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PERFORMANCE ANALYSIS OF THE UNITED STATES MARINE CORPS WAR RESERVE MATERIEL PROGRAM PROCESS FLOW

December 2016

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Using historical data from January through March 2003, this project is specifically 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. By conducting a process analysis and using computer modeling, our recommendations are focused on improving efficiency and reducing lead time in an effort to better support future contingencies.

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LIST OF ACRONYMS AND ABBREVIATIONS

C2	Command and Control
CARF	Combat Active Replacement Factor
CCDR	Combatant Commander
CJCS	Chairman of the Joint Chiefs of Staff
CMC	Commandant of the Marine Corps
CoC	Chain-of-Command
COCOM	Combatant Command (command authority)
CONUS	Continental United States
CPM	Critical Path Method
CSA	Combat Support Agency
DC	Deputy Commandant
DLA	Defense Logistics Agency
DMAIC	Define, Measure, Analyze, Improve, and Control
DOD	Department of Defense
DON	Department of the Navy
DOS	Days of Supply
DPMO	Defects per Million Opportunities
EF21	Expeditionary Force 21
GCC	Geographic Combatant Command
HQMC	Headquarters Marine Corps
I&L	Installations and Logistics
ID/IQ	Indefinite Delivery; Indefinite Quantity
IM	Item Manager
LOGCOM	Logistics Command; officially COMMARCORLOGCOM
LSS	Lean Six Sigma
MAGTF	Marine Air-Ground Task Force
MCDP	Marine Corps Doctrinal Publication
MRO	Materiel Request Order

NSN	National Stock Number
OIF	Operation Iraqi Freedom
OPLAN	Operations Plan
OSD	Office of the Secretary of Defense
P&R	Programs and Resources (HQMC)
PERT	Program Evaluation and Review Technique
RDD	Requested Delivery Date
SABRS	Standard Accounting Budgeting Reporting System
SecDef	Secretary of Defense
SOP	Standard Operating Procedures
USTRANSCOM	US Transportation Command
USMC	United States Marine Corps
WRM	War Reserve Materiel
WRMRF	War Reserve Materiel Requirement Force-held
WRMRI	War Reserve Materiel Requirement In-stores
WRS	War Reserve System
WRWP	War Reserve Withdrawal Plan

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I. INTRODUCTION AND BACKGROUND

A. MOTIVATION

Since 11 September 2001, the United States military has been faced with enormous challenges, ranging from simultaneous wars in Iraq and Afghanistan, the Arab Spring resulting in collapsed governments across the Middle East, and a new global terror threat known as the Islamic State, just to name a few. Add in humanitarian aid missions for natural disasters, the internal friction of budget cuts, and manpower reductions, and now military planners are looking for ways to do more with less.

For the Marine Corps, the fundamental quandary today is how to get "*the right force, in the right place, at the right time*" (HQMC, 2014). This challenge becomes more difficult as global security changes at an ever increasing pace and the resources needed to respond become harder to obtain. Expeditionary Force 21 (EF21), published in 2014 by Headquarters Marine Corps (HQMC) focuses on realigning the force to meet the challenges of the future while maintaining the expeditionary culture shown in Figure 1.

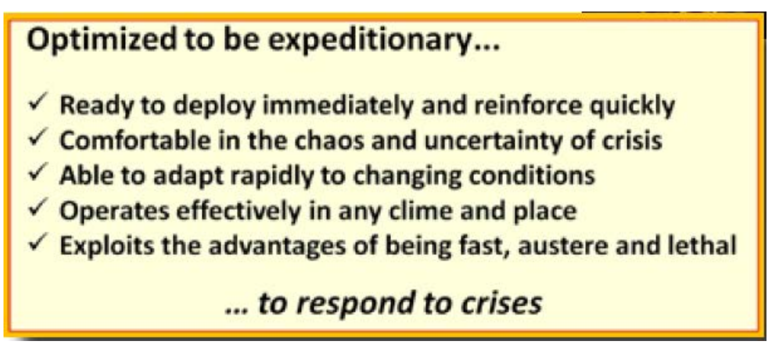

Figure 1. USMC Expeditionary Focus. Source: HQMC (2014).

The Marine Corps has designed the War Reserve Materiel (WRM) Program to aid in the fast, austere and lethal response to global contingencies. Managed by Marine Corps Logistics Command (LOGCOM), they try and answer the question: *Are we storing the right equipment, in the right places, at the right quantities in order to rapidly and accurately support the force?*

B. OBJECTIVE

The stockpiles of equipment and supplies the Marine Corps have strategically positioned provides a response capability to any crisis. Former Secretary of Defense (SecDef) Chuck Hagel has stated "The Marine Corps' inherent agility, crisis response capabilities, and maritime focus make it well suited to carry out many priority missions under the President's defense strategy" (HQMC, 2014). In order to maintain those capabilities, the Marine Corps must continually analyze and update the war reserve stocks being held around the world.

This research project analyzes historical usage data from the WRM Program's support of Operation Iraqi Freedom (OIF) in 2003. Our focus is to conduct a process improvement analysis internal to LOGCOM and our objective is focused on reducing delay time to ensure Required Delivery Dates (RDD) of critical equipment into theater are met with higher frequency.

C. RESEARCH QUESTIONS

In order to focus our research onto a process improvement analysis, we developed specific questions focused only on instances in which an item was requested from the WRM Program but not held within the inventory. The three major questions we sought to answer include:

1. When an item is requested from the WRM Program but not held in the inventory, what are the internal procedures that take place to acquire that item?
2. How much administrative delay do those procedures create?
3. How often does the delay contribute to missing a RDD?

D. SCOPE

Highlighted by Figure 2, the scope of this research project solely focuses on the internal procedures of LOGCOM when providing items from within the WRM Program. Specifically, we are looking at those processes that occur when an item is requested but not held within the WRM Program inventory.

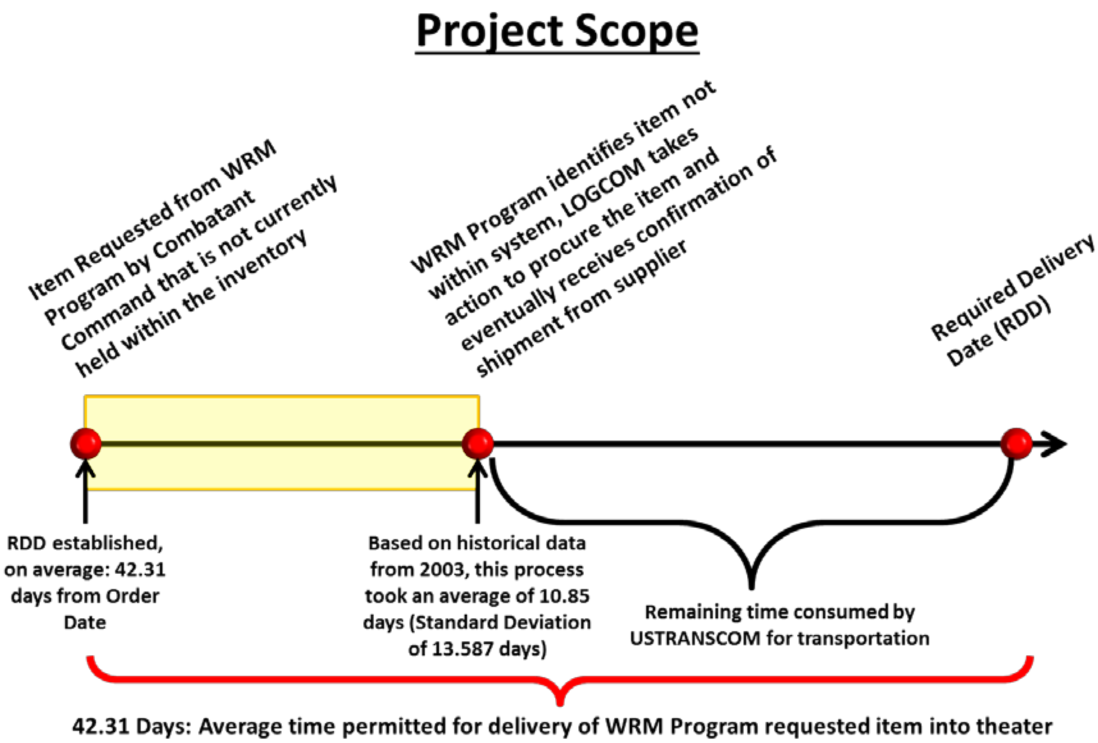

Figure 2. Project Scope and Background Data, Using Average Flow Times.
Source: LOGCOM (2003).

Based on data from 2003 in support of OIF, when an item was requested from the WRM Program and not held in the inventory, LOGCOM was given on average 42.31 days to meet the RDD in those cases. Knowing that those 42.31 days also includes transportation time, we aim to analyze and provide recommendations on how to shorten the administrative delays caused within LOGCOM in order to increase the likelihood that RDD will be met. This project will not attempt to analyze transportation timelines by United States Transportation Command (USTRANSCOM) as that is outside the direct control of the Marine Corps and LOGCOM.

E. METHODOLOGY

This research uses simulation and Lean Six Sigma (LSS) Process Improvement as a methodology. As discussed above, our analysis showed there is a significant amount of time consumed by what LOGCOM has described as administrative delays. Using that information, we have received detailed input from Marines and Department of Defense (DOD) civilians that know the system and are familiar with the processes that must take place. With their inputs (Optimistic, Pessimistic, and Most Likely) on how long each process takes, we built a Crystal Ball simulation model in order to conduct a Six Sigma Process Improvement analysis.

Our initial data collection was coordinated by LOGCOM personnel. It provided us with an insider perspective to how the system was utilized in 2003 during the buildup to OIF. This initial data and conversations with LOGCOM led us to focusing on the administrative delays. Further data was then collected from LOGCOM personnel known as Item Managers who are directly involved in the processes that take place when an item is requested but not held in the inventory. We relied on their subject matter expertise to conduct our process improvement analysis.

The Crystal Ball program allowed us to run various simulations in an effort to uncover the most likely factors contributing to missing RDD. The output functions of this software add strength to our recommendations by allowing us to provide LOGCOM with hard data resulting from thousands of simulated runs.

F. PROJECT OUTLINE

This report is organized as follows: Chapter II reviews the topics relevant to our analysis including Crystal Ball software, Program Evaluation and Review Technique (PERT), Critical Path Method (CPM), and LSS methodologies. Chapter III is focused on collection and analysis of our data to include the building of Crystal Ball models for simulation. Chapter IV offers analysis of our findings and the recommendations we offer to LOGCOM. Chapter V recommends ideas for further research.

II. LITERATURE REVIEW

A. DOD LOGISTICS OVERVIEW

Acquiring and supplying materiel to deployed forces is a complicated process. While we conducted our analysis on LOGCOM's role in this system, we thought it was important to familiarize ourselves with the overarching process to better understand the factors may facilitate or hinder LOGCOM's ability to execute its mission. Here we will discuss the top-level organizations and their roles in the delivery of materiel to the warfighter.

As this is a Process Flow topic, we will simplify the depiction of the process by assigning roles: the "provider," "transporter," and "customer." Additionally, we will introduce other organizations, alternative providers, that may be used for orders the primary provider is unable to fill. This distinction is important, as neither the providers nor the wholesalers have manufacturing capabilities and must source existing materiel or generate new orders. Figure 3 illustrates how each role fits in the organizational structure within the DOD.

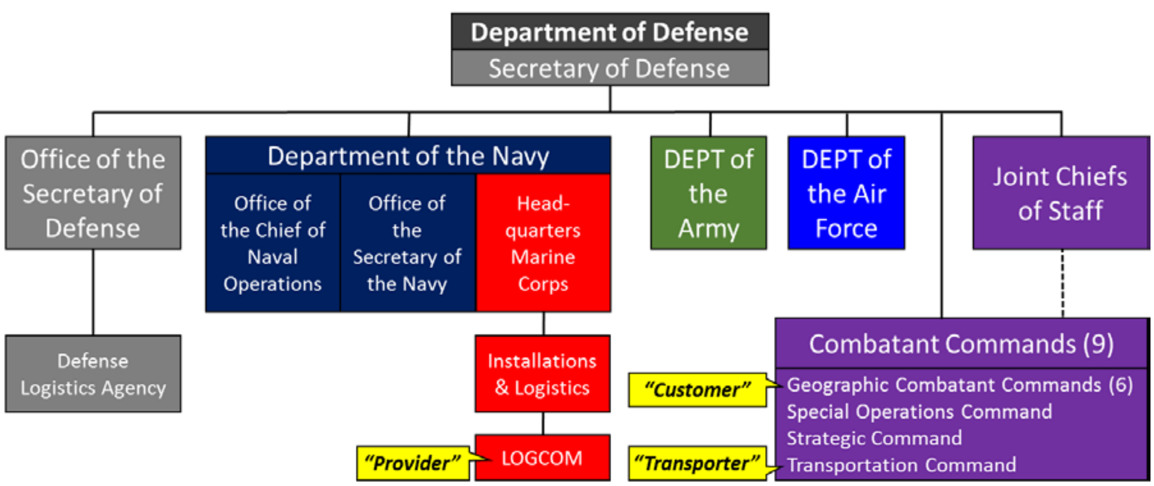

Figure 3. Simplified DOD Organization Chart Highlighting the Roles of "Provider, Transporter, and Customer." Adapted from United States Department of Defense (2013).

Within this hierarchical structure, many parallel organizational chains must operate laterally to receive, source, and deliver order requests. We will now discuss an overview of DOD logistics while introducing each of the organizations that fulfill these roles in order to familiarize the reader with the roles and responsibilities of LOGCOM and how it fits in the larger process.

1. Joint Logistics Overview

As depicted in Figure 3, the "President and SecDef exercise authority, direction, and control of the Armed Forces through two distinct branches of the chain of C2 [command and control]" (Joint Chiefs of Staff, 2013). For operational direction, the SecDef uses the Combatant Commanders (CCDR) and the forces within their Geographic Combatant Command (GCC). For any other purposes, the SecDef will operate via the service departments, such as the Department of the Navy (DON). In the case of logistics, this includes the acquisition and provision of items to their respective service departments. This command structure is important to note as forces transition from their parent commands to GCCs and the logistics train is altered.

2. Geographic Combatant Commands

When operationally ready units transition to a GCC, the CCDR assumes Combatant Command authority over those units and they are retained for use in accomplishing the CCDR's mission. Put simply, they belong to the CCDR and the new Chain-of-Command (CoC) is responsible for sustaining the unit, typical for all military units, assets, and installations within its geographic theater. However, when a USMC unit first arrives in theater, it is doctrinal for the war reserve to support the unit for only 90 days before the CCDR designates theater support agencies to assume the responsibility of logistical support to the unit. Thus, the *"customer"* is any given USMC unit that sought support from the WRS as they deploy to a GCC.

3. United States Transportation Command

In this simplified model, the chief "*transporter*" task belongs to USTRANSCOM, a Functional Combatant Command. USTRANSCOM "plans, coordinates, directs, and monitors movement and deployment of forces and materiel necessary to meet military objectives. [It] assures integration of components supporting plans for common-user lift of forces and materiel for contingencies and general war" (USTRANSCOM, 2016). Its role and authority as a Functional Combatant Command is crucial as it places USTRANSCOM on "equal footing" with the GCC, its customers, to prevent abuse of the command's capabilities and assets.

