the characteristics of penalty variable in military inventory management.

4. Modifying the Expected Marginal Profit Function

Our model disregards profits due to the obvious reasons centered around federal fiscal policies in the interest of the public. In the military context, lost profit translates to lost military capabilities. Therefore, our penalty cost function attempts to capture the lost warfighting capabilities in monetary terms. Since the military context drives the revenue variable to zero and we assume no alternative procurement source during the initial 60-day surge deployment, we rewrite the cost of inventory shortage as

$$C_s = -c + p.$$

Thus, we redefine the expected marginal profit as

$$Expected\ Marginal\ Cost\ of\ Inventory\ Shortage\ = P(Demand > Q) \times C_s.$$

Our redefined cost of inventory shortage function focused heavily on defining the penalty variable. We propose that the penalty variable for the USMC War Reserve inventory management requires consideration of two characteristics. The first characteristic is to minimize the cost of holding materiel in the War Reserve. However, the first characteristic alone provides only partial definition of penalty because the penalty variable implies that there is a fundamental reason for the penalty. The second characteristic is the effects of materiel availability on achieving military objectives. As a result, the USMC would benefit from readily available reserve materiel, but potentially suffer fiscally with higher inventory level. Conversely, a lower inventory level would penalize the USMC operationally. Our capstone research focused on converting the operational penalty into monetary terms to be able to use the newsvendor model.

We also recognize that there are many ways to characterize the penalty variable other than War Reserve Materiel cost and availability. For example, relational data between casualties and inventory availability could potentially serve as a powerful decision-making factor. However, we did not find sufficient data that links War Reserve directly to military operational success.

Thus we further define penalty as the cost equal to the intrinsic value of the materiel related to its role in enabling the Marines' capabilities—in other words, how much the Marine Corps would value materiel when the inventory is short. Figure 5 shows the graphical representation of the relationship between expected marginal cost of inventory overage and expected marginal cost of inventory shortage. Resulting from the CDF of the demand distribution, the expected marginal shortage cost decreases with increase in quantity due to the probability of actual demand not meeting the inventory level. As such, the expected marginal overage cost increases with increase in inventory level.

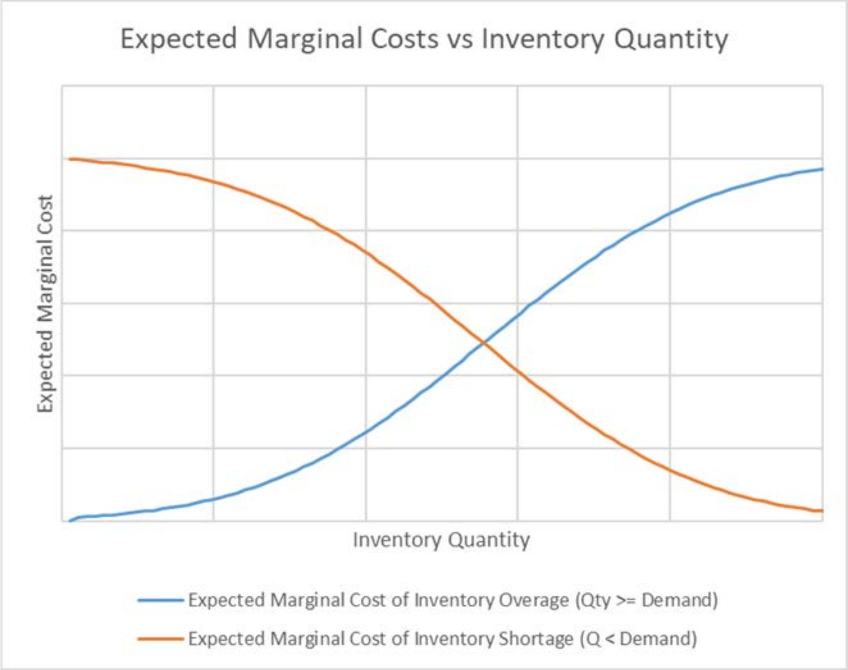

Figure 5. Expected marginal cost vs. inventory quantity

B. DEFINING THE COST OF INVENTORY SHORTAGE FUNCTION

In this section, we provide in detail the modifications to the cost of inventory shortage function. More specifically, we discuss the concept of how items are described in terms of monetary value in the absence of revenue and profit. The discussion on monetary value of items leads to the introduction of new variables that affect the overall penalty cost function. As previously mentioned, without the revenue variable, the cost of shortage function becomes mathematically ill-defined. The modified variables allow the model to function in an environment where profit is nonexistent and loss is measured in military effectiveness rather than dollars.

1. Defining Materiel Availability in Terms of Monetary Value

Our modified model is representative of the classic newsvendor model in that it comprises cost of inventory overage and shortage given a normally distributed demand. While increase in probability of achieving military objectives through increased availability of materiel may be intuitive, defining the materiel value in terms of cost is a less intuitive task.

For any materiel that is considered valuable to military operations, not only are there initial procurement costs, but there is an intangible value associated with items required for military operations. Hildebrandt’s (1985) study on the *Capital Valuation of Military Equipment* describes military assets in monetary terms by assigning valuation of military capital using cost over time. While Hildebrandt (1985) defines military valuation by examining the value of multiple assets over the cost of respective service lives, we scaled the concept down to define the value of a single item within the first 60 days of a surge deployment. Additionally, demand distribution of the newsvendor model allows the application of intrinsic value to inventory management decisions. A key assumption for using intrinsic value for defining the penalty variable is that successfully achieving military objectives by having to store and maintain one more critical item is comparatively far more beneficial than the cost associated with having to either procure at higher cost or potentially failing to achieve military objectives.

2. Relative Capability Factor

To convert the intrinsic value of a military asset in terms of cost, we introduce a variable called “Relative Capability Factor” (β). The Relative Capability Factor is characterized by the authorized military equipment of a MEU and the inventory level. The Relative Capability Factor is represented as

$$\beta = \frac{i}{i_a},$$

$where\ i: Arbitrary\ Inventory\ Level,$ and

$i_a: Doctrinally\ Authorized\ Quantity\ of\ item$

Foundational to the Relative Capability Factor is the USMC’s determination of personnel and equipment authorizations for the entire Marine Corps. More specifically, we reference the table of equipment of a single MEU consisting of approximately 400–600 Marines of various skillsets in the analysis. The authorized quantity of an item is a single value determined through capability analysis at the USMC Headquarters echelon and therefore is not easily changed. The Relative Capability Factor characterizes the materiel availability using doctrinal analysis of how Marines fight. The intent behind analyzing one MEU versus the entire Marine Corps is the flexibility to scale inventory as needed.

3. Penalty Cost Function

To define the cost of inventory shortage, or penalty cost when demand is higher than inventory, we apply the Relative Capability Factor to the materiel procurement cost as an exponent.

$$Penalty\ Cost: p = C_i^{\alpha - (\frac{\beta}{\gamma})},$$

$$where\ C_i: unit\ cost\ of\ an\ item$$

$$\alpha: materiel\ intrinsic\ value\ parameter$$

$$\gamma: conflict\ intensity\ parameter$$

To explore the sensitivities of materiel intrinsic value and conflict intensity parameters, Figure 6 graphically represents impact to the penalty cost perceived by the USMC rather than the expected marginal costs. Figure 6 also validates the behavior of the materiel intrinsic value parameter affecting the magnitude of the cost and conflict intensity factor affecting the slope, or the rate, at which penalty cost decreases with increasing quantity.