USTRANSCOM has several notable Component Commands that provide various logistics functions for the movement of personnel and materiel:

- Surface Deployment and Distribution Command; Army
- Military Sealift Command; Navy
- Air Mobility Command; Airforce

These Component Commands are manned by their respective services, and each can be expected to support joint efforts, according to the needs of the supported GCC. USTRANSCOM must work with the provider and the customer to determine the most efficient and timely distribution of resources and personnel.

While it is important to understand the relationship between each of major players in the Process Flow, the timeline of materiel transportation by USTRANSCOM will not be considered in our analysis. Once materiel has been relinquished from the WRM inventory for movement by USTRANSCOM, LOGCOM has no further influence on the timeliness of the delivery to the customer. Thus, due to the scope of our problem, we will focus solely on the portions of the overall delivery that LOGCOM can affect.

4. Service Department Logistics

Each service department has their own structure for all functions of logistical efforts; thus, we will focus on LOGCOM under HQMC as the "*provider*" in this model. When a deploying unit makes an order request to be fulfilled by the war reserve, LOGCOM will seek to satisfy it from their inventory or issue a request to a different provider, such as the Defense Logistics Agency (DLA). LOGCOM will be addressed in more detail under Section II-A-6: Logistics Command Overview.

5. Defense Logistics Agency

DLA, also noted in Figure 3, is a Combat Support Agency (CSA) under the Office of the Secretary of Defense (OSD). Under many circumstances, DLA could very well serve as an alternative provider in the big picture model. Indeed, when the WRM Program is unable to fill an order from their inventory, LOGCOM will attempt to leverage DLA to meet the need, and it cannot directly influence the process from that point until receipt. This is significant as the order and receipt from DLA contributes to the WRS timeline for delivery, which will be addressed as we examine the Process Flow of orders' receipt to fulfillment.

6. Logistics Command Overview

The USMC takes the strategic, operational, and tactical levels of logistics into consideration and must be able to deploy self-reliant Marine Air-Ground Task Forces (MAGTFs). The strategic level generates, sustains, and provides for forces capable of deployment. The tactical level maintains and moves deployed forces within the area of responsibility. The operational level is the realm that bridges the two, using all available logistics efforts to meet the needs of forces as they conduct operations theater-wide (HQMC, 1999). LOGCOM and the WRM Program are primarily involved in strategic and operational levels to facilitate the tactical execution.

The focus of our analysis is LOGCOM's role as the provider. The WRM Program is the method used to provide sustainment capability to deployed Marine units and a principal enabler in accomplishing LOGCOM's mission. At the strategic level, the WRM Program determines sustainment requirements to identify appropriate levels of materiel. At the operational level, it plans for sustainment of forward units and execute its portion of an Operations Plan (OPLAN) if called upon. OPLANS serve as broad plans to give structure to roles of all players in the event of a contingency. A portion of an OPLAN is reserved for a War Reserve Withdrawal Plan (WRWP). These WRWPs denote the levels of sustainment required from the reserve, determined by high-level planning efforts. In short, the WRM Program's strategic level contributions include planning and sourcing, while those at the operational level are the actual execution of the WRWP or modifications thereof.

LOGCOM falls under the Installations and Logistics (I&L) agency under HQMC. While it is a very complex process, LOGCOM sources and maintains inventory levels of materiel in accordance with the aforementioned plans. Using the War Reserve System (WRS), LOGCOM can use this interface to search its inventory and commit materiel to a requesting customer, should it exist in their inventory. Theoretically, it should match the WRWP; however, real-world contingencies often do not perfectly mirror the envisioned ones or developing requirements. If the necessary materiel is not in the WRS, LOGCOM uses the system to initiate an order to outside agencies, such as DLA.

B. WAR RESERVE MATERIEL PROGRAM OVERVIEW

Ultimately, the WRM Program's process seeks to sustain a MAGTF. Within the program, the WRS is used to calculate the requirements for this effort. The WRS is a collection of software, procedures, and inventory management systems that facilitate compliance with WRM Policy and LOGCOM's mission of assisting the deployed MAGTF.

Depending on the MAGTF's task organization, it is classified into a type of task force largely correlating to its size and the level of leadership assigned to its command. These types, from smallest to largest, are Marine Expeditionary Units (MEU), Marine Expeditionary Brigades (MEB), and Marine Expeditionary Forces (MEF). Each of these types is capable of self-sustainment for the first fifteen, thirty, and sixty days of deployment, respectively. After these time periods have expired, the WRM Program may be expected to source the supply effort.

The WRM Program's support to these MAGTFs is doctrinally planned to last up to ninety days upon the MAGTF's arrival into theater. WRM Days of Supply (DOS) are the units of measurement to one day's worth of sustainment for a given MAGTF.

Regardless of the MAGTF's self-sustainment capabilities, the GCC becomes responsible for the sustainment sourcing on day ninety, depicted in Figure 4.

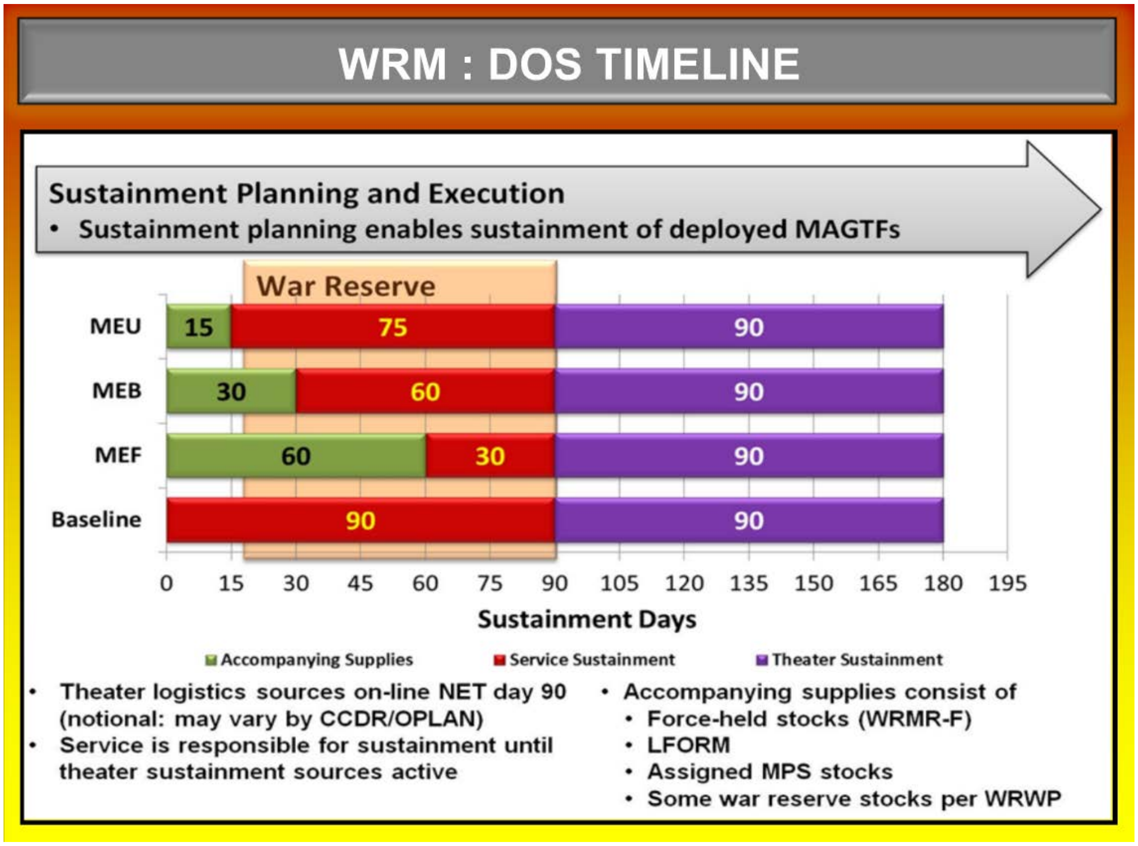

Figure 4. Depiction of WRM Sustainment of MAGTF for the First Ninety Days of Deployment. Source: HQMC (2016).

1. War Reserve Materiel Policy

The WRM Policy is over-arching guidance designed to ensure the USMC can "provide sufficient ground materiel to sustain the Operating Force (OPFOR) from inception to the establishment of the theater support capability" (Commandant of the Marine Corps, 2011). It is set by the referenced order, which is in turn guided by DOD Instructions concerning war reserve requirements (DOD Instruction 3110.06). As ordered by the Commandant of the Marine Corps (CMC), the Deputy Commandant Installations and Logistics (DC I&L) maintains the policy directives that guide the program. Within this agency, the DOS are calculated for various scenarios and units based off GCC Marine Corps component needs and other variables.

LOGCOM, as directed by policies such as the one above, maintains and reports on the "materiel status and changes in War Reserve Materiel Requirement Force-held (WRMRF) [and] War Reserve Materiel Requirement In-stores (WRMRI)" (Commandant of the Marine Corps, 2011). These are inventory levels held by Marine Corps forces and the actual WRM Program itself, respectively. LOGCOM is notably responsible for WRS file maintenance and reviewing the WRM Program, among many other requirements outlined in the policy order.

2. War Reserve Materiel Program

"The WRM Program provides guidance for the computation, acquisition and management of ground materiel required to sustain operating forces across a spectrum of missions and contingencies" (HQMC, 2011). It is the method by which the USMC complies with the aforementioned policy. The program defines six WRM Functions from inception to theater support capability, depicted in Figure 5.

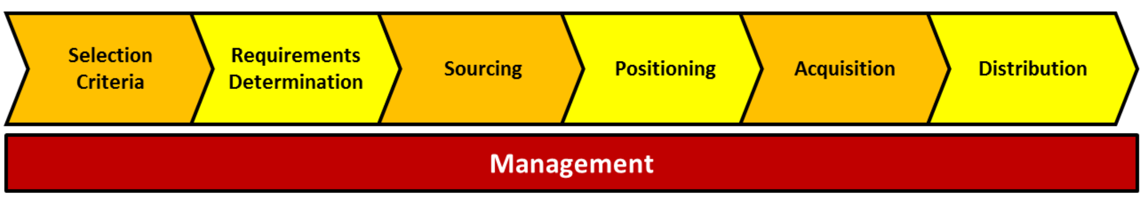

Figure 5. WRM Functions. Source: HQMC (2011).

These functions "are the means by which the Marine Corps provides for sufficient materiel, within the limits of acceptable risk, to sustain operating forces from inception to the establishment of the theater support capability" (HQMC, 2011). While each of these functions is critical and interrelated to the others, our analysis will primarily reside in the Distribution function. It is important to realize that the "computations [of sustainment requirements] do not address distribution within the battlespace, which is a transportation function" (HQMC, 2016). Distribution, in this sense, is concerned with the operational level of logistics as it seeks to support units arriving and operating in their designated theater.

Additionally, external Sourcing has a role to play as well when the WRMRI cannot satisfy an order with its inventory and must source externally. This differs from acquisition, which is associated with designing, manufacturing, and maintaining new or updated items. The remaining functions certainly have a role to play in the timeline of sustaining deployed forces, but affect transportation and other variables not directly associated with the order Process Flow and are outside the scope of this research.

3. War Reserve Inventory Planning and Withdrawal

When calculating requirements to be sourced and retained in the WRM Program, the WRS is used to track quantities and incorporate variables such as climate, unit size, operational phase, and mission requirements. While not unique to the WRM Program, items are organized into classes, listed in Table 1.

Table 1. Classes of Supply. Source: HQMC (2011).

Class	Description
Class I	Subsistence (Food, Rations, and Water)
Class II	Clothing and Individual Items
Class III	Petroleum, Oils, and Lubricants; Including Bulk Ground Fuel
Class IV	Lumber, Field Fortification and Construction Materiel
Class V	Ammunition
Class VI	Personal Demand Items
Class VII	End Items
Class VIII	Medical supplies
Class IX	Repair Parts
Class X	Materiel to Support Nonstandard Military Operations

Using the previously-mentioned WRM Functions, WRM sustainment planning at the strategic level involves many agencies and working groups to determine the requirements. At the operational level, the WRM Program seeks to support deployed MAGTFs and the CCDR OPLANs. When an actual WRWP must be executed, the sustainment requirements should be sourced in accordance with the planning inputs. The requested items, or WRM Materiel Request Orders (MROs), are released from the inventory, or "withdrawn," and can then be transported to the MAGTF via USTRANSCOM.

The notional timeline "to support planning purposes only" is depicted in Figure 6 (HQMC, 2011). While it is concerned with orders that the WRMRI has on hand, there is relevant information in the early steps. We noted that "HQ Admin/Funding Actions Complete" occurs by approximately Day 13. These first thirteen days encompass *Steps A* through *H* in our Process Flow; the WRM Programs distribution responsibilities from "Release Actions" up to "Complete Embarkment at [Aerial/Surface Port of Embarkation] A/SPOE" would only be applicable if the item were in the WRMRI. As we are concerned with items that were not on-hand and procured, the Inner Service Agency satisfying the order would be responsible for its transportation to the A/SPOE, where it is turned over to USTRANSCOM (HQMC, 2011).

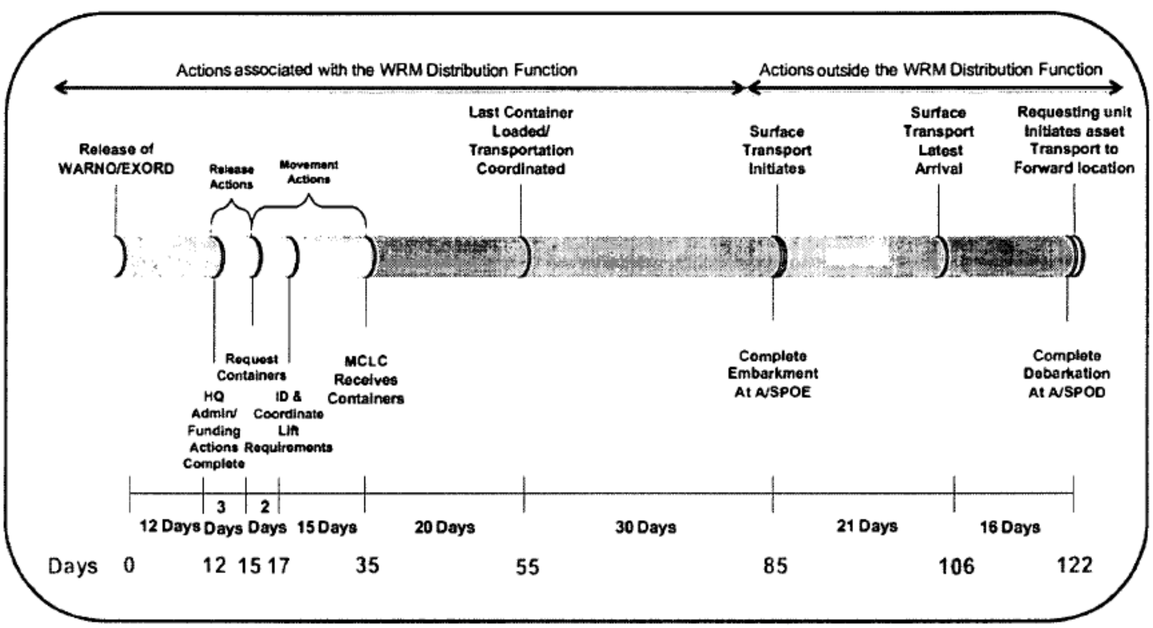

Figure 6. Withdrawal Timeline (Notional Example). Source: HQMC (2011).