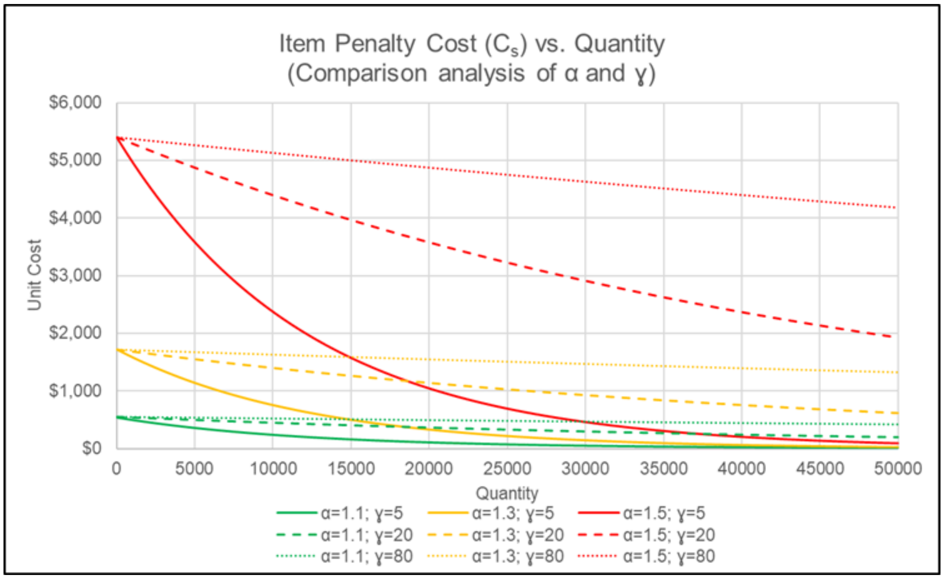

Figure 6. Item penalty cost (C_s) vs. quantity

The materiel criticality factor (α) describes how valuable materiel is considered ranging from value of 1.1 to 1.5 and affects the behavior of the monetary value of an item. A value of 1.1 indicates that an item has low value whereas 1.5 assigns a high value to an item. While the selection of the conflict intensity factor is subjective, it provides a relative relationship between how materiel is perceived in achieving military objective.

The materiel intrinsic value parameter (γ) describes the intrinsic value of the materiel in terms of achieving military objectives. The parameter's lower limit is 1.0, which describes the materiel's value as insignificant in achieving the OPLAN's military objectives. A materiel intrinsic value parameter of 1.0 describes a scenario where no items are stored in inventory. Since the decision for inventory level is described by the relative capability factor (β), or $\beta=0$ for when $\alpha=1.0$, the penalty cost of an item is just the initial procurement cost of the item. The parameter's upper limit is theoretically infinite because certain items could be deemed priceless if the planning decision was faced with the prospect of having none of the items. The materiel intrinsic value parameter is important because it affects the model's behavior to define the materiel's monetary value when items are in shortage. While the numerical range of the parameter is subjective, our iteration of the model showed a value above 1.5 results in unrealistic costs whereas values below 1.1 drives the expected marginal costs of shortage towards zero. The importance of the variable is the relative relationship between how materiel is perceived in achieving military objective. We found that values between 1.0 and 1.5 provide the best representation of how critical materiel is perceived.

The conflict intensity parameter (γ) describes the relative conflict intensity as a planning factor with valures range between 1.0 and infinity. The conflict intensity factor affects the behavior of the slope of the monetary value of an item. For example, if the conflict intensity is insignificantly low to a point where military intervention is unnecessary, the slope becomes steep and drives the model to a lower quantity. Similar to the materiel intrinsic value parameter, our capstone sought to provide suggested parameter values that best represent realistic planning considerations. A value of 1.0 indicates a relatively low intensity conflict whereas a value of 80.0 indicates a high intensity conflict. Our efforts to iterate the model with a range of numbers showed that the model was not as significantly sensitive to values over 20.0 while value between 1 and 5 affected the results greatly. Figure 7 provides a graphical sensitivity analysis results for conflict intensity values ranging from 20.0 to 80.0. While the sensitivity analysis results question the potential need for values greater than 20.0, we wanted to be inclusive to extremes of high intensity conflict where a ɣ value of 80.0 produces results that would be significant enough to make an impact on the overall planning decision for expected marginal cost of inventory shortage.

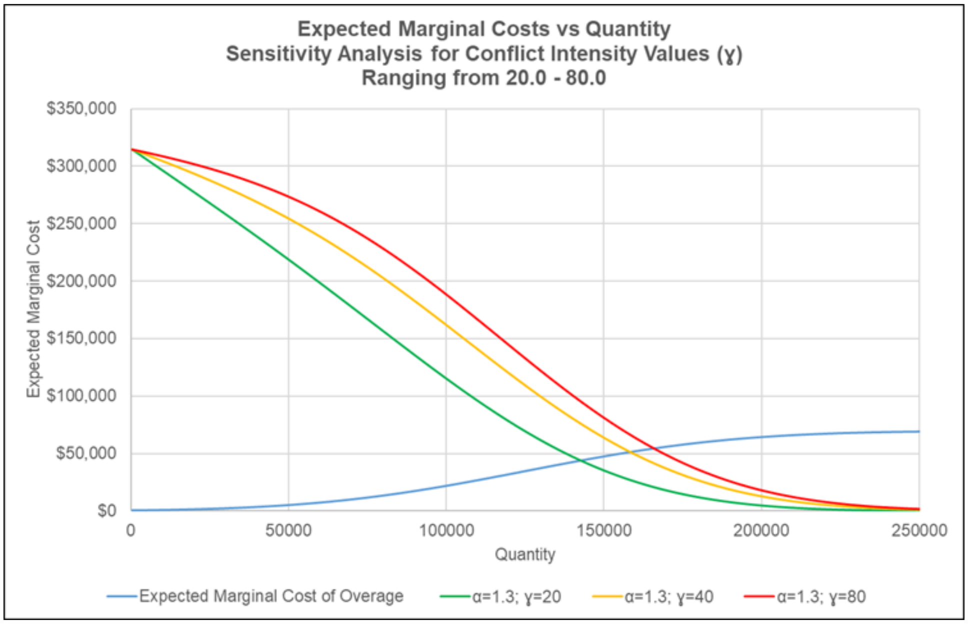

Figure 7. Sensitivity analysis for conflict intensity values

Based on our requirements decomposition, we determined that every item used in the military will have consideration for materiel's intrinsic value and conflict intensity. The level at which each factor affects the inventory varies between items. Therefore, we provide a penalty function that encompasses the intrinsic value and intensity factors to aid sensitivity analysis required for the decision process.

The penalty cost function provides an exponential relationship of cost and demand. The exponential effects of this relationship are further emphasized by the materiel intrinsic value and conflict intensity parameters. While the penalizing costs are not objectively measurable without substantial market research on cost of alternate sources, our model provides *relative importance* of availability in terms of cost for inventory decision-making process.

Finally, we are able to rewrite the fully defined expected marginal cost of inventory shortage, or the expected marginal cost of penalty as

$$Expected\ Marginal\ Cost\ of\ Shortage = P(Demand > Q) \times (-c + C_i^{\alpha - (\frac{\beta}{\gamma})}).$$

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IV. WRM MARIGINAL COST ANALYSIS TOOL (WRMMCAT)

In this chapter, we provide the results of our model through results from the Microsoft Excel-based WRMMCAT. We discuss the impact of the WRMMCAT to the War Reserve Materiel planners and follow up with sample calculations using the BA-5590/U non-rechargeable batteries.

A. PURPOSE OF THE (WRMMCAT)

The purpose of the WRM Marginal Cost Analysis Tool is to provide the planners with the optimal inventory level based on demand distribution and procurement cost data. Furthermore, the model provides planners with flexibility to choose the values for the materiel intrinsic value and conflict intensity parameters to reflect expected marginal costs of inventory overage and shortage. It is important to note that the resultant quantity does not account for several key risk assessment factors such as fiscal policies, USMC's risk tolerance for magnitude of costs, and OPLAN requirements.

Though intended for use in developing anticipated inventory levels for all items maintained by the WRM, we chose to use BA-5590/Us as an example for our model for two reasons. First, these batteries are used by a wide range of electronic devices, many of which are critical to mission success in any operational environment. Second, conversation with stakeholders identified BA-5590/Us as an item that was critically understocked during surge events in the War on Terror.

One limitation of our tool is the inability to dynamically change the original demand distribution data since the capstone group did not have the resources to automate the empirical data collection from real-world databases such as the Total Force Structure Management System (TFSMS) or the Global Combat Support System-Marine Corps (GCSS-MC). These operational databases in addition to surveying operational organizations provide essential information on materiel demand. Currently, the demand distribution data must be manually entered by the planners. Our results are based on the BA-5590/U non-rechargeable batteries. However, the WRMMCAT tool is to provide analysis for any materiel as long as the demand distribution and materiel cost profile can be defined.

B. SAMPLING WITH BA-5590/U NON-RECHARGEABLE BATTERIES

The BA-5590/U is a non-rechargeable lithium-sulfur-dioxide (LiSO2) battery that has been in service since the early 1990s (Sherpa Inc. 2016). These high energy batteries are the most widely used within the DOD, and power a wide range of the electronic equipment operated by the USMC. Though often associated with radios and other communication equipment, this battery is also essential for weapon systems such as the Javelin and TOW missile systems. As such, it represents a disposable supply that is vital to mission success regardless of operational intensity, as communication is just as critical to a low intensity operation such as HADR as it is to a near-peer conflict. This ubiquity makes the BA-5590/U an ideal candidate for use in our model.

The second motivating factor for using these batteries as a basis for our model was the fact that they were critically understocked during the opening actions of Operation Iraqi Freedom. Although 180,000 BA-5590/Us were maintained as a reserve in the period leading up the beginning of the conflict, initial demand for the batteries was nearly 620,000, far exceeding the ability of reserves to fulfill (Sherpa Inc. 2016). According to a 2016 DLA-sponsored battery study, these shortages "created significant risk to the mission" (Sherpa Inc. 2016).

1. BA-5590/U Non-rechargeable Battery Demand Calculation

Based on the current doctrinal table of equipment, a MEU is authorized up to 61 pieces of equipment that require BA-5590/U batteries to function (Boyd et al., unpublished data, 2013). From this, we can derive the number of batteries required for operations based on average battery life and with an assumption that the batteries withdrawn from the War Reserve will be used in 24-hour operations. Based on available data, and estimation tool provided by the sponsors, we estimated about 13,920 batteries as the mean of the demand distribution with a standard deviation of 5817. By characterizing the demand distribution, we are able to define the Relative Capability Factor for BA-5590/U batteries as

$$\beta = \frac{i}{13{,}920}\,,$$

which results a percentage of a MEU's potential capability above normal operational authorization quantity.

With a normally distributed demand, we extracted information from both the probability density function (PDF) and the cumulative density function. The PDF provides two critical pieces of information. The first information is the relative likelihood associated with any given demand quantity. The second information is inferential analysis to define the potential conflict intensities associated with the demand quantity. While the inferential analysis is limited by the available demand data per various known historical conflicts, the mean value of 13,920 batteries represents a scenario where a MEU has the need to withdraw from the War Reserve to fill 100% of authorized equipment that uses the BA-5590/U batteries. The PDF then implies that multiple OPLANS vary in materiel demand ranging from needing less than 13,920 for low-intensity conflict to needing more than 13,920 for high-intensity conflict.

While the PDF provides the relative likelihood of any given quantity over the entire distribution, the cumulative density function (CDF) provides the probabilities that actual demand is lower, or the likelihood of an inventory shortage quantity of 13,920. The complement of the CDF provides the probability that quantities are higher, or inventory overage, than the mean demand of 13,920. The mathematical expression yields:

$$F(Q) = Prob\{Demand \leq Q)\ as\ the\ probability\ of\ overstock$$

and

$$1 - F(Q)\ as\ the\ probability\ of\ understock.$$

2. Cost functions of BA-5590/U Non-rechargeable Batteries

The WRMMCAT model represents much of the classic newsvendor model. We recall the modified newsvendor model expressions as

$$C_s = -c + p = -c + C_i^{\alpha - (\frac{\beta}{\gamma})}$$

$$C_o = h + c.$$

3. Cost of BA-5590/U Non-rechargeable Batteries

Several military battery references indicated that cost of one BA-5590/U battery is in the range of $70–$85. Upon further market research on BA-5590/U type batteries in the commercial market, the price ranges between $70 up to $150. The research on price indicated that through the federal acquisition process, the cost of BA-5590/U batteries is much lower than in the commercial market. This further indicates that the demand for BA-5590/U batteries are most likely limited to military applications. Therefore, if the military were to procure batteries in the commercial market, it is likely going to penalize them in terms of procurement costs. For demonstration of the tool, we selected a price of $77 per single battery.

4. Cost of Holding (Storage) and Maintenance

Although we recognized that the BA-5590/U batteries are stored outside of the USMC War Reserve inventory, there is still costs associated with storing and maintaining the batteries for WRM purposes. The BA-5590/U batteries are shipped to the military in a package of four batteries. Furthermore, they have specific storage requirements due to its classification as a hazardous materiel. Since many materiels share the same warehouse space, calculating battery-specific storage costs has proven to be challenging and most likely inaccurate. One assumption to achieve a pro-rated storage cost for batteries was to use DLA-provided cost factor for cubic feet of storage. Table 3 shows the break-down of storage costs per cubic feet.

Table 3. DLA-provided storage cost factors per cubic feet

Storage Rate	Monthly	Annual
Covered	$0.73	$8.78
Open	$0.10	$1.22
Specialized	$1.04	$12.50

We also assumed a standard 48-inch by 48-inch pallet, which is about 48 cubic feet at 3 feet height. By using dimensions of the BA-5590/U battery, we determined that each standard 48″x48″ pallet can hold 1,105 batteries at 2,439lbs. The weight was also an important consideration in the calculation because the 48″x48″ pallet has a 3,700lb capacity.