The portion of Process Flow wherein the Source of Supply is assigning Shipping Status Codes, *Step I*, is a departure from the timeline depicted Figure 6. Another notable difference is that the average RDD of orders from the 2003 data was 42 days, while the notional Withdrawal Timeline depicts 122 days for planning purposes, with 85 of those being consumed by "Actions associated with the WRM Distribution Function." This demonstrates a dramatic departure from the notional timeline, but still offers some insight into the desired duration of WRM Distribution tasks in proportion to an entire realistic Withdrawal Timeline. There are important "assumptions and constraints associated with [the] Withdrawal process," depicted in Figure 7. A particularly noteworthy one is that the "administrative actions are conducted in the minimum amount of time required" (HQMC, 2011).

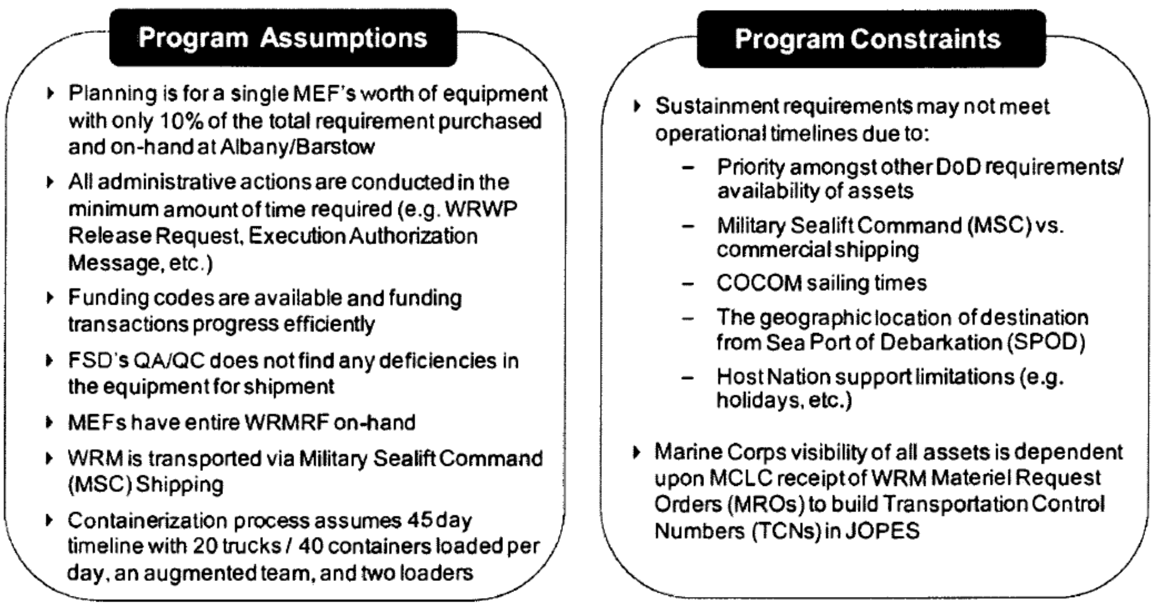

Figure 7. Withdrawal Assumptions and Constraints. Source: HQMC (2011).

C. MANAGEMENT PRACTICES AND METHODOLOGIES

After reviewing the WRM Program and its role, we will examine management practices for efficiency improvement. We seek techniques that may be applicable for analysis and recommendations for the WRM Programs process flow, and have identified several that could serve this goal, discussed in the remainder of this chapter. While several of these have been developed for business practices, we determined their potential due to the parallel process between the war reserve process and that of large, commercial organizations. These organizations continue to implement theories and management practices to reduce redundancies, waste, and delays to increase overall improvement processes and efficiencies. Excess volume and lengthy processes increase delays and costs. Scholars have developed concepts, tools, and methodologies to maximize efficiencies in products, services, and delivery schedules. Below are methodologies organizations have implemented to reduce defects, eliminate non-value added steps, and accurately predict optimal results, each potentially benefitting the WRM Program.

1. Lean Manufacturing

The theory of lean manufacturing, the elimination of waste, became fully incorporated into the manufacturing process by Henry Ford in 1913. Ford's production flow was generated from the creation of an assembly line as he was able to manufacture and assemble various components in an expedited manner. This quickly reduced time and costs as compared to traditional manufacturing practices. Kiichiro Toyoda, founder of Toyota, carefully examined Ford's practices to further enhance both variety and fabrication flow as he focused heavily on the entire production system as opposed to just a single step. Toyoda adjusted their manufacturing cycle to reduce excess volume and conjoined steps to increase the flow of information.

Although practiced for years, the theory of lean manufacturing was first cited in 1990 by James Womack, Daniel Jones, and Daniel Ross in "The Machine That Changed the World." Their citation introduced all industries to a new theory only practiced by select organizations. The "lean manufacturing approach is based on finding efficiencies and removing wasteful steps that don't add value to the end product" (Mindtools, n.d.). Within the lean approach, the eight areas of waste are identified in Table 2:

Table 2. Eight Wastes of Lean. Source: Sarkar (2009), Mindtools (n.d.).

Transportation	Unnecessarily moving products not required to perform the process
Inventory	Finished products not processed
Motion	Equipment or employees' movement that adds zero value
Waiting	Time spent waiting for follow on production steps; delays or interruptions
Overproduction	Producing unnecessary products; products not demanded
Over Processing	Lengthy approach to a simple problem
Defects/Scrap	Errors or mistakes; effort required to inspect and fix defected products
Un-utilized People	Employees not employed to full potential

By eliminating waste, organizations can reduce costs and production time while simultaneously improving overall quality (Apte & Kang, 2006). Lean approach theory has been widely accepted and applied to various industries to include the military, as well engineering and automobile manufacturers. Companies seek to align the production cycle to achieve maximum value and efficiency. The five lean principles are described in Table 3 and depicted cyclically in Figure 8.

Table 3. Principles of Lean. Source: Womack & Jones (1996).

Value	Specify the value from the standpoint of the end customer by product family.
Value Stream	Identify all the steps in the value stream for each product family, eliminating whenever possible those steps that do not create value.
Flow	Make the value-creating steps occur in tight sequence so the product will flow smoothly toward the customer.
Pull	As flow is introduced, let customers pull value from the next upstream activity.
Perfection	Begin the process again and continue it until a state of perfection is reached in which perfect value is created with no waste.

The concept of lean thinking determines those steps, activities, and resources that add value. Any additional step not adding value is detrimental to the production, considered waste, and must be removed. From the client's perspective, customers will pay for any action or process that adds value to fulfill their requirements (Mindtools, n.d.). The lean approach is a theory that must constantly respond to unforeseen changes and adapt accordingly to properly manage value added steps and remove waste. Before the next step in the cycle can begin, the prior event must be accomplished. If the event cannot be completed, the organization must retreat to the previous step or the beginning as depicted in Figure 8.

Figure 8. Principles of Lean Cycle. Source: Lean Enterprise Institute (2016).

While the WRM Program is not a manufacturing organization, the concept of lean manufacturing introduces management philosophies that are nested in more applicable techniques to follow.

2. Six Sigma

Lean manufacturing tackled problems from a quantitative standpoint, but organizations wanted to qualitatively measure production cycles, increase overall efficiencies, and reduce costs. Six Sigma's management practice aims to distribute near-perfect products and services by reducing defects in their products or services (Six Sigma Basics, n.d.). Defects include product costs, quality of services or products, and delivery performance. For every defect in the service or product, companies lose money by losing customers, repeating steps, wasting time, or replacing parts.

Bill Smith, Motorola Engineer and quality assurance chief, wanted to measure defects on a micro level to increase profits and improve service and product quality. Smith wanted to measure the defects per million opportunities (DPMO) instead of the traditional method of defect in thousands of opportunities ("The History of Six Sigma," n.d.).

Sigma measures the standard deviations, variations or dispersion in a dataset, from perfection. The name Six Sigma was coined as a Sigma level of Six results in near perfection as there are only 3.4 DPMO. Most companies are currently operating around Sigma level Three to Four resulting in roughly a quarters worth of lost revenue due to existing defects (Six Sigma Basics, n.d.). The Sigma Scale in Table 4 shows the relationship between Sigma levels and their respective defects per million:

Table 4. The Sigma Scale. Source: Six Sigma Basics (n.d.).

Sigma	Percent Defective	Defects per Million
1	69%	691,462
2	31%	308,538
3	6.70%	66,807
4	0.62%	6,210
5	0.02%	233
6	0.00%	3.4
7	0.00%	0.019

Six Sigma utilizes an improvement process to advance existing practices known as Define, Measure, Analyze, Improve, and Control (DMAIC). DMAIC helps organizations improve processes where each phase is interconnected with the previous phase and the next phase (Apte & Kang, 2008).

Through a data analysis approach, Six Sigma provides sufficient savings for large organizations by removing the root causes of products or service defects. Appropriate oversight and quality control measures can reduce costs, improve overall quality, and increase revenue. Similar to the lean approach cycle, Six Sigma is a cyclic effort that must be adaptive to unexpected changes.

In order for Six Sigma to become effective throughout the organization, key roles are assigned by leaders. These individuals, based on the extent of their training, hold hierarchal billets and responsibilities at various levels to promote and implement the principles of Six Sigma throughout the organization ("Six Sigma," 2016).

3. Lean Six Sigma

Six Sigma and lean manufacturing have been applied and practiced unconnectedly for years. Practitioners have blended both methodologies to analytically remove waste while utilizing Six Sigma's DMAIC phases. LSS's intentions are to eliminate waste, reduce defected products or services, and improve processes. LSS "drives customer satisfaction and bottom-line results by reducing variation, waste, and cycle time, while promoting the use of work standardization and flow, thereby creating a competitive advantage" ("What is Six Sigma?," 2009). Similar to Six Sigma, LSS seeks to identify a problem, analyze appropriately, and successfully implement a solution. Innovative thinking can help implement valid practices to minimize waste and defects.

Lean and Six Sigma methodologies have been successful in improving business operations. However, in order to be better equipped, LSS can help the organization confront more unique problems and broaden their approach to waste elimination. Organizations employing LSS will reap larger benefits than mastering either Six Sigma or lean manufacturing.

4. Program Evaluation and Review Technique and Critical Path Method

The previous concepts certainly appealed to manufacturing, profit-centric organizations, but other methodologies explore process improvement in a more general manner. PERT and CPM will likely be applicable to our analysis of the WRM Program process flow. These practices seek to identify issues that limit the speed and efficiency of accomplishing an objective, such as the WRM Program fulfilling an order.

PERT was established in the 1950s by an operations research team consisting of the United States Navy, Lockheed, and contractor Booz, Allen, and Hamilton during the development of Polaris-Submarine weapon system and Fleet Ballistic Missile capability ("Program Evaluation and Review Technique," 2016). CPM was also developed in the 1950s by Morgan Walker and James Kelley ("Critical Path Method," 2016). Walker and Morgan credited the development of CPM from the fundamentals of PERT. PERT and CPM, although independently developed, are nearly identical. Both methodologies focus on project management, scheduling, and concentrate on a vital critical path in a network of tasks. A critical path is the longest path to project completion, and is generated from a system of events performed in sequential order.

PERT, as a management tool, identifies all critical events, interrelations between different events, times to complete each event, and minimum time to project completion. A graphic provides managers with a visual representation of the sequence of events or those actions that can be independently completed. After analyzing the network of events and associated time to complete the task, organizations can assign additional resources to those steps causing delays. The critical path "is a sequence of individual activities of a project that must be finished on schedule so that the whole project is completed on time. Activities along the path cannot begin until a predecessor activity is complete" (Kielmas, n.d.). Similar to PERT, CPM computes the longest path of schedule steps to project completion. The process recognizes both critical and non-critical events to prevent bottlenecks and wasted time. Often, a flowchart will depict the relationships between tasks and the expected time to complete each step and entire process.

5. Variability in Activity Times

Each activity or step within the given PERT or CPM requires three estimates to complete that given task. Estimates of the three durations are as follows (OR-AS, 2011):

- Optimistic Time Estimate (a): Shortest possible time to complete the given task if all things go according to plan.
- Most-likely Time (m): Under given circumstances, the most likely time the task can be completed.
- Pessimistic Time Estimate (b): Longest possible time to complete the given task with unfavorable circumstances.

The three estimated durations provide a weighted average (expected time), standard deviation, and variance. The expected time is the "likeliness that the real activity duration lies close to the realistic estimate (m) is larger than the likeliness that it lies closer to the two extreme values a or b" (OR-AS, 2011). Both standard deviation, the amount of dispersion or variation from the mean, and the variance, the squared deviation from the mean, are necessary for a beta distributed data set. If all activities in the duration are beta distributed, "the general principle is that the standard deviation assumes that almost all observations will lie between the extreme values a and b" (OR-AS, 2011). Given the three estimated durations, the expected time, standard deviation and variance formulas are:

Expected Time: Time (t) = (a + 4m + b) / 6
Standard Deviation: Standard Deviation (sd) = (b – a) / 6
Variance of Times: Variance (v) = [(b – a)] / 6] ^2

PERT utilizes probability distribution for all estimated event times. This allows for variability within the given data set and estimated times. However, CPM assumes the estimated times are fixed and variability does not exist. During the execution of a War Reserve Drawdown, the duration of each task will not be given as a fixed time. The three estimates for each duration will include variability given the bureaucratic procedures within LOGCOM.

Research has shown and questions have been raised about the limitations that may exist in the use of the beta distribution. With beta distribution estimates, the optimistic and pessimistic task times are accepted as end points and so we acknowledge that we could be underestimating risk, most critically in our pessimistic times. As Klastorin states, it is difficult for individuals to provide accurate estimates of task durations they have never experienced. "This requires the decision maker to not consider possible catastrophic events when making this estimate. Thus, the manager/expert must make an accurate appraisal for hundreds or thousands of tasks of the worst time that could occur under 'normal' conditions" (Klastorin, 2004). With additional time and access to the LOGCOM procedures, we would recommend more detailed interviews and research by asking managers/experts to provide fractile estimates for each task (Klastorin, 2004); however, for this research we proceed using the beta distribution.

6. Risk Analysis and Crystal Ball Monte-Carlo Simulation

Risk can be defined as "the probability of occurrence of an undesirable outcome. Thus, risk is related to the uncertainty associated with things that one cannot control and the results of this uncertainty" (Evans & Olson, 2002). Further, risk analysis can be stated as "a comprehensive understanding and awareness of the risk associated with a particular variable of interest" (Hertz & Thomas, 1983). In our research on the WRM Process Flow, the particular variable that we have identified is time and the ability of the Marine Corps to deliver supplies within a given timeline. Through research and simulation, we look to identify the contributing factors to the schedule risk and offer recommendations on how to mitigate delays in the delivery process.

As Evans and Olson (2002, p. 114) state, "the challenge to risk analysts is to frame the output of risk analysis procedures in a manner that makes sense to the manager and provides clear insight into the problem," suggesting that simulation has many advantages. To aid us in our spreadsheet simulation, we will utilize the Crystal Ball software which automates and simplifies the complex and tedious steps in the Monte-Carlo simulation process. Sampling from a distribution, replicating model results and most importantly tools to address risk related questions are all benefits to using the Crystal Ball program (Evans & Olson, 2002).