At about 50 cubic feet, the monthly cost of a specialized storage for items such as the BA-5590/U is estimated at $52. Unfortunately, our model does not account for maintenance as a separate independent variable. For items such as the battery, refrigerated storage has proven to extend the shelf-life and thus an important factor in battery storage as War Reserve Materiel. Since our model is representing a single 60-day period for the analysis, we included potential increase in refrigerated storage and assumed $110 in storage and maintenance cost per 1,000 batteries, or $0.11 per battery. This assumption simplifies an unknown factor of battery shelf-life. While sponsors indicated that the BA-5590/U batteries have about 10 years in shelf-life, our study does not account for the time factor that affects batteries over long-term.

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V. RESULTS

A. SENSITIVITY OF MATERIEL INTRINSIC VALUE AND CONFLICT INTENSITY PARAMETER

With battery demand mean of 13,920, we consider three possible scenarios represented in Table 4. Each of the rows are fixed with the same α value while each column is fixed with the same γ value.

Table 4. Test parameter values for WRMMCAT

	Low Conflict Intensity (ɣ)	Medium Conflict Intensity (ɣ)	High Conflict Intensity (ɣ)
Low Materiel Intrinsic Value (α)	α: 1.1 γ: 5	α: 1.1 γ: 20	α: 1.1 γ: 80
Medium Materiel Intrinsic Value (α)	α: 1.3 γ: 5	α: 1.3 γ: 20	α: 1.3 γ: 80
High Materiel Intrinsic Value (α)	α: 1.5 γ: 5	α: 1.5 γ: 20	α: 1.5 γ: 80

Setting the intrinsic value parameter to 1.1, we conducted sensitivity analysis for various intensity factors. We forego testing α value of 1.0 because it drives the expected marginal cost of shortage to simply the unit cost. Figure 8, Figure 9, and Figure 10 graphically represents the different behavior of the penalty costs to the optimal quantities and the expected marginal cost of inventory shortage. We observed that as intrinsic value parameter increases, the expected marginal cost of shortage increases as clearly indicated on the vertical axis. While the monetary value of the batteries is subjective, the model represents how the costs are changed based on how critical materiels are perceived as. As a result, the optimal quantity increases as the materiel intrinsic value increases.

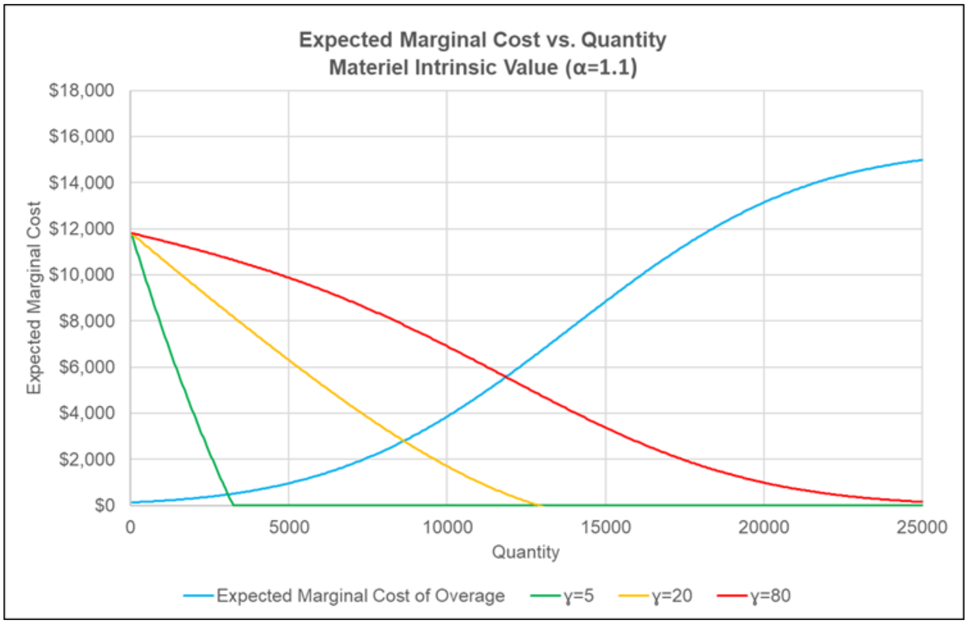

Figure 8. Materiel intrinsic value(α=1.1) vs. various conflict intensity parameters (ɣ)

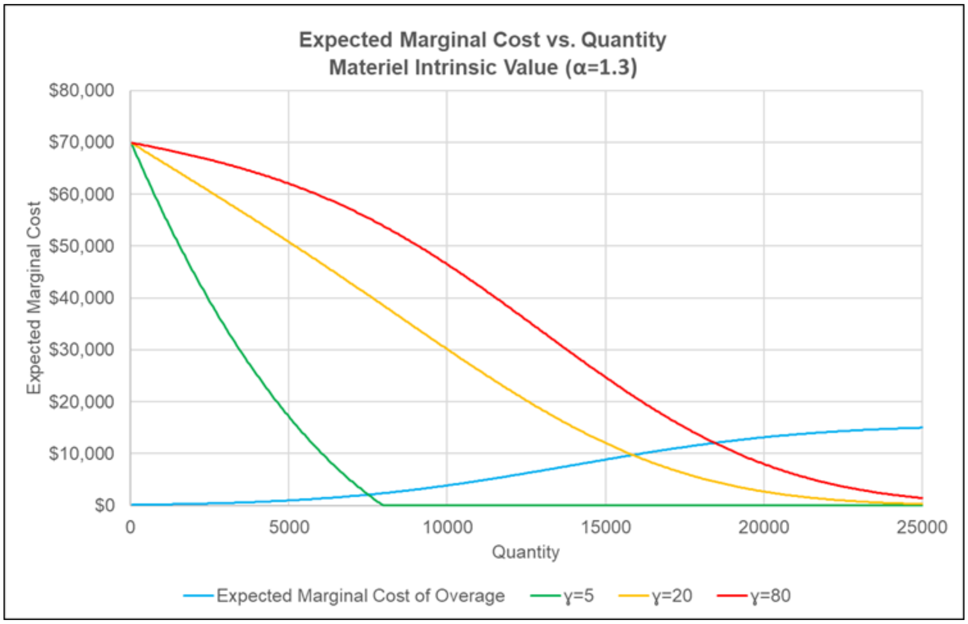

Figure 9. Materiel intrinsic value(α=1.3) vs. various conflict intensity parameters (ɣ)