With our goal of recommending process improvements in order to reduce internal timelines of LOGCOM and the WRS, we believe that conducting simulation using Crystal Ball will be advantageous for the following reasons (Balakrishnan, Render, & Stair, 2013):

- Flexibility: When properly implemented, the model can be made to accommodate several changes to the problem scenario.
- Allows for What-If Scenarios: We will have the flexibility to run the simulation many times trying several different policy decisions within a matter of minutes.
- No interference with the real-world system: With the data we have collected, we will be able to experiment using the model and not impacting real-world WRM Process Flow.
- Replication: Using Crystal Ball software will allow us to run thousands of replications, increasing the validity and usefulness of our outputs.

D. SUMMARY

This chapter introduced a broad overview of the DOD logistics system and its complexities. The focus was then narrowed onto the Marine Corps, LOGCOM and ultimately the WRM Program and its role in support of contingencies around the world.

The final section of this chapter discusses business management practices and methodologies that we intend to use in our analysis of the WRM Program. We will use computer simulation to conduct a schedule risk analysis centered on meeting RDD (i.e., Time). Using those results we will implement the principles of LSS and Process Improvement to reduce the risk of missing deadlines.

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III. METHODS AND INPUTS

A. THE DATA

With support from the personnel at LOGCOM who manage the WRM Program, we were able to access historical usage data from their computer database. The general time frame of data we received was between the period of January and March 2003. This time period is significant in that it coincides with the Marine Corps build up in the Middle East in preparation for the invasion of Iraq signaling the start of OIF. This was the last time the WRM Program was utilized in support of a significant ground war, and so we feel confident that this data sample is an accurate reflection on the WRM Program's performance.

The first data set we were given included over 40,000 lines of individual orders placed for various pieces of equipment or supplies. These orders ranged anywhere from principle end items to maintenance parts, including entire trucks down to a pair of boots. Figure 9 shows a simplified example of two individual order requests to better explain the type of information we were provided.

Column Descriptions
DIC: Document Identifier Code (Z11 = Request from WRM Program)
Doc Number: Unique Document Number (Embedded within this is Julian Date of the order)
Stock Number: National Stock Number for item being requested
Item Name: Military nomenclature for item being requested
SAC: Stores Account Code (SAC 3 item is a principle end item, in this case a weapon)
QTY: Quantity being requested from the WRM Program
Date: The Required Delivery Date (RDD) expressed in Julian Dates

DIC	DOC NUMBER	STOCK NUMBER	ITEM NAME	SAC	QTY	Date
Z11	M9880730160002	1005011289936	RIFLE,5.56 MILLIMET	3	01716	064
Z11	M9880730590003	1005013592714	MACHINE GUN,7.62 MM	3	00012	105

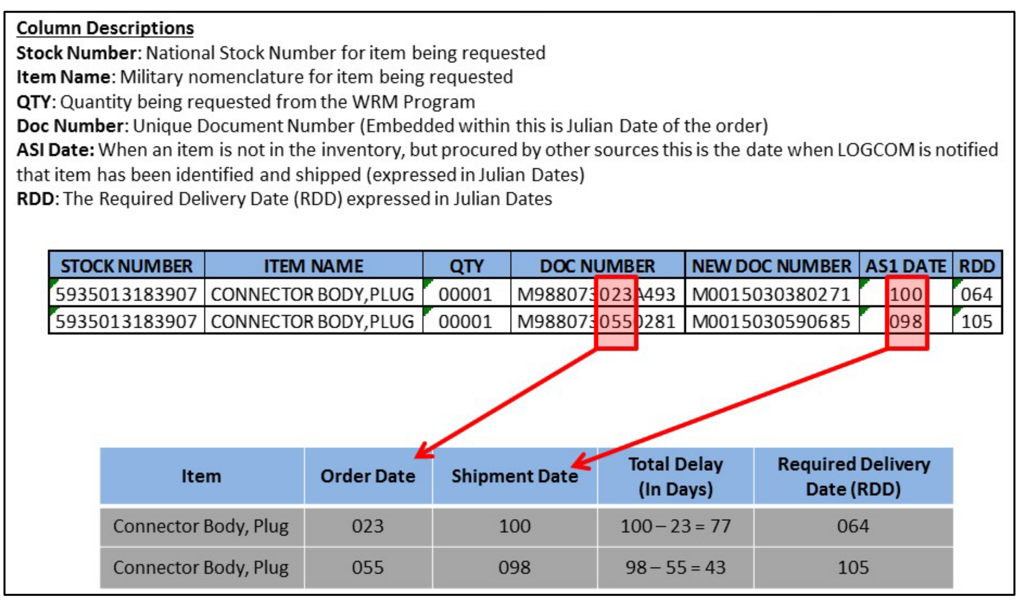
Item	Order Date	Required Delivery Date (RDD)	Time Permitted for Delivery in Days
Rifle, 5.56 Millimeter	016	064	48
Machine Gun, 7.62 Millimeter	059	105	46

Figure 9. Examples of WRM Program Requests in Support of OIF

The first line item is for a Rifle, 5.56 Millimeter with a quantity of 1,716. The date of “064” signifies the RDD based on a Julian Date Calendar. The second line item is for a Machine Gun, 7.62 Millimeter with a RDD of “105.” The order dates are embedded within the Document Numbers, and are shown in more detail in Figure 9.

Using the dates provided within the order information (highlighted in red within Figure 9) we were then able to calculate the time LOGCOM was given per order to have that item in theater (Required Delivery Date – Order Date = Time Permitted for Delivery). In the case of these two examples they had 48 days and 46 days for the rifle and machine gun, respectively. This was valuable information for us, as it quickly gave us a starting point from which to grade LOGCOM on its performance. However, knowing that part of that timeline was utilized by USTRANSCOM for the physical shipment of the item, we had to dig deeper to figure out what part of this timeline LOGCOM was actually responsible for, and potentially able to control.

The second data set that we analyzed included all the orders that were requested from the WRMRI, but not held within the inventory. Within the scope of this project, it is this set of data that provided us with a way to judge LOGCOM on their control of their processes. Using Figure 10, we will explain the metrics we used in our research.


Column Descriptions
Stock Number: National Stock Number for item being requested
Item Name: Military nomenclature for item being requested
QTY: Quantity being requested from the WRM Program
Doc Number: Unique Document Number (Embedded within this is Julian Date of the order)
ASI Date: When an item is not in the inventory, but procured by other sources this is the date when LOGCOM is notified that item has been identified and shipped (expressed in Julian Dates)
RDD: The Required Delivery Date (RDD) expressed in Julian Dates

STOCK NUMBER	ITEM NAME	QTY	DOC NUMBER	NEW DOC NUMBER	AS1 DATE	RDD
5935013183907	CONNECTOR BODY,PLUG	00001	M988073023A493	M0015030380271	100	064
5935013183907	CONNECTOR BODY,PLUG	00001	M9880730550281	M0015030590685	098	105

Item	Order Date	Shipment Date	Total Delay (In Days)	Required Delivery Date (RDD)
Connector Body, Plug	023	100	100 – 23 = 77	064
Connector Body, Plug	055	098	98 – 55 = 43	105

Figure 10. Items Requested but not Held within the WRM Program Inventory

The two items shown in Figure 10 were pulled from over 12,000 individual line items. Each of the 12,000+ lines represent individual orders for equipment or repair parts that were not currently held within the WRM Program’s inventory. In this case we purposely displayed two orders for identical items. The repair part “Connector Body, Plug” with the exact same Stock Number was requested on at least two separate occasions as we have shown. Utilizing Julian Date formats, we were then able to begin building a timeline to determine how much time LOGCOM was consuming with respect to meeting RDD. This becomes increasingly interesting when identical items show significant variation in procurement times, as this example does.

Going step-by-step for the first line item, we see that a “Connector Body, Plug” was ordered on Julian Date “023” with a quantity of “00001.” Finally, we see that in this particular case, LOGCOM did not receive confirmation of shipment until day “100,” despite the RDD being registered as “064.” To summarize this single item, it was ordered on day “023” but was not shipped until day “100” resulting in a total delay of 77 days under LOGCOM control, which is significant considering there were only 41 days given to meet RDD. For this order of a “Connector Body, Plug” we have found it was ready for shipment 36 days after RDD.

Looking at the second line we see that the same item, in the same quantity was ordered on day “055,” or 32 days after the first line item. Applying the same math explained above we discover the delay under LOGCOM is only 43 days, with a total of 50 days given to meet RDD. And so for this order of a “Connector Body, Plug” we have the item ready for shipment seven days before RDD. We can say these are “crossed orders” in the sense that order in line two was placed later but shipped sooner. So, first-come-first-served priority is not being maintained (Bashyam & Fu, 1998).

B. ANALYZING THE DATA

1. WRM Program Performance

In the section above we have two identical items, ordered in identical quantities with drastically different procurement timelines. The first item shipped 36 days after RDD and the second item shipped seven days before RDD. Obviously shipment after RDD is a failure, but what we could not measure was how far in advance of RDD should LOGCOM have a shipment confirmation in order to be considered successful in meeting RDD. It should be reiterated that the scope of the research does not include USTRANSCOM and so the timelines for shipment are still an unknown variable even though they are factored into the RDD. When we present the results of our data in Chapter four, we will estimate transportation times in order to judge effectiveness.

Focusing on the 12,000+ lines of data representing orders not held within the inventory, we first needed to establish the average amount of time that was permitted for RDD to be met. Shown in Table 5, the average RDD was 42.31 days from the order date (12,753 line items used in the calculation).

Table 5. RDD (All Data)

RDD (All Data)	
Mean	**42.3142006**
Standard Deviation	**3.40362931**
Minimum	**33**
Maximum	**58**
Count	**12753**

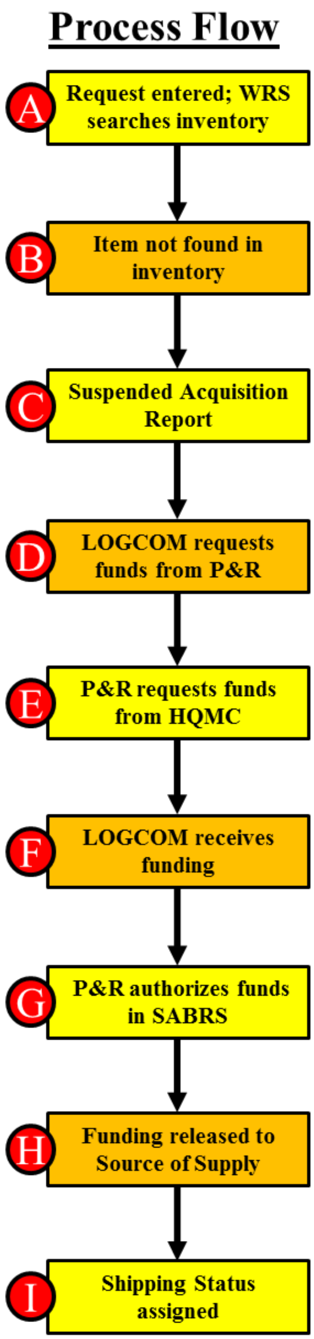
The next step we took was to determine the average amount of time LOGCOM needed when an item was not in their inventory. Ultimately it is this number that our research will aim to reduce, and as a result increase the likelihood of meeting RDD on a more consistent basis. As Table 6 indicates, in 2003 LOGCOM was consuming on average 10.85 days for an item to be procured and shipped, however we noticed the standard deviation of 13.57 was significant and needed further investigation.

Table 6. LOGCOM Delays (All Data)

LOGCOM Delays (All Data)	
Mean	**10.8525053**
Standard Deviation	**13.5763316**
Minimum	**2**
Maximum	**239**
Count	**12753**

2. PERT Analysis

With the objective of reducing delays, our next step was to determine the procedures that must take place within LOGCOM when items are requested and not in the inventory. Using the inputs from subject matter experts familiar with the process, we built the process flow chart in Figure 11. The process flow steps are labeled *A* through *I*, which will be consistent labeling throughout our depictions. For simplicity purposes, we excluded portions that would exit the scope of our analysis, such as the requested item being found in WRMRI or contracting the industrial base for acquisition, which begins its own, much longer, process as the contracts are sought, negotiated, and fulfilled.



Step	Description
A	Upon the request being entered into the WRS, the software searches the WRMRI and LOGCOM's inventory for the item and quantity.
B	For the scope of our analysis, we are concerned with only those items that are not present in the inventory; if the item were present this process would skip immediately to Step I.
C	The request is then posted as a "Suspended Acquisition Report". An Item Manager (IM) then "catalogs" the item, deciding if an appropriate substitute exits and if the request is valid.
D	Should no substitute exist within the inventory, procurement is necessary and funds must be requested up the CoC. Note that if industrial base contracting must occur, procurement exits this process flow.
E	The request for funding continues up the CoC to HQMC. The IM has determined that an Inner Agency Service (GAO, DLA, US Army, etc.) has the item in question and will be the Source of Supply.
F	After relevant budget considerations are taken, HQMC determines LOGCOM can be given the requested funds.
G	After the approval of the funds, Programs and Resources (P&R) authorizes the funds for use by LOGCOM in the Standard Accounting Budgeting Reporting System (SABRS).
H	The funds are applied and released to the Source of Supply in exchange for the item requested.
I	LOGCOM assigns the appropriate Status Code to the order. The initial response ("BA, BB, BD")* should ultimately change to Shipping Status "AS".

*Notes on Status Codes
- BA: source will supply, although it could be a partial quantity
- BB: source has backordered item; LOGCOM can expect an estimate of when source will be able to supply
- BD: source is conducting internal research and will follow with BA or BB when finished
- AS: item has shipped

Figure 11. Process Flow Chart. Source: LOGCOM (2016).

In our interviews with LOGCOM, we were also given flow time estimates for every procedure highlighted above. From the subject matter experts point of view, these times were given as the Optimistic (a), Pessimistic (b) and Most Likely (m) amounts of time each procedure would take. Using the three-point approximation technique, we were able to derive the mean and standard deviation for each step (task) using the following formulas (OR-AS, 2011):

Mean Task Time = (a + 4m + b) / 6
Task Time Standard Deviation = (b – a) / 6

It should be noted here that in our interviews we collected this data using days as the unit of measure. In a few cases, the interviewees reported the Optimistic, Pessimistic or Most Likely time simply as "less than 1 day." In those cases, we substituted 0.25 days for the Optimistic estimate (to represent six hours), 0.75 days for the Most Likely estimate (representing 18 hours) and 1 for the Pessimistic estimate (representing 24 hours). Table 7 shows the results of our interviews.

Table 7. Process Analysis Using 2016 Inputs

Process Analysis Using 2016 Inputs						
Step	**Activity**	**Optimistic Estimate**	**Most Likely Estimate**	**Pessimistic Estimate**	**Mean**	**Standard Deviation**
A	Request Entered in System	0.2500	0.7500	1.5000	0.7917	0.2083
B	Item Not Found in Inventory	0.2500	0.5000	0.7500	0.5000	0.0833
C	Request Posted to Suspended Acquisition Report	0.2500	0.7500	1.0000	0.7083	0.1250
D	Funds Requested from P&R (LOGCOM)	0.2500	0.7500	1.0000	0.7083	0.1250
E	P&R Requests Funding from HQMC	0.2500	1.0000	2.0000	1.0417	0.2917
F	LOGCOM Recieves Funding	0.2500	3.0000	7.0000	3.2083	1.1250
G	P&R Authorizes Funds in SABRS	0.2500	1.0000	1.0000	0.8750	0.1250
H	Funding Applied and Released to Source of Supply	0.2500	0.7500	1.0000	0.7083	0.1250
I	Receive Shipping Status from Source of Supply				6.9481	12.8429

We also want to address an assumption that was made regarding the computation of mean and standard deviation for *Step I*. It is at this point that we acknowledge the blending of information received via interviews in 2016, and the data we were given from back in 2003. For *Step I*, we wanted to know the amount of time it would take for LOGCOM to receive notice of shipment from the source of supply and felt the best way to forecast that was to use the 12,000+ actual occurrences we have in the 2003 database.