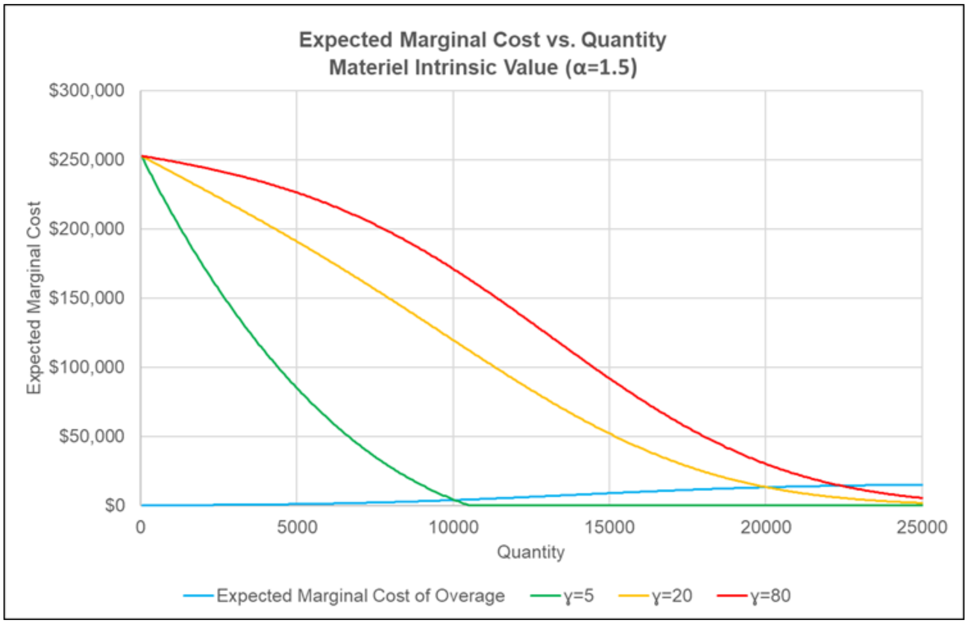

Figure 10. Materiel intrinsic value(α=1.5) vs. various conflict intensity parameters (ɣ)

Table 5 provides the resultant optimal quantities based on the user input data. Numerically, we observed a significant difference between two extreme scenarios. In the instance of using the BA-5590/U battery as the sample materiel, our model indicates a difference of up to 19,350 batteries between the lowest and the highest α and γ values. This is important to consider in the operational planning factor since the final cost is multiplied by the number of MEUs in the planning.

Table 5. Optimal quantities materiel intrinsic value (α) vs. various conflict intensity factor (ɣ) parameters

	Low Conflict Intensity (ɣ)	Medium Conflict Intensity (ɣ)	High Conflict Intensity (ɣ)
Low Materiel Intrinsic Value (α)	α: 1.1; γ: 5 **Q*=3,100**	α: 1.1; γ: 20 **Q*=8,650**	α: 1.1; γ: 80 **Q*=11,900**
Medium	α: 1.3; γ: 5	α: 1.3; γ: 20	α: 1.3; γ: 80

Materiel Intrinsic Value (α)	**Q*=7,550**	**Q*=15,900**	**Q*=18,500**
High Materiel Intrinsic Value (α)	$\alpha: 1.5;\ \gamma: 5$ **Q*=10,100**	$\alpha: 1.5;\ \gamma: 20$ **Q*=20,050**	$\alpha: 1.5;\ \gamma: 80$ **Q*=22,450**

Based on these results, the WRMMCAT demonstrates that consideration for the value of the BA-5590/U in terms of money affects the expected marginal cost greatly while consideration for conflict intensities affect the slope at which penalty cost applies as quantity changes. An alternative graphical representation of the penalty cost sensitivity is shown in Figure 11, Figure 12, and Figure 13. By fixing the conflict intensity values, planners can easily compare the expected marginal costs of shortage for three difference possible operational scenarios. An observation to note in Figures 11–13 is that as values for conflict intensity variable increases, the magnitude of change in optimal quantities decreases.

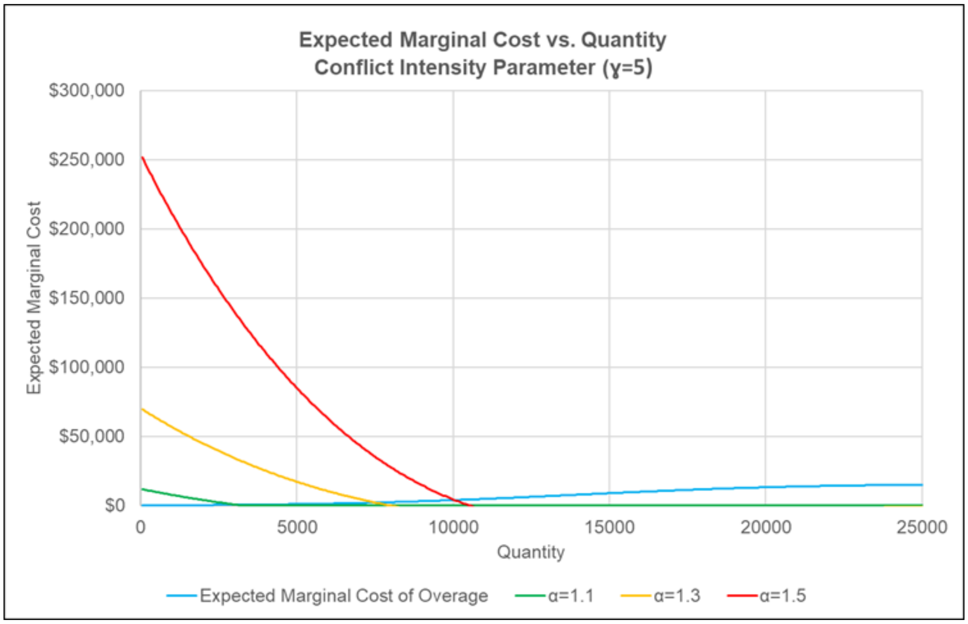

Figure 11. Conflict intensity parameter (ɣ=5) vs. various materiel intrinsic value (α)

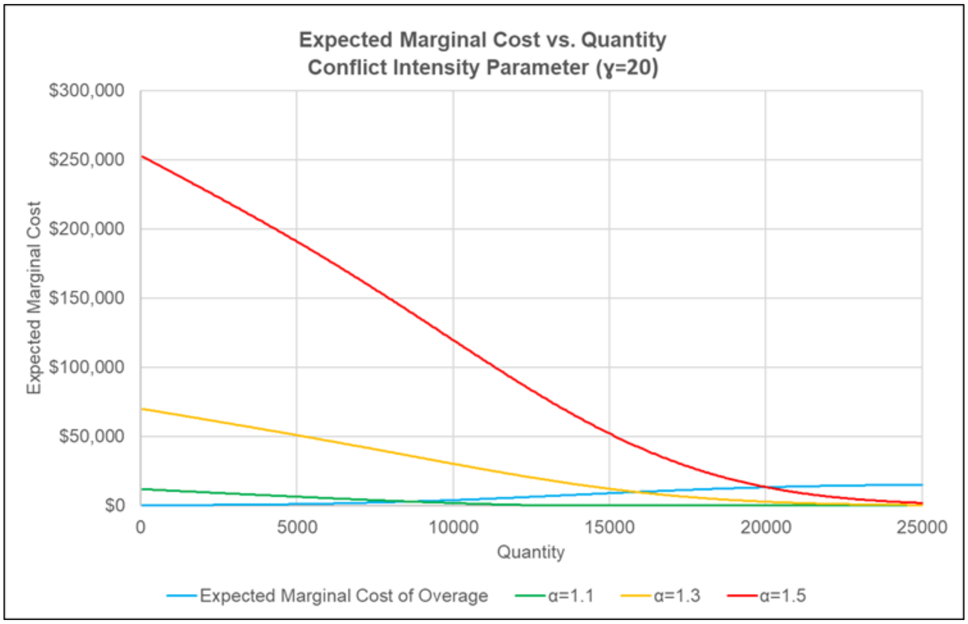

Figure 12. Conflict intensity parameter (ɣ=20) vs. various intrinsic value (α)