So the mean and standard deviation computations for *Step I* were not done using the three-point approximation technique and were instead done using actual data, with the acknowledgement it is from 2003.

3. Crystal Ball Model

Using the data above we were able to construct our Crystal Ball model. Table 8 is a screen shot of the model, where the blue colored cell represents the total time for the process to be completed. By defining this blue cell as a forecast cell, Crystal Ball will track the completion times for every simulation that we run and will provide outputs that we can analyze in follow on chapters. Each of the green cells are defined distributions which vary depending on the way the data was collected for each particular step.

Table 8. Crystal Ball Model with 2016 Interview Inputs

Crystal Ball - 2016 Inputs				
Step	**Activity**	**Start Time**	**Duration**	**End Time**
A	Request Entered in System			
B	Item Not Found in Inventory			
C	Request Posted to Suspended Acquisition Report			
D	Funds Requested from P&R (LOGCOM)			
E	P&R Requests Funding from HQMC			
F	LOGCOM Receives Funding			
G	P&R Authorizes Funds in SABRS			
H	Funding Applied and Released to Source of Supply			
I	Receive Shipping Status from Source of Supply			

Steps A through *H* were defined using a BetaPERT distribution. According to the Crystal Ball software, "this distribution is derived from the beta distribution and is commonly used in project risk analysis for assigning probabilities to step durations and costs. The parameters required for the BetaPERT distribution are the optimistic (Minimum), most likely (Mode), and pessimistic (Maximum) estimates" (Oracle Corporation, 2008). Figure 12 is an example of the BetaPERT distribution created in Crystal Ball for "*Step F: LOGCOM Receives Funding.*" The distribution parameters are pulled directly from the data shown in Table 8, and this process was done exactly the same for all *Steps A* through *H*.

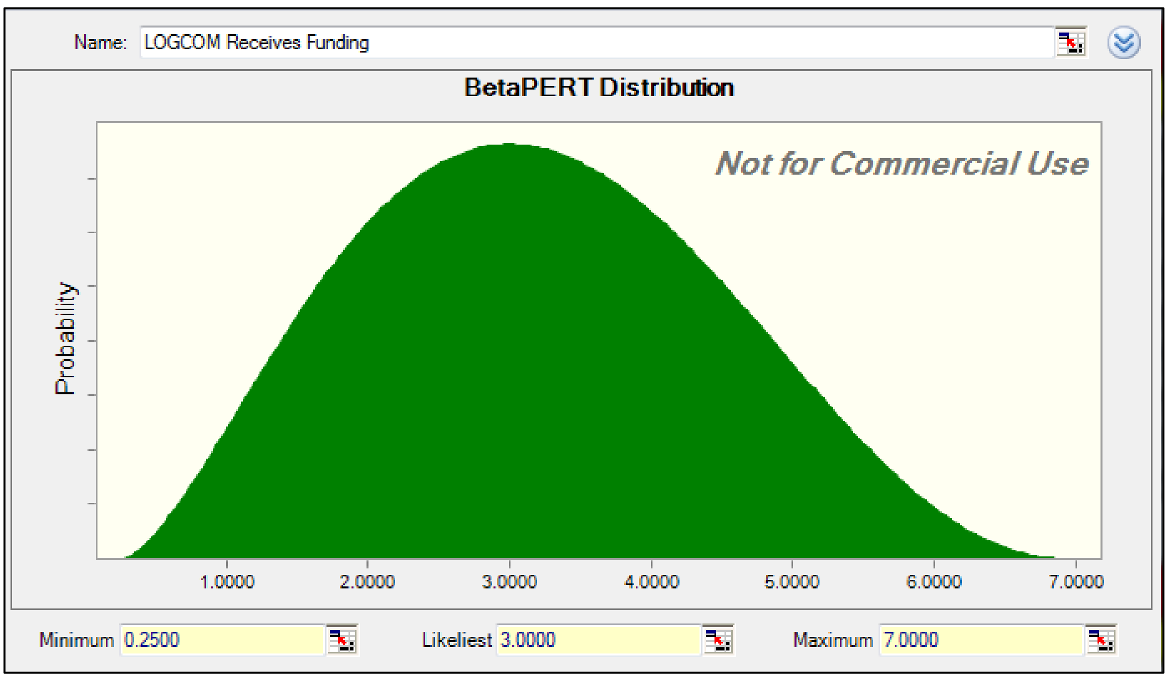


Figure 12. BetaPERT Distribution of *Step F*

Step I was defined using a Lognormal Distribution. Using the 12,753 lines of actual data, we ran the Anderson-Darling goodness-of-fit statistics tool within Crystal Ball. The Crystal Ball outputs to support our decision are shown in Figure 13.

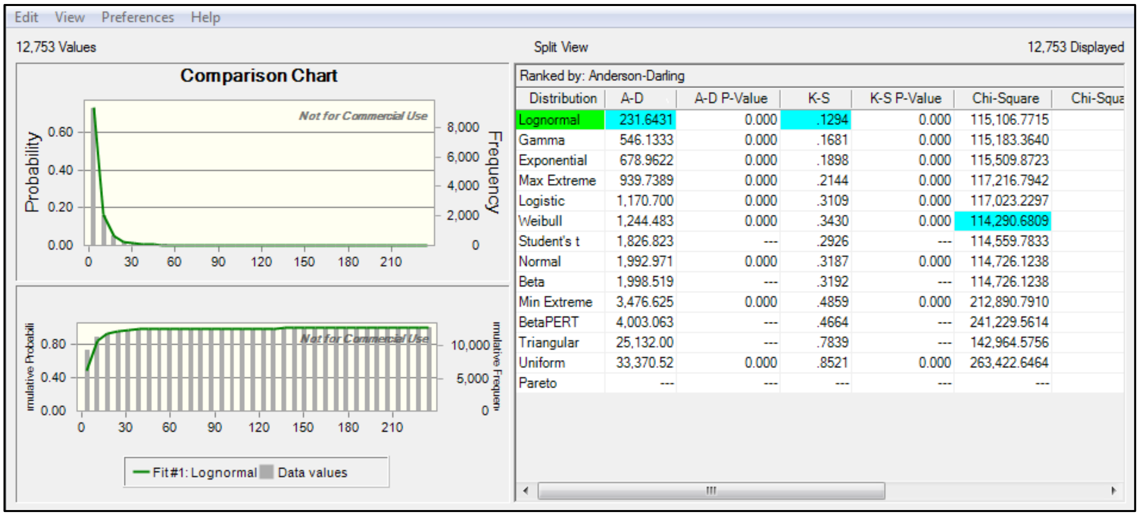


Figure 13. Goodness-of-fit Statistics Tool Results of *Step I*

We concluded the Lognormal Distribution was a good fit for our data since the minimum times must be more than zero, and on rare occasion times could increase seemingly without limit. Figure 14 shows the Lognormal Distribution in our model that uses the 12,753 lines of actual data.

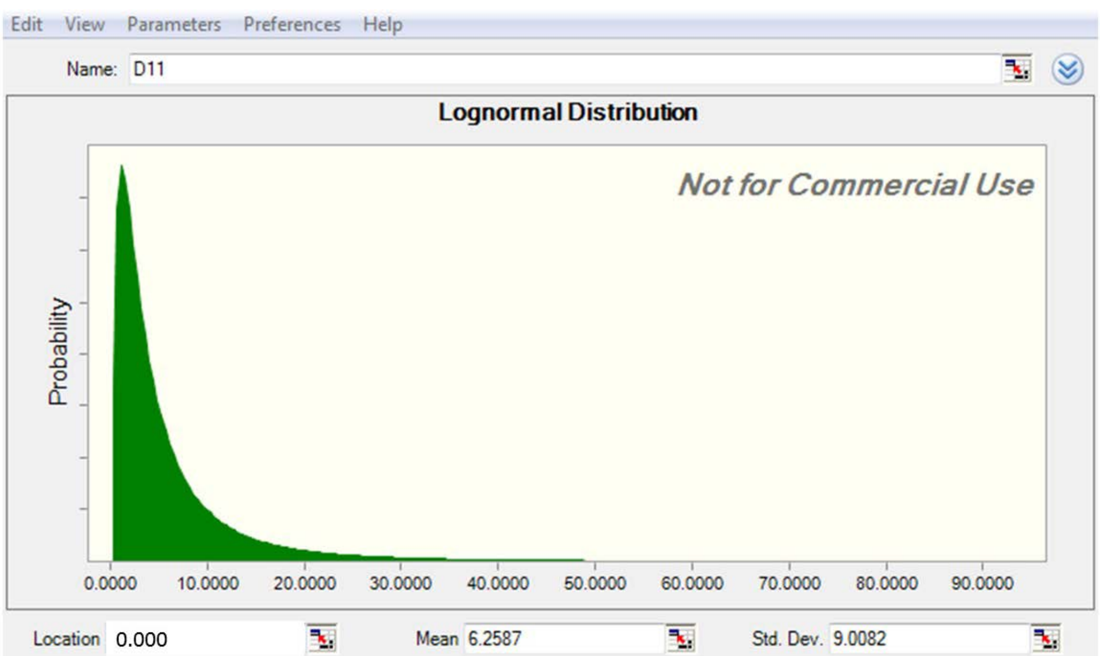


Figure 14. Lognormal Distribution for 2003 Data *of Step I*

C. SUMMARY

We also sought to incorporate an activity-on-node diagram in accordance with common PERT methodologies; however, it proved to be of little use as the path we analyzed was determined to be the critical path, as far as the scope of this research would allow. As it was completely linear, no viable slack would exist ("Program Evaluation and Review Technique," 2016). Thus, we determined it to be unserviceable for our purposes.

The primary method for our analysis was then to determine the likelihood of satisfying an order within an acceptable service window by leveraging Crystal Ball software. These outputs, coupled with our understanding of the critical path's steps, aided us in identifying areas of risk and suggesting applicable mitigation practices, leading us to Chapter IV: Results and Recommendations.

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IV. RESULTS AND RECOMMENDATIONS

A. RESULTS USING 2016 PROCESS FLOW

1. Overview

At this stage of our research, we are ready to discuss the results of our findings. Using the Crystal Ball Software, we display the outputs after running 100,000 trials. Figure 15 shows the summarized statistics and Figure 16 is the distribution of all outputs for all 100,000 trials.

100,000 Trials — Statistics View — 100,000 Displayed

Statistic	Forecast values
Trials	100,000
Base Case	15.4898
Mean	14.8342
Median	12.3566
Mode	---
Standard Deviation	9.1215
Variance	83.2013
Skewness	6.31
Kurtosis	103.22
Coeff. of Variability	0.6149
Minimum	5.2841
Maximum	427.9033
Mean Std. Error	0.0288

Figure 15. Summarized Statistics of Crystal Ball Trials

Figure 15 shows us that after 100,000 trials, our average (mean) expected delay time for LOGCOM is 14.8342 days, or just over two full weeks. Our standard deviation of 9.1215 is high resulting in the large range in values that we identified. After 100,000 trials the shortest amount of time the LOGCOM process took to complete was just over five days, and the longest was just over 427 days. A completion time of 427 days back in 2003 would have obviously been an issue considering that the USMC began the invasion of Iraq on 20 March 2003, and combat operations were declared complete by President George W. Bush on 1 May 2003.

Figure 16 takes the summary statistics and displays them in a way to visually see the distribution with the mean of 14.8342 labeled. We acknowledge that the usefulness of Figure 16 is limited due to the fact that we have the Crystal Ball settings adjusted in order to display all 100,000 trial results. In follow on figures we will eliminate the tail ends of the distribution in order to provide a more meaningful visualization, but for now we wanted to emphasize the range of our results.

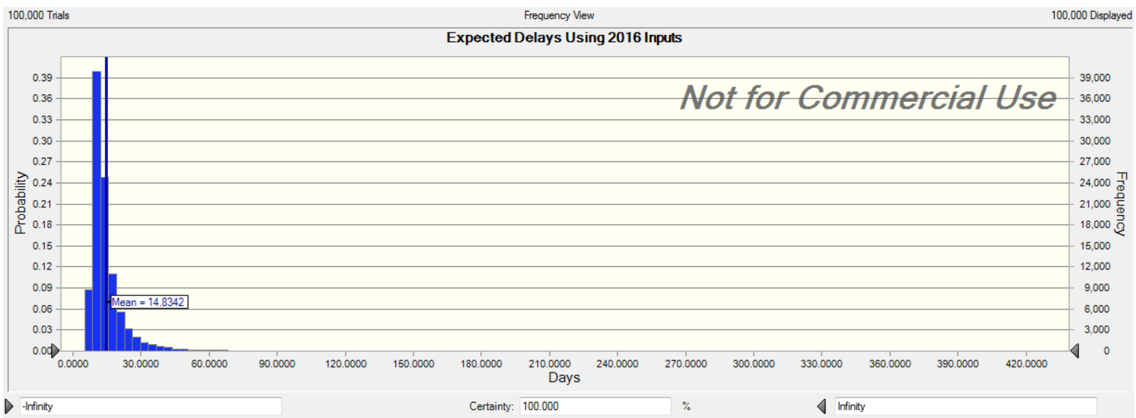


Figure 16. Distribution of Outputs from Crystal Ball Trials

2. Probability of RDD Being Met

We now take a closer look at the distribution of completion times. Using the same set of results from our 100,000 trials (only 98,002 displayed) we provide probabilities of a particular item being shipped within timelines that we feel is sufficient to meet RDD. For this part of our analysis, we reference data discussed in Chapter III where we identified the average RDD in 2003 was 42.31 days (will round down to 42 days). With RDD established at 42 days, we will use ten day increments (10/20/30 days) to allow for variability in the USTRANSCOM transportation process.

Thus, if an item takes all 42 days to be processed for shipping, it is guaranteed to exceed the RDD when accounting for USTRANSCOM's physical shipping. If an item takes RDD minus 10 days, this affords USTRANSCOM those 10 days to physically transport the item and increasing the likelihood of the item arriving on or before RDD. The same applies for RDD minus 20 or 30, further increasing the probability of the item arriving prior to RDD. In general terms, when an item is processed faster, USTRANSCOM has more time to deliver the item, and the probability of meeting RDD is increased. These increments give us flexibility in our analysis, as the variability of USTRANSCOM's transportation times are outside the scope of this report.

Figure 17 shows that after 100,000 trials there is a 98.244% probability that an item will be shipped on or before RDD of 42 days. The mean of 14.8342 can be seen relative to the rest of the distribution.

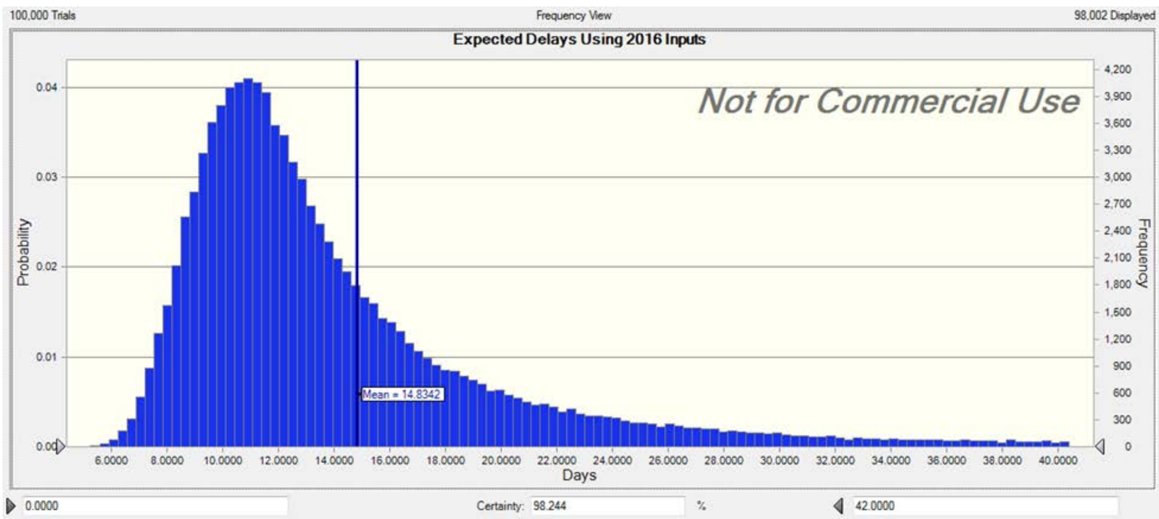


Figure 17. Probability of Shipping before RDD (42 Days or Less)

Figure 18 shows that after 100,000 trials there is a 96.112% probability that an item will be shipped on or before RDD minus 10 days (32 days from order date). This model would tell LOGCOM that they have a 96.112% chance of meeting RDD if USTRANSCOM needed only 10 days or less to ship the item into theater. The instances that would then exceed RDD are shown in red.

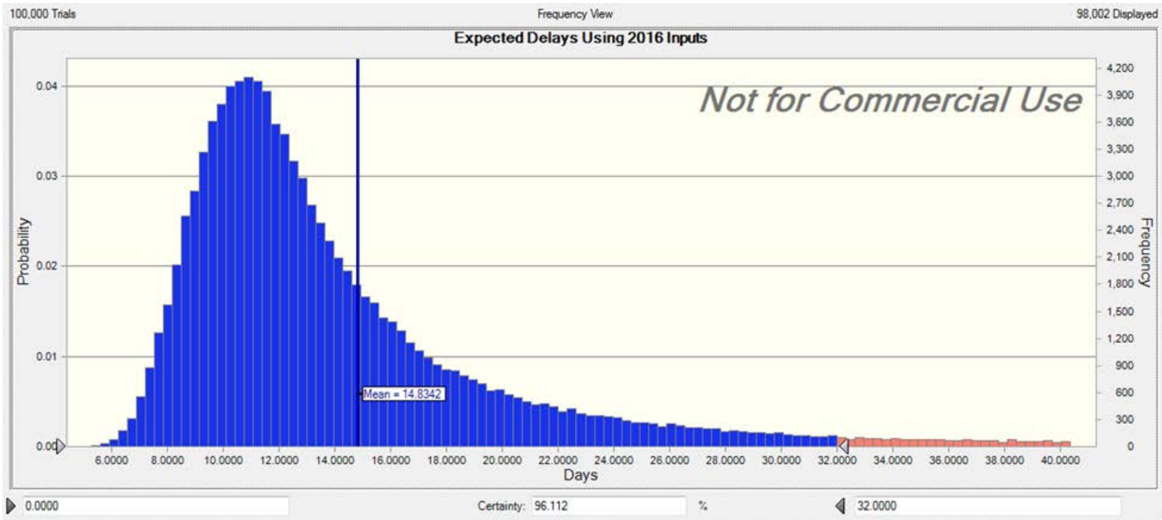


Figure 18. Probability of Shipping before RDD Minus 10 (32 Days or Less)

Figure 19 shows that after 100,000 trials there is an 89.114% probability that an item will be shipped on or before RDD minus 20 days (22 days from order date). This model would tell LOGCOM that they have an 89.114% chance of meeting RDD if USTRANSCOM needed only 20 days or less to ship the item into theater. The instances that would then exceed RDD are shown in red.

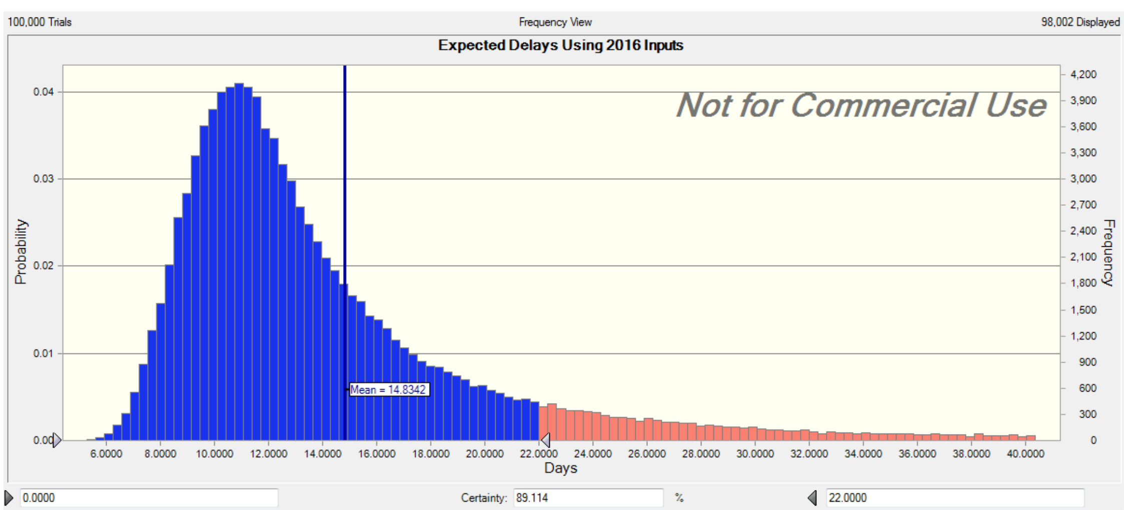


Figure 19. Probability of Shipping before RDD Minus 20 (22 Days or Less)

And finally Figure 20 shows that after 100,000 trials there is a 46.142% probability that an item will be shipped on or before RDD minus 30 days (12 days from order date). This model would tell LOGCOM that they have a 46.142% chance of meeting RDD if USTRANSCOM needed 30 days or less to ship the item into theater. The instances that would then exceed RDD are shown in red.

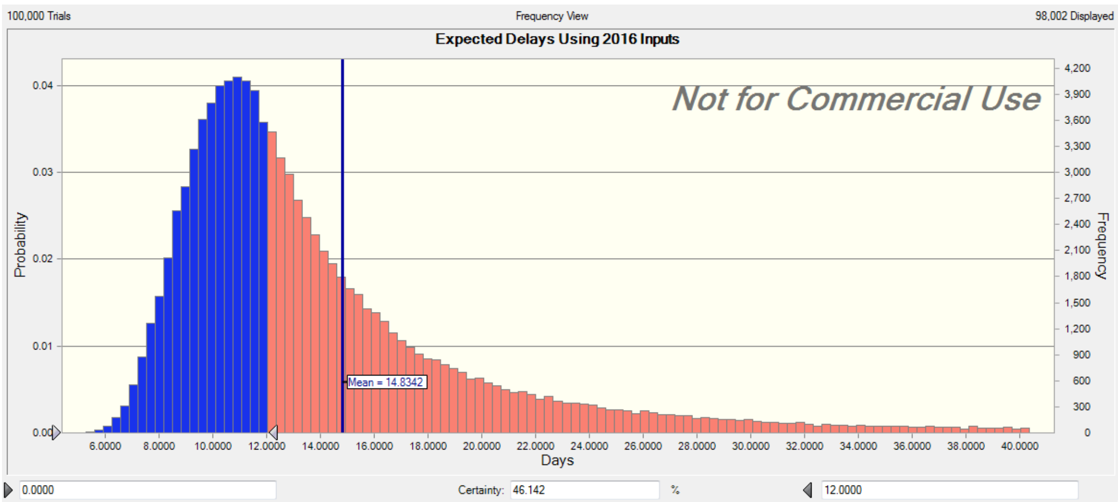


Figure 20. Probability of Shipping before RDD Minus 30 (12 Days or Less)

We feel that this type of analysis will be valuable for LOGCOM during their planning process. When a decision is being made on whether to keep certain parts in inventory, they can now understand the level of risk, stated in days, of not having that item in inventory and how likely they will be to miss the RDD.

B. RESULTS OF HYPOTHETICAL MODELING

It is this point in our research that our Crystal Ball simulation provides its greatest value by allowing us to simulate hypothetical scenarios and analyze possible areas for improvement. We have spent extensive time researching the processes within LOGCOM and the completion times of each step. We have also shown levels of risk associated with missing RDD when the current processes are completed. Now we will manipulate completion times of the various steps and rerun our model in order to show where investment in improvements might be most valuable.

1. Generating Hypothetical Scenarios Using LSS Methods

Our first step in implementing improvements was to identify the processes that contributed the most to delays and variability. Using Crystal Ball we produced a Tornado Diagram (similar to a Pareto Chart) in order to tell us where to focus our efforts. The results of the Tornado Diagram are shown in Figure 21.

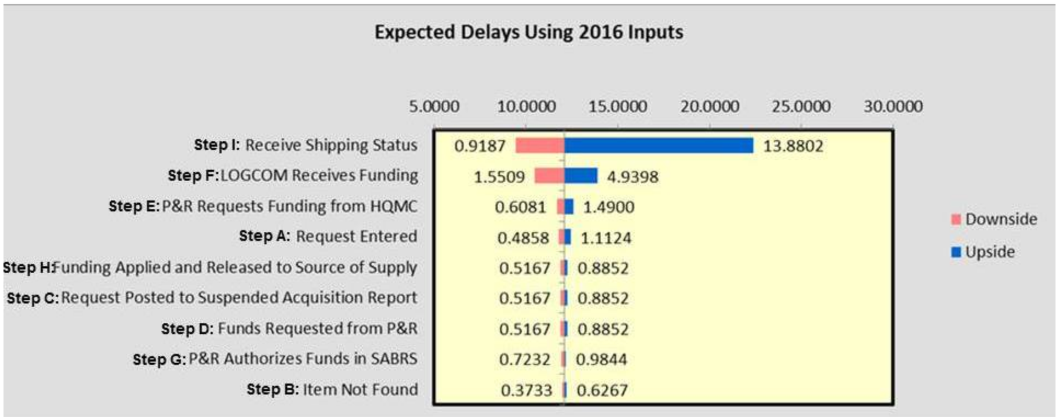


Figure 21. Tornado Diagram of Expected Delays Using 2016 Inputs

Using the results shown in the Tornado Diagram, we will focus on two hypothetical scenarios to show the impacts that could be made on meeting RDD. The first scenario will be centered on LOGCOM establishing standards with suppliers to not only reduce turnaround time, but also variability (*Step I*). The second scenario will focus on the internal procedures of the USMC in how LOGCOM requests and receives approval for funding (*Steps D, E, F* and *G*).

A good tool to help categorize delays within each step is the cause and effect diagram, also known as the fishbone diagram. There are many factors that may be contributing to delays, but the key is to identify which factors are controllable. Therefore, each factor causing delay will be classified as:

- C: Controllable (Knowledge)
- P: Procedural (Systems, People)
- N: Noise (Uncontrollable, External)

The outline of a fishbone diagram associated with the WRM Program's Process Flow can be found in Figure 22. The corresponding Table 9 identifies potential defect origins and uses the previously discussed classifications to determine the likelihood of making improvements. For the purpose of building our hypothetical models, we only focused on *Steps D, E, F, G* and *I*. With more time it should be noted that a deep-dive into every step should be conducted in order to find all potential improvements.

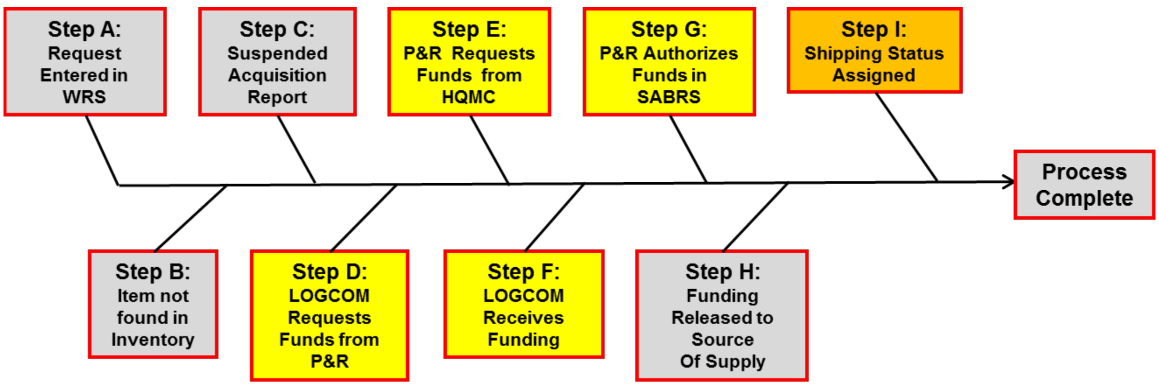


Figure 22. Fishbone Diagram of WRM Program's Process Flow

Table 9. Possible Defect Origins in WRM Program's Process Flow

Steps	Control Factor	Possible Defect Origin	Defect Class	Potential Issues with Origin
D - G	Average Completion Time	WRS Software SABRS	P	Is the system software antiquated, inefficient, or difficult to use? Would updates to the WRS reduce time spent during these steps? Would additional training on SABRS or WRS reduce time spent on these steps?
		Procedure	C	Are there administrative steps that do not add value to the process? Can these steps be eliminated, combined, or changed to add value?
		Limited Staff	P	Is the staff significantly affected by surges in orders or abnormal orders? Would additional staff during surges alleviate a potential bottleneck?
I	Variability	Different Sources of Supply	P	Do certain Sources of Supply have longer completion times or are they less consistent/reliable? Can the Sources of Supply be influenced to mitigate completion time? Are there practices that can be implemented to streamline the communication to/from the Source of Supply?
		Different Item Orders	N	Uncontrollable

Steps D through *G* all correspond to obtaining funding in order to acquire the items requested but not held in the inventory. In *Step D*, LOGCOM must route an unfunded deficiency report to P&R requesting approriate funding to fulfill shortfalls. *Step E* cannot begin until P&R has received LOGCOM's valid funding request. P&R assesses and validates LOGCOM's request and subsequently routes it to HQMC, *Step F,* for their approval. HQMC is now the third party involved in certifying LOGCOM's funding request. Once approved by HQMC, P&R will then authorize funding in Standard Accounting Budgeting Reporting System (SABRS), *Step G*. SABRS is a database that integrates budgeting and accouting information to allow the USMC to manage appropriations and monitor a unit's authorized, committed, obligated, and liquidated expenses.