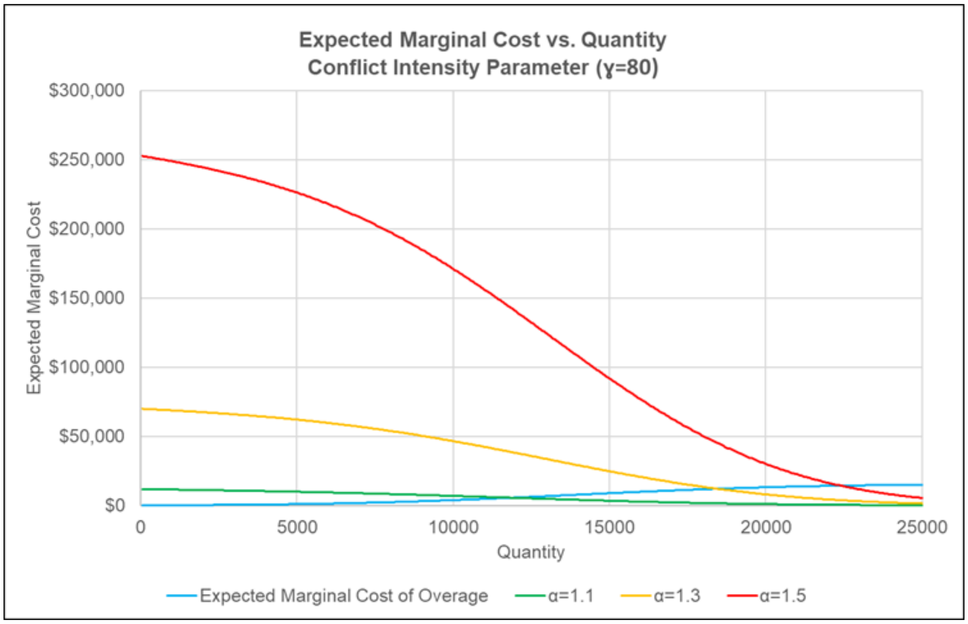

Figure 13. Conflict intensity parameter (ɣ=80) vs. various materiel intrinsic value (α)

The graphical representations provide a quick visualization of the sensitivities to the penalty cost function. However, the planners must consider the probabilities of such events occurring. Since the optimal quantity is determined based on the cost profile and demand distribution function, the probabilities are linked to the demand's CDF. Table 6 presents the probabilities of overstock and understock given the mean demand distribution.

Table 6. Probabilities of inventory overage and shortage

	Low Conflict Intensity (ɣ)	Medium Conflict Intensity (ɣ)	High Conflict Intensity (ɣ)
Low Materiel Intrinsic Value (α)	$\alpha: 1.1; \gamma: 5$ Q*=3,100 **Over: 3%** **Under: 97%**	$\alpha: 1.1; \gamma: 20$ Q*=8,650 **Over:18%** **Under: 82%**	$\alpha: 1.1; \gamma: 80$ Q*=11,900 **Over: 36%** **Under: 64%**
Medium Materiel Intrinsic Value (α)	$\alpha: 1.3; \gamma: 5$ Q*=7,550 **Over: 14%** **Under: 86%**	$\alpha: 1.3; \gamma: 20$ Q*=15,900 **Over: 63%** **Under: 37%**	$\alpha: 1.3; \gamma: 80$ Q*=18,500 **Over: 78%** **Under: 22%**
High Materiel Intrinsic Value (α)	$\alpha: 1.5; \gamma: 5$ Q*=10,100 **Over: 74%** **Under: 26%**	$\alpha: 1.5; \gamma: 20$ Q*=10,050 **Over: 85%** **Under: 15%**	$\alpha: 1.5; \gamma: 80$ Q*=22,450 **Over: 93%** **Under: 7%**

B. CHAPTER SUMMARY

Understanding the probabilities associated with the optimal quantity was important to using the WRMMCAT model because it highlights the inherent challenge of our problem which is the unknown demand, unknown conflict intensity, and unknown materiel intrinsic value in the next war or conflict. While our capstone does not define how the parameters of the materiel intrinsic value and conflict intensity translate operationally, it provides the relational and relative logic between cost and demand as it pertains to potential penalty for not having enough War Reserve inventory. Moreover, the demand distribution, while only a representative of historical data, comes with a caution of the inherent unknown future demand.

On one hand, stocking the War Reserve at low-intensity, low-intrinsic value levels reduce the expected marginal costs significantly. Ultimately, the planners must determine the ‘value’ of having particular materiel. If materiel is not of value to the overall OPLAN that war reserve support, then the planners are inherently accepting that there is no risk of being short of the materiel in question. Given that our model incorporates both qualitative and quantitative variables to describe the cost risk to USMC, the WRMMCAT model represents an alternative perspective on military inventory management.

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VI. CONCLUSION

This section outlines this capstone's conclusions. In addition, it identifies some key limitations of the resulting model, and some areas for further research that would enhance the model and its usefulness towards its intended role. This section also reviews the purpose and goals motivating the development of the model as well as the resulting product that incorporated all stakeholder requirements.

The purpose of our capstone project was to provide USMC LOGCOM and I&L with a planning tool to provide an alternative approach on optimal WRM inventory levels. This approach considered the probabilistic nature of demand and the costs associated with maintaining too much or too little of an item, rather than the traditional approach of storing for a worst case scenario. Our goal was to produce a model that utilized concepts based on the newsvendor model but modified to account for the differences between the military and economic benefit of the items in questions. The intent for this model was to inform inventory stockage level decisions and enable more efficient outlay of constrained fiscal policies. Our key supporting objectives were to identify critical variables for this model through a systems engineering approach, and to utilize the BA-5590/U non-rechargeable batteries as a trial to demonstrate the efficacy of our model.

Activities associated with requirements decomposition resulted in identification of model components consisting of the variables demand, cost of overage, and cost of underage. Subsequently, further literature reviews on inventory management concepts and statistical analysis led to developing a model based on modifying the newsvendor model accounting for not only the financial costs associated with maintaining an inventory, but also the potential effect on military mission effectiveness associated with said inventory level.

In addition to defining the model, the capstone team also developed a Microsoft Excel-based tool to enable the sponsors to easily apply our model to any inventory item as long as cost and demand profiles are available. This tool requires user input on item demand

and costs associated with the procurement and storage, and projects the recommended inventory levels across a spectrum of possible conflict intensities.

This capstone makes a number of contributions to inventory management. The first is the identification of the changes to the newsvendor model that are required for its application in a military setting where there are only costs associated with both overage and underage. The second is the identification of a need to quantify the cost of being short and the suggestion of a possible form that that cost could take, though others are certainly possible. The final contribution is that we demonstrated our model using the BA-5590/U battery as an example and illustrated the sensitivity of the optimal number to the variables in our cost parameter.

A. LIMITATIONS AND FUTURE RESEARCH

The most important limitation of the WRMMCAT is that while it calculates a suggested inventory level for a MEU over a range of operational intensities, it does not calculate the chance over a given period of time, that conflicts of those intensities will occur. This presents an opportunity for future research to refine the model and its results. A model that could predict the frequency and intensity of future conflicts involving the USMC and release of WRM stores with some degree of accuracy could, in combination with our model, provide a more accurate inventory storage level.