In examining *Steps D* through *G,* eliminating or streamlinging over processing and beauracratic procedures could potentially improve LOGCOM's process cycle time. It is understood and acknowledged that LOGCOM must request additional funding through multiple levels of HQMC's CoC. However, during major contigency operations, wasted time associated to overprocessing can be crucial in determining mission success. Solutions could include refining standard operating procedures with any eye towards efficiency and eliminating unnecessary steps, or perhaps a common software solution that would make approval and application of funds simultaneous.

To reduce delays in *Step I,* LOGCOM can establish various contracting methods with vendors to expediate the items release for shipping. A USMC Regional Contracting Office will help LOGCOM establish contracts associated to acquiring products with little lead time. Contracting officers can establish indefinite delivery; indefinite quantity contracts (ID/IQ) with multiple vendors that can be executed during contingency operations. ID/IQs are ideal when LOGCOM cannot determine a precise quantity during a specific period and they need to streamline the process and delivery. Another option to simplify acquisitions procedures is through blanket purchase agreements. Blanket purchase agreements, similar to charge accounts, are utilized to fulfill anticipated repetitive requirements with trustworthy vendors. Streamlining the process will reduce delays as it removes the contracting administrative burden.

Assuming that some of these LSS approaches and contracting methods could be applied, we will generate two separate hypothetical process flows scenarios. These scenarios will be simulated using reduced completion times and standard deviations to reflect implementation of the principles discussed in this section. Outputs of the models will illustrate the potential effects.

2. Scenario #1: Controlling Variability

Our research clearly showed that *Step I* was the largest contributor to delays and variability. Analysis of the 2003 historical data showed that *Step I* had an average completion time (mean) of 6.2587 days, and a standard deviation of 9.0082 days.

In this scenario, we ran our simulation using a reduced completion time for *Step I* at 5.000 days and a reduced standard deviation of 3.000 days. We have used the following figures to once again judge our results based on the RDD of 42 days. We also use estimated shipment times in 10-day increments (10/20/30 days) in order to account for the variable of USTRANSCOM requirements.

After 100,000 trials using the modified data for *Step I*, we see results outlined in Figure 23. When compared to the original simulation, some of the improvements are significant. The mean is reduced from 14.8342 days to 13.5502 days; however, it is the levels of variation that are most notable. Standard deviation is reduced from 9.1215 down to 3.3020 (coefficient of variation reduced from .6149 to .2437). The reductions in variability are valuable in that the maximum wait time for a particular item is now just 51.0121 days versus the original 427.9033 days. It should be noted that there was a slight increase in minimum completion times due to the reduction in variability. We conclude this is a valuable tradeoff with the ability to more accurately forecast completion time.

100,000 Trials

Statistic	Forecast values
Trials	100,000
Base Case	13.5417
Mean	13.5502
Median	12.9915
Mode	---
Standard Deviation	3.3020
Variance	10.9029
Skewness	1.51
Kurtosis	7.99
Coeff. of Variability	0.2437
Minimum	6.1085
Maximum	51.0121
Mean Std. Error	0.0104

Figure 23. Summarized Statistics of Crystal Ball Outputs for Scenario #1

Figure 24 shows that after 100,000 trials there is a 99.991% probability that an item will be shipped on or before RDD of 42 days. In other words, in this simulation there is only a .009% probability that the item will ship after the 42 day RDD deadline. The mean of 13.5502 can be seen relative to the rest of the distribution.

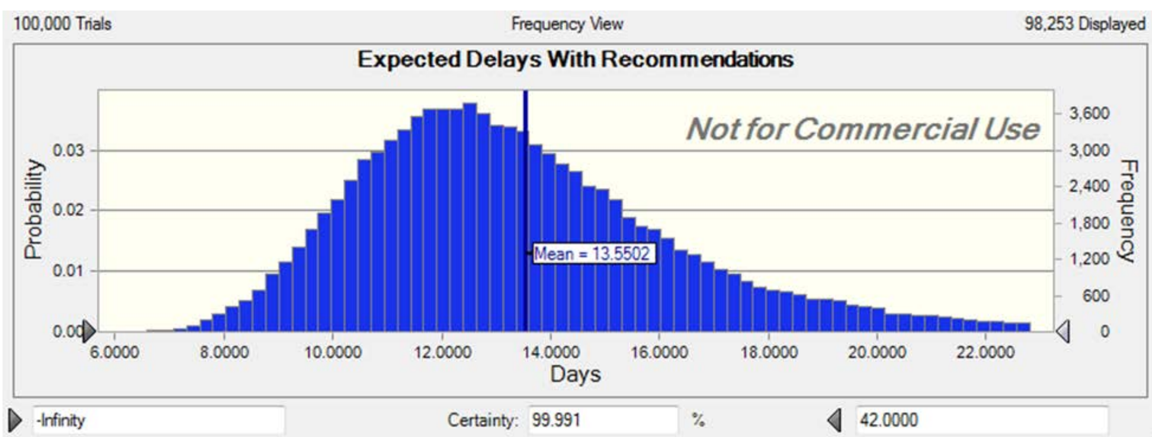


Figure 24. Scenario #1 Probability of Shipping before RDD (42 Days or Less)

Figure 25 shows that after 100,000 trials there is a 99.890% probability that an item will be shipped on or before RDD minus 10 days (32 days from order date). This model would tell LOGCOM that they have a 99.890% chance of meeting RDD if

USTRANSCOM needed only 10 days or less to ship the item into theater. This is an improvement from the original model which showed a success rate of only 96.112%.

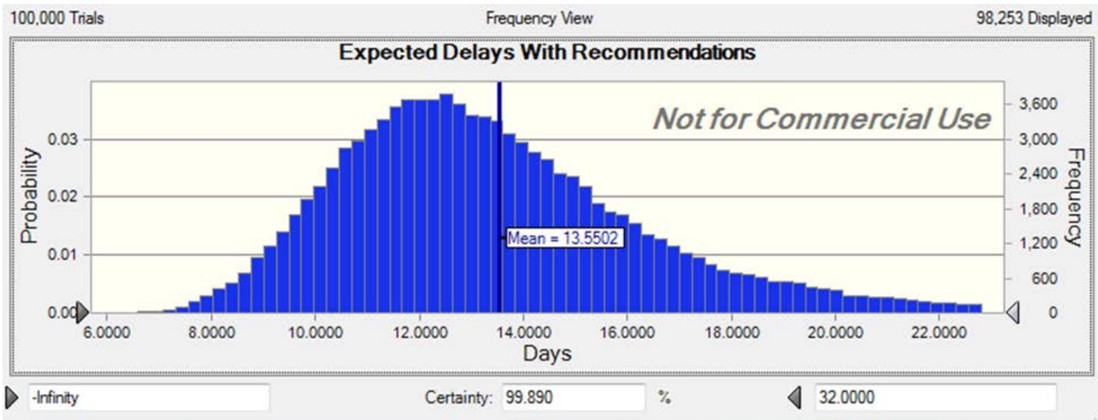


Figure 25. Scenario #1 Probability of Shipping before RDD Minus 10 (32 Days or Less)

Figure 26 shows that after 100,000 trials there is a 97.731% probability that an item will be shipped on or before RDD minus 20 days (22 days from order date). This model would tell LOGCOM that they have a 97.731% chance of meeting RDD if USTRANSCOM needed only 20 days or less to ship the item into theater. We again see performance improvement as the original model only gave LOGCOM an 89.114% of success. The instances that would then exceed RDD are shown in red.

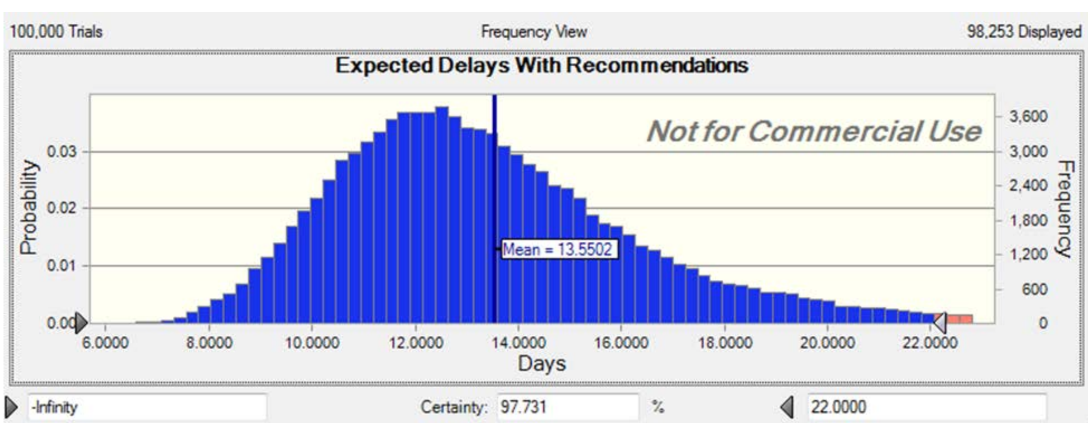


Figure 26. Scenario #1 Probability of Shipping before RDD Minus 20 (22 Days or Less)

And finally Figure 27 shows that after 100,000 trials there is now a 34.935% probability that an item will be shipped on or before RDD minus 30 days (12 days from order date). This model would tell LOGCOM that they have a 34.935% chance of meeting RDD if USTRANSCOM needed 30 days or less to ship the item into theater. The instances that would then exceed RDD are shown in red. This scenario actually shows a loss in performance as the original model gave LOGCOM a 46.142% chance of meeting RDD minus 30 days. The tradeoff here is by reducing variability planners could more accurately forecast delivery despite its slower overall speed.

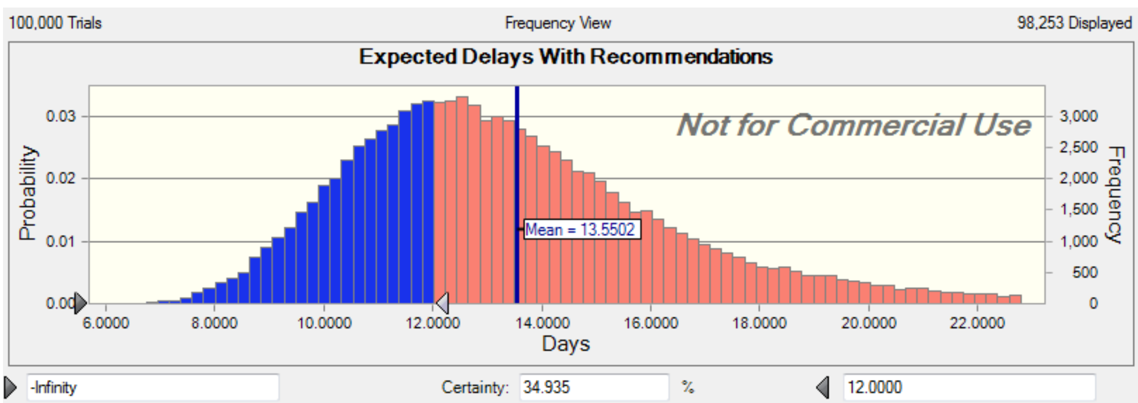


Figure 27. Scenario #1 Probability of Shipping before RDD Minus 30 (12 Days or Less)

3. Scenario #2: Controlling Mean Completion Time

Our second scenario focused on process improvement takes a look at *Steps D, E F and G*. Each of these steps are USMC procedures for LOGCOM to receive funding to acquire necessary items. It is because each of these steps are closely related, and within the control of USMC and LOGCOM that we feel improving this set of steps is possible.

In our original model the combined average completion time for these four steps is 5.8333 days, with the pessimistic estimate as high as 11 days. The combined standard deviation is 1.1755 days. Table 10 shows the original values for *Steps D, E, F and G* when compared to our new estimates (Adjusted Values) used in running the simulation for scenario #2. Average completion time is now assumed to 1.8750 days, and a combined standard deviation of .1909 days.

Table 10. Scenario #2 Adjusted Values (Changed Values Highlighted in Blue)

Process Analysis with Adjusted Values						
Step	**Activity**	**Optimistic Estimate**	**Most Likely Estimate**	**Pessimistic Estimate**	**Mean**	**Standard Deviation**
A	Request Entered in System	0.2500	0.7500	1.5000	0.7917	0.2083
B	Item Not Found in Inventory	0.2500	0.5000	0.7500	0.5000	0.0833
C	Request Posted to Suspended Acquisition Report	0.2500	0.7500	1.0000	0.7083	0.1250
D	Funds Requested from P&R (LOGCOM)	0.2500	0.2500	0.2500	0.3333	0.0833
E	P&R Requests Funding from HQMC	0.2500	0.2500	0.2500	0.3333	0.0833
F	LOGCOM Recieves Funding	0.2500	1.0000	1.0000	0.8750	0.1250
G	P&R Authorizes Funds in SABRS	0.2500	0.2500	0.7500	0.3330	0.0833
H	Funding Applied and Released to Source of Supply	0.2500	0.7500	1.0000	0.7083	0.1250
I	Receive Shipping Status from Source of Supply				6.9481	12.8429

After 100,000 trials using the modified data for *Steps D, E, F and G*, we see results outlined in Figure 28. When compared to the original simulation, the mean is reduced from 14.8342 days to 10.8245 days. However, standard deviation is reduced from 9.1215 down to just 8.7747 and the coefficient of variation actually increases from .6149 to .8106. While minimum completion time is reduced, we still have high variability within the overall process. This results in the rare possibility of significant wait times as we see in this simulation (maximum completion time of over 261 days).

100,000 Trials

Statistic	Forecast values
Trials	100,000
Base Case	11.5314
Mean	10.8245
Median	8.1792
Mode	---
Standard Deviation	8.7747
Variance	76.9960
Skewness	6.02
Kurtosis	80.67
Coeff. of Variability	0.8106
Minimum	3.5758
Maximum	261.1065
Mean Std. Error	0.0277

Figure 28. Summarized Statistics of Crystal Ball Outputs for Scenario #2

Figure 29 shows that after 100,000 trials there is a 98.706% probability that an item will be shipped on or before RDD of 42 days. The mean of 10.8245 can be seen relative to the rest of the distribution. This result of 98.706% probability is a slight increase when judged against the original model that provided a 98.244% probability.

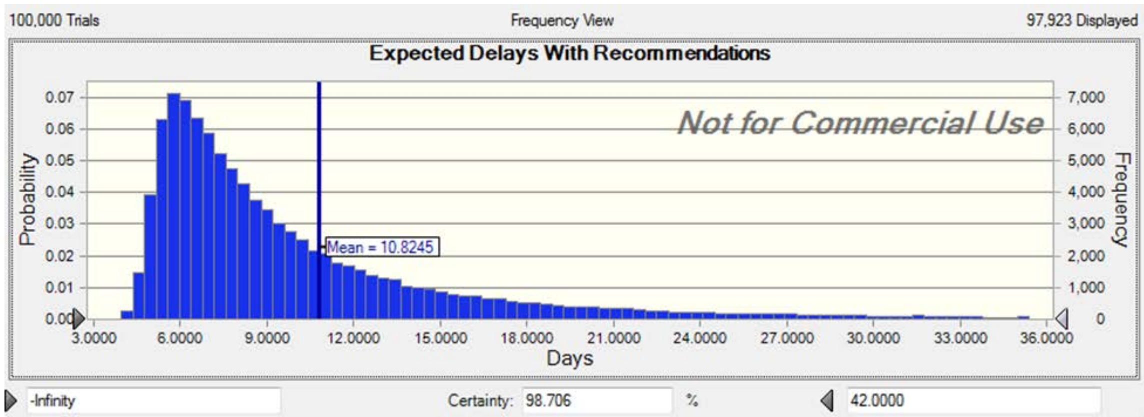


Figure 29. Scenario #2 Probability of Shipping before RDD (42 Days or Less)

Figure 30 shows that after 100,000 trials there is a 97.299% probability that an item will be shipped on or before RDD minus 10 days (32 days from order date). This model would tell LOGCOM that they have a 97.299% chance of meeting RDD if USTRANSCOM needed only 10 days or less to ship the item into theater. This shows performance improvement as the original only gave 96.112% probability of success.