An additional limitation of our model is specific to our use of BA-5590/U non-rechargeable batteries to demonstrate the model. We operate under the assumption that all of the batteries are employed when on full charge and are utilized until completely empty, generating no waste in the process. This ideal scenario is not representative of operational realities in which some waste is certain to occur out of mission necessity. Research into item wastage during differing intensities of conflict would allow for refined estimates on optimal inventory levels.

A second potential future research is to expand the WRMMCAT's utility by integrating economic order quantity concepts for determining inventory reordering frequencies for expendable items such as the BA-5590/U. While WRMMCAT's purpose is to determine the optimal inventory level using single-period analysis model, providing the USMC with a tool to assist in planning for reordering inventory has potential for significant value added to the overall military inventory management.

We highly encourage the USMC and users of the WRMMCAT to first define materiel criticality and conflict intensities as it pertains to planning factors. Since we developed the WRMMCAT by using subjective determination of the relative value of an item to the accomplishment of a mission, it is critical that the variables are captured with absolute definitions to maintain consistency. This fact makes possible for the manipulation of the model by those intending to shape an argument.

B. FINAL THOUGHTS

This capstone generated an alternative model for USMC LOGCOM and I&L to use in WRM inventory level decisions. The model utilized objective data and subjective value assessments to identify optimal WRM for a given item using a systems engineering approach. This model is intended to supplement, rather than replace, current inventory determination methodologies by allowing for consideration of the effect on military mission accomplishment in addition to financial factors.

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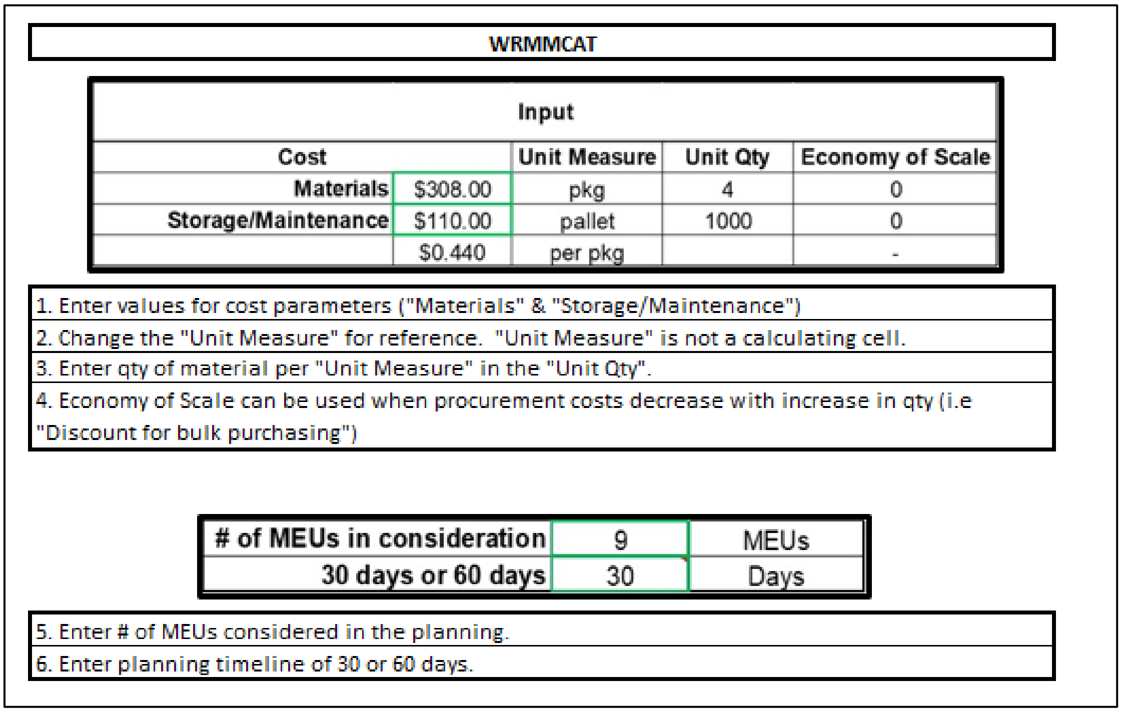
APPENDIX. WRMMCAT TOOL

This appendix provides screenshots of the WRMMCAT’s user interface. The screenshots are for reference only in understanding the data input and data output.



WRMMCAT

Input

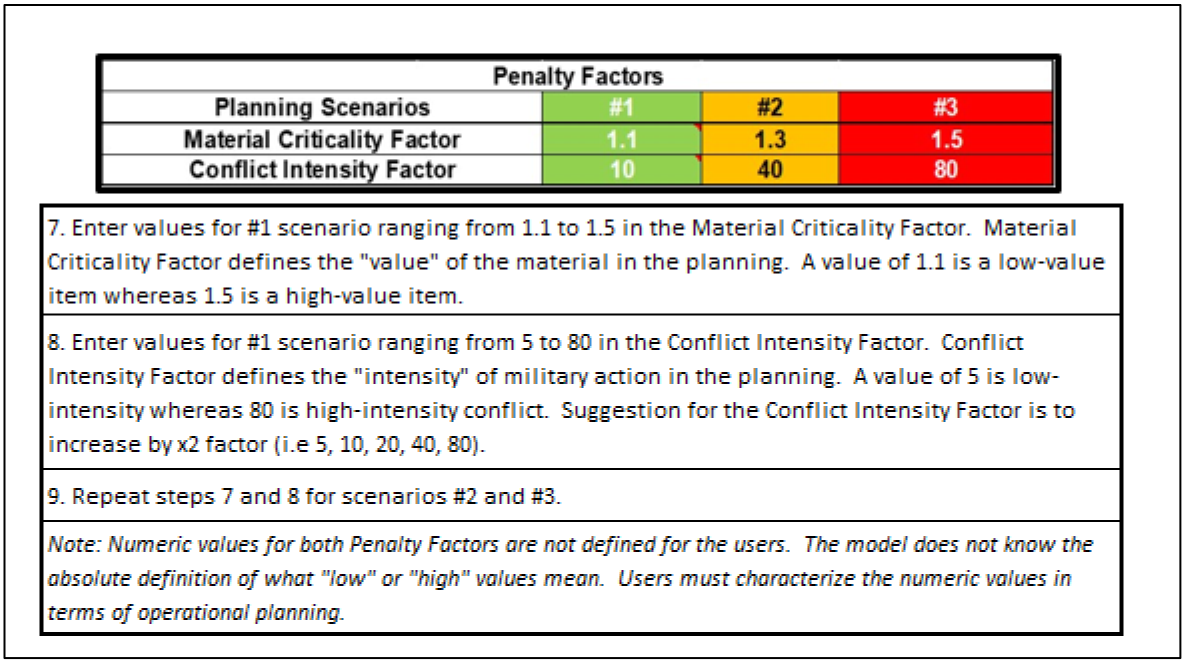
Cost		Unit Measure	Unit Qty	Economy of Scale
Materials	$308.00	pkg	4	0
Storage/Maintenance	$110.00	pallet	1000	0
	$0.440	per pkg		-

1. Enter values for cost parameters ("Materials" & "Storage/Maintenance")
2. Change the "Unit Measure" for reference. "Unit Measure" is not a calculating cell.
3. Enter qty of material per "Unit Measure" in the "Unit Qty".
4. Economy of Scale can be used when procurement costs decrease with increase in qty (i.e "Discount for bulk purchasing")

# of MEUs in consideration	9	MEUs
30 days or 60 days	30	Days

5. Enter # of MEUs considered in the planning.
6. Enter planning timeline of 30 or 60 days.

Figure 14. WRMMCAT required data input



Penalty Factors			
Planning Scenarios	#1	#2	#3
Material Criticality Factor	1.1	1.3	1.5
Conflict Intensity Factor	10	40	80

7. Enter values for #1 scenario ranging from 1.1 to 1.5 in the Material Criticality Factor. Material Criticality Factor defines the "value" of the material in the planning. A value of 1.1 is a low-value item whereas 1.5 is a high-value item.