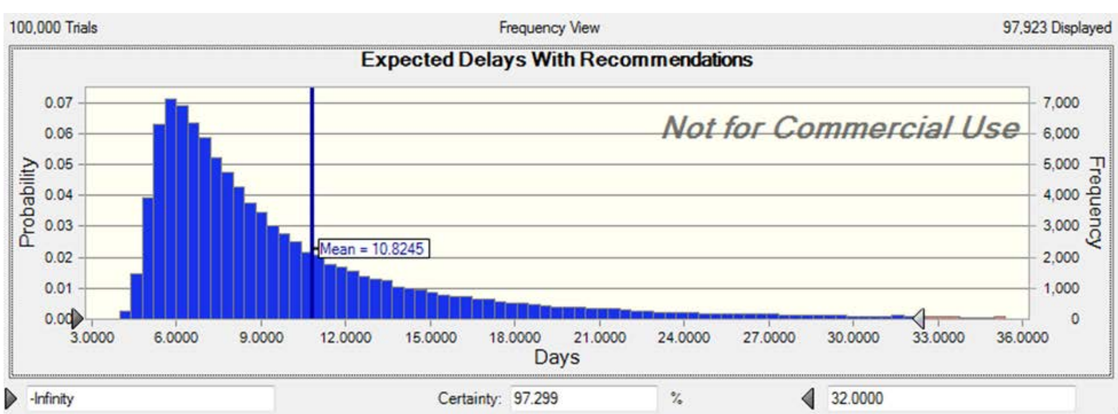


Figure 30. Scenario #2 Probability of Shipping before RDD Minus 10 (32 Days or Less)

Figure 31 shows that after 100,000 trials there is a 93.280% probability that an item will be shipped on or before RDD minus 20 days (22 days from order date). This model would tell LOGCOM that they have a 93.280% chance of meeting RDD if USTRANSCOM needed only 20 days or less to ship the item into theater. The instances that would then exceed RDD are shown in red. This again shows performance improvement as the original model only gave 89.114% probability of success.

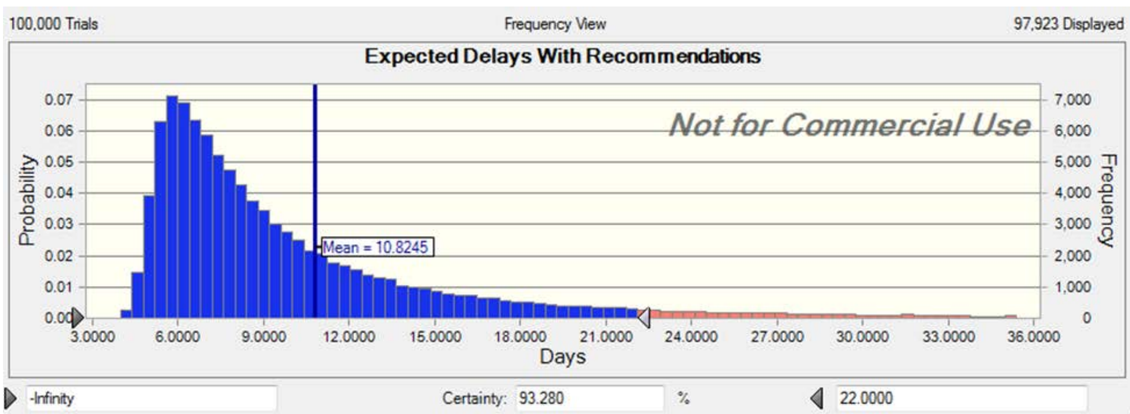


Figure 31. Scenario #2 Probability of Shipping before RDD Minus 20 (22 Days or Less)

Finally, Figure 32 shows that after 100,000 trials there is a 75.407% probability that an item will be shipped on or before RDD minus 30 days (12 days from order date). This model would tell LOGCOM that they have a 75.407% chance of meeting RDD if USTRANSCOM needed 30 days or less to ship the item into theater. The instances that would then exceed RDD are shown in red. Here we see dramatic performance improvement as the original model only gave 46.142% probability of success.

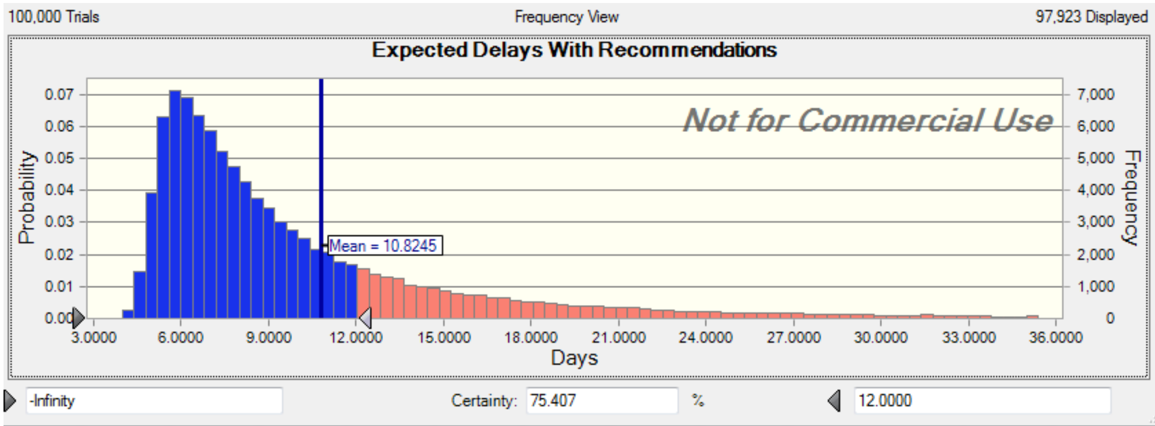
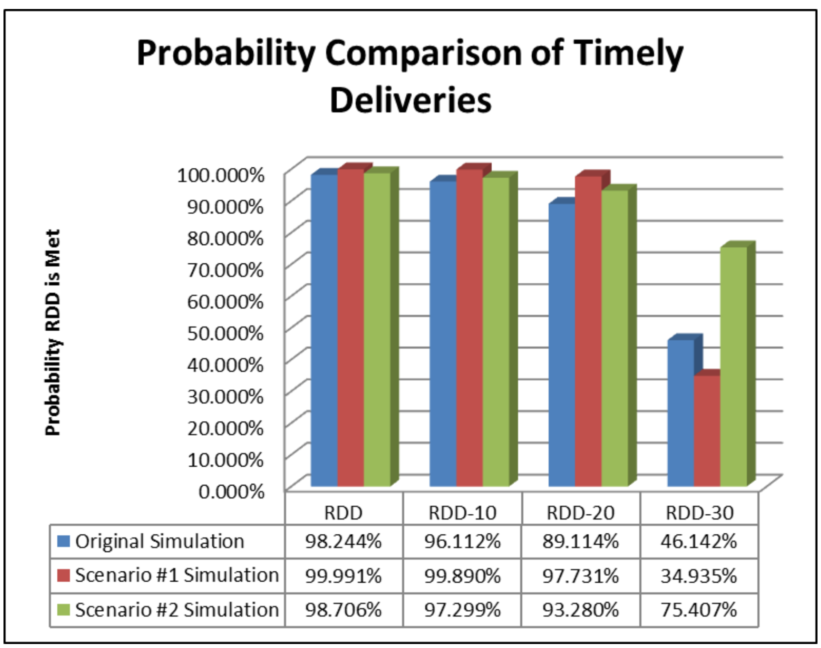


Figure 32. Scenario #2 Probability of Shipping before RDD Minus 30 (12 Days or Less)

C. SUMMARY AND RECOMMENDATIONS

Having now run three separate simulations (100,000 trials each), we use the results to shape our recommendations. First we want to discuss Figure 33, which gives a visual comparison of the three separate simulations we outlined previously.



	RDD	RDD-10	RDD-20	RDD-30
Original Simulation	98.244%	96.112%	89.114%	46.142%
Scenario #1 Simulation	99.991%	99.890%	97.731%	34.935%
Scenario #2 Simulation	98.706%	97.299%	93.280%	75.407%

Figure 33. Probability Comparison of Timely Deliveries between Original Simulation and Scenarios #1 and #2

The original simulation results shown in blue were extracted from Crystal Ball by using current LOGCOM procedures and task time estimates. No modifications were made to task times in this simulation.

In red we show the results for Scenario #1, where we reduced the task time and standard deviation of *Step I*. It is in this simulation that we saw dramatic improvement in variability, but not much improvement in mean completion time. In using RDD, RDD minus 10 and RDD minus 20 we see improvement in performance, but notice that in the probability of meeting RDD minus 30 (i.e., shipment after 12 days from order date) we actually see a reduction to just 34.935%.

In green we have the results of Scenario #2, where we modified the times for *Steps D, E, F* and *G*. Impacts of this scenario were mostly focused on reducing mean task time, and less about reducing variability. Across all four RDD situations, we see improvement when compared with the original simulation. The most dramatic improvement comes in RDD minus 30 where probability of success increases to 75.407%. While this improvement is significant, we acknowledge that within Scenario #2 the issue of variability still exists resulting in the potential for significant wait times when the system misses a deadline. In our simulation, the maximum wait time was still over 261 days.

Our first recommendation to LOGCOM is to analyze all steps and focus on reducing the mean completion time of the overall process. In Scenario #2 we focused on *Steps D, E, F* and *G* because each of these steps are closely related, and within the control of USMC and LOGCOM. Additionally, if we assume that transportation times can take as long as 30 days (as is often the case) then improving probability of success from 46.14% (original model) to 75.40% (Scenario #2) is a worthwhile investment.

Our second recommendation to LOGCOM is to address the issue of variability, and reduce it to acceptable levels. Scenario #2 showed performance improvements, but without reducing the main sources of variability the model showed wait times that seem unacceptable. Put simply, when Scenario #2 missed a deadline – it had a potential to miss big. Scenario #1 on the other hand focused on *Step I* to show the value in reducing variability. While we acknowledge a decrease in performance in the category of “RDD minus 30,” it is the maximum wait times that should be highlighted. In Scenario #2, the maximum wait time was over 261 days, compared to Scenario #1 where it was only 51 days. That could mean the difference between getting an item late, versus never getting it at all.

Knowing that Step I is dependent on third party suppliers, improvements in this area could be challenging. Future contracts should be written in a way that outline the priorities of the service and holds suppliers accountable to delivery timelines. Building and maintaining relationships between suppliers and the service will also help to ensure that as priorities shift all parties are informed and are prepared to meet the future needs of the Marine Corps.

V. FURTHER RESEARCH RECOMMENDATIONS

A. INVENTORY CONSIDERATION

1. Inventory/Risk Calculations

We were unable to conduct an in-depth study on the WRMR calculation process by the WRS. These calculations are used by annual planning conferences to determine the required inventory levels, and the accuracy of their predictions affect the number of withdrawals that will not be able to be satisfied by the WRMRI alone. While these calculations and plans could never be perfected due to the uncertainty of future events, perhaps the levels of risked assumed while using them could be better understood by future studies. Example considerations are:

- Can the WRS calculations for inventory requirements be updated or improved?
- What methods can be developed to improve risk estimation throughout the planning process?
- Can any efficiencies be gained in the system/personnel planning process?

2. Cost/Benefit Analysis of Maintaining Inventory

Additionally, should certain item types prove to be more prone to delays or incur proportionally more risk if they were delayed, a Cost/Benefit Analysis could prove useful. This CBA could examine the possibility and feasibility of keeping a surpluses of said item types and incorporate their findings into recommendations for the planning process.

B. TRANSPORTATION VARIABILITY CONSIDERATIONS

As noted in Figure 18 in Chapter IV-A-3, there are transportation times incorporated in the entire timeline from both LOGCOM and USTRANSCOM (HQMC, 2011). While both were outside our scope, an examination of whole timeline, to include transportation variability, could offer more insight into the process, from customer request to receipt.

To do so would require research into USTRANSCOM, which is enormous and complex. We believe that value could still be gained by just examining the movement actions and transportation aspects of LOGCOM and improve upon our analysis of WRM Programs Process Flow.

C. ANALYSIS OF CRITICAL RESOURCES

While we sought potential efficiency throughout the administrative Process Flow, we were unable to conduct sensitivity testing on request queues. Our analysis assumes an average flow of orders, and does not account for backlogs and what resources would be strained under such circumstances. Thus, further research could seek to answer:

- How significantly does an increase of order quantities affect the Process Flow?
- How sensitive is the Process Flow to fluctuations in order quantities?
- What bottlenecks exist in the Process Flow and how can capacity be increased at the bottlenecks?

D. CONTRACT PROCESS ANALYSIS

While determining the Process Flow, we noted that if a requested item is not available in the WRMRI and no Inner Agency Service is able to support, contracting must be pursued. This exits the Process Flow we examined and enters a significantly longer one which could not be incorporated into the scope of our analysis. LOGCOM's War Reserve inventory is a stockpile of assets or consumables produced by multiple contractors. Simplified acquisition or contracting methods have been established to expedite deliveries or anticipate future requirements. Future research could answer the following questions related to contracting:

- Can the delivery of products from contractors be expedited if a Regional Contracting Office is established at LOGCOM locations?
- How can contracting officers at LOGCOM utilize Federal Acquisition Regulation Part 13, Simplified Acquisition Procedures, to replenish a depleted stock during contingency operations?

- Will established blanket purchase agreements or indefinite delivery; indefinite quantity contracts with various contractors reduce the probability of LOGCOM missing the RDD?
- To support future contingencies, can funding for blanket purchase agreements or indefinite delivery; indefinite quantity contracts be expedited by HQMC for LOGCOM?
- When items are not in stock and no substitute is readily available, will offering fixed-price incentive contracts to contractors increase the probability that LOGCOM can meet RDD?

E. ITEM TYPE CONSIDERATIONS

All unique document numbers utilized in the research were SAC I or II items, primarily maintenance parts and consumable items. SAC I and II items are significantly cheaper to acquire than SAC III, principle end items. SAC III assets, such as M1A1 Abram Tanks and Mine Resistant Ambush Protected Trucks, are procured and acquired through stricter channels due to the costs and sensitivity. Using unit levels are able to order SAC I and II items through their organic supply chain, but unable to order SAC III items. SAC III items must be requested through multiple CoCs.

Within LOGCOM, SAC I and II items are easier to maintain a substantially larger stockpile than SAC III items. When a request for SAC III items cannot be fulfilled, LOGCOM has to take an alternate approach to satisfy that request than they do for SAC I or II items. LOGCOM is unauthorized to order these assets despite additional funding provided by HQMC. After analyzing historical OIF withdraw data, future research could answer the following questions:

- How can LOGCOM obtain SAC III assets quicker if they are not currently held within the existing War Reserve inventory?
- Based off the current WRWP, can LOGCOM’s existing inventory successfully fulfill all SAC III requests for a contingency similar in size and demand to OIF?

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