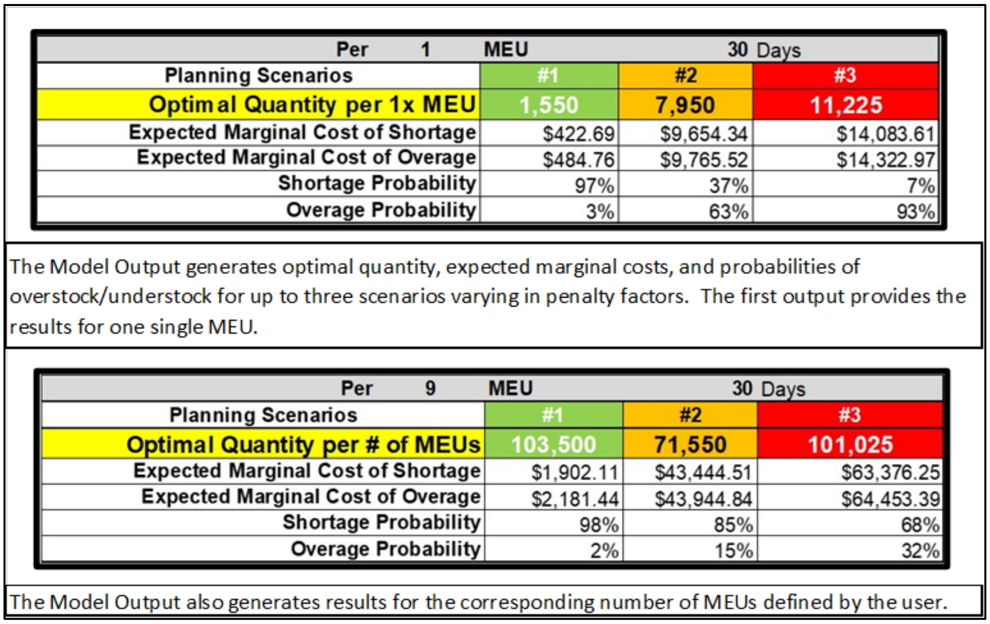
8. Enter values for #1 scenario ranging from 5 to 80 in the Conflict Intensity Factor. Conflict Intensity Factor defines the "intensity" of military action in the planning. A value of 5 is low-intensity whereas 80 is high-intensity conflict. Suggestion for the Conflict Intensity Factor is to increase by x2 factor (i.e 5, 10, 20, 40, 80).

9. Repeat steps 7 and 8 for scenarios #2 and #3.

Note: Numeric values for both Penalty Factors are not defined for the users. The model does not know the absolute definition of what "low" or "high" values mean. Users must characterize the numeric values in terms of operational planning.

Figure 15. WRMMCAT required data input continued

Figure 16 shows the spreadsheet output of the WRMMCAT results. Our capstone highlights that the optimal quantity is where the expected marginal cost of overage and shortage equal. The WRMMCAT produces approximated costs because the quantities are set in intervals of 50 for the calculation. Therefore, while the WRMMCAT output for the expected marginal costs of overage and shortage are not 100% equal.



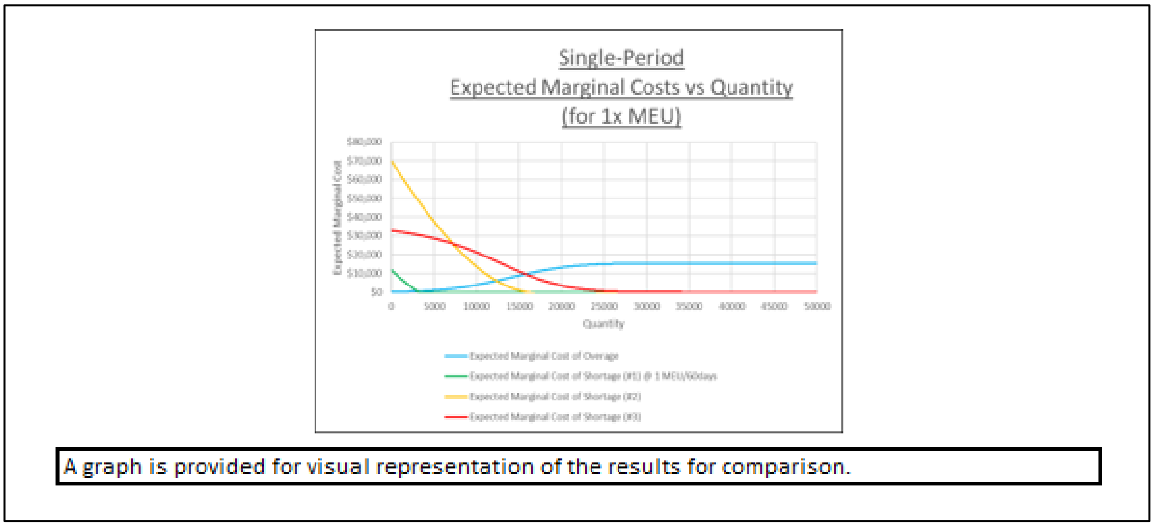
Per 1	MEU		30 Days
Planning Scenarios	**#1**	**#2**	**#3**
Optimal Quantity per 1x MEU	**1,550**	**7,950**	**11,225**
Expected Marginal Cost of Shortage	$422.69	$9,654.34	$14,083.61
Expected Marginal Cost of Overage	$484.76	$9,765.52	$14,322.97
Shortage Probability	97%	37%	7%
Overage Probability	3%	63%	93%

The Model Output generates optimal quantity, expected marginal costs, and probabilities of overstock/understock for up to three scenarios varying in penalty factors. The first output provides the results for one single MEU.

Per 9	MEU		30 Days
Planning Scenarios	**#1**	**#2**	**#3**
Optimal Quantity per # of MEUs	**103,500**	**71,550**	**101,025**
Expected Marginal Cost of Shortage	$1,902.11	$43,444.51	$63,376.25
Expected Marginal Cost of Overage	$2,181.44	$43,944.84	$64,453.39
Shortage Probability	98%	85%	68%
Overage Probability	2%	15%	32%

The Model Output also generates results for the corresponding number of MEUs defined by the user.

Figure 16. WRMMCAT output based on required data input



A graph is provided for visual representation of the results for comparison.

Figure 17. WRMMCAT graph output based on required data input

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