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THESIS

**EVALUATING INVENTORY POLICIES OF CLASS IX
ITEMS IN THE USMC-DLA LOGISTICS SYSTEM**

by

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March 2020

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**EVALUATING INVENTORY POLICIES OF CLASS IX ITEMS IN THE
USMC-DLA LOGISTICS SYSTEM**

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ABSTRACT

The U.S. Marine Corps utilizes its Supply Management Units (SMU) to provide Class IX repair parts support for the Marine Expeditionary Forces. These SMUs work with the Defense Logistics Agency to maintain an inventory of Class IX items that meets customer demand. Each SMU calibrates the inventory levels for each of its repair parts by adjusting several parameters: reorder point (ROP), time between inventory inspections (TBI), and requisitioning objective (RO). ROP and TBI determine when the SMU should replenish its inventory, and the RO determines how much should be ordered. Although current practice has allowed the SMUs to meet customer demand, due to budget cycle pressure and inaccurate parameter setting, parts overages and shortages occur. These lead to issues such as returning unordered materiel for reduced credit, increased inventory overhead costs, and longer customer wait times. This thesis constructs a stochastic simulation model using Simio to investigate if there are more efficient inventory policies than the SMUs' current practice. The research focuses on customer wait time and aims to provide recommendations on inventory policies to the SMUs.

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LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|------|----------------------------|
| CWT | Customer Wait Time |
| DLA | Defense Logistics Agency |
| MEF | Marine Expeditionary Force |
| RO | Requisitioning Objective |
| ROP | Reorder Point |
| SMU | Supply Management Unit |
| TBI | Time between Inspections |
| USMC | United States Marine Corps |

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EXECUTIVE SUMMARY

The USMC relies on its Supply Management Units (SMU) to provide the bulk of its Class IX repair parts support. Without repair parts from the SMU, Marine maintainers and operators would be forced to wait longer for parts, impairing mission readiness. To avoid running out of critical parts, the SMUs use their inventory policies to anticipate customer demand and reduce customer wait times. Inefficient inventory policies can impair the SMU's ability to provide support. Forecasting errors cause parts overages and shortages, increasing inventory costs at the SMU and customer wait times for the warfighter. With over 16,000 different Class IX repair parts in its inventory, finding more efficient inventory policies is crucial to reducing excess inventory and cutting wait times.

The thesis constructs a simulation model in Simio based on actual SMU data to test current SMU inventory policies and suggest possible improvements. Selecting six repair parts with differing levels of demand, the model varies three parameters: reorder point (ROP), time between inspections (TBI), and requisitioning objective (RO) to determine their effects on customer wait time (CWT). ROP is the inventory level of an item at which the SMU reorders its resupply while TBI determines how often the SMU checks its inventory. RO is the maximum level of SMU inventory.

Results from the simulation show that as ROP and TBI increase in value, the SMU replenishes its inventory more often, leading to less CWT. By reordering more often, the SMU can also reduce the level of RO required to match current values of CWT. Given a TBI of 1 week and an ROP set to 70% of RO, an SMU could decrease the inventory of most of the examined parts by 30% and still maintain its current level of customer wait time. The reduced inventory levels also comply with USMC policy by being able to support 60 days of operations. The results show that SMU can reduce the inventories of setscrews, filters, and caps by 30% of the current practice, and maintain both their current CWT and the 60-day inventory level. While an SMU can also reduce its diesel parts inventory, it can only reduce the inventory level by 17% to ensure that the 60-day inventory level is maintained.

This reduction in inventory would allow the SMUs to allocate funds away from parts with excess inventory to parts with shortages. Increasing the RO of parts which currently experience shortages would decrease their CWT and help improve Marines' mission readiness. The model indicates that two parts would benefit from increased inventory levels. While bolts and batteries can reduce their ROs by 21% and maintain current practice CWT, the model indicates that the current practice CWT could be lowered if the RO were higher. If both parts, bolts and batteries, had an ROP of 70% of RO and RO increased by 20% compared to current practice, the average CWT would be reduced by 1.3 hours and 2.35 hours, respectively. By increasing ROP and RO for these parts, the SMU can decrease CWT.

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I. INTRODUCTION

The United States Marine Corps (USMC) seeks to improve its logistics operations for its Class IX repair parts. While current USMC inventory policies have proven adequate for supporting the warfighter, USMC Headquarters Installations & Logistics (USMC HQ –ILP) partnered with the Defense Logistics Agency (DLA) to investigate whether increased collaboration with DLA could make the USMC supply depots more effective and efficient. While the collaboration decreased customer wait time for parts and reduced inventory, due to differing viewpoints, USMC did not pursue further integration with DLA. Instead of increased collaboration with DLA, this thesis investigates how varying inventory policies at the USMC supply depots affect customer wait times and inventory.

A. PROBLEM STATEMENT

The USMC faces the critical issue of how to set their inventory policies to meet the Class IX repair part demands facing the USMC Supply Management Units (SMUs). Per Army Manual 4–40, Class IX repair parts are “any part, subassembly, assembly, or component required in the maintenance or repair of an end item, subassembly, or component” (Department of the Army [DA] 2013, p. 2–5). Without these, the USMC would likely ground to a halt. Supporting the various supply requirements from Marine Expeditionary Force (MEF) customers is a key role of the SMU. Knowing when to reorder inventory (reorder point – ROP) and how much to order (requisitioning objective – RO) can make the difference between a unit receiving a critical part in time or not. These parameters make up the inventory policies the SMU use to manage their inventory. The accuracy of an inventory policy also dictates whether there will be a shortage of an item or a wasteful surplus. Historically, SMU forecasting miscalculations have periodically caused parts to be ordered at the incorrect time and/or in the incorrect amount. These inaccuracies have led to various problems to include increased inventory costs and shortages for critically required parts. According to the Marine Corps Strategic Prioritization Process, Enterprise Performance Support Memorandum of Agreement (MOA) provided by Mr. Matthew B. Hakola, the Operations Officer for USMC Headquarters, Installations &

Logistics, Logistics Planning, in fiscal year 2013 (FY13), \$10 million worth of Class IX SMU inventory was issued back to DLA Disposition Material Returns program. In FY14/FY15, inventory turned into DLA Disposition grew to over \$30 million (Hakola 2018a). Inefficient inventory management also leads to increased customer wait times. Customer wait times (CWT) are defined as the time from when the part is first ordered to final receipt to the customer. As such, inaccurate parts forecasting can adversely affect CWT.

Having the correct inventory policy has been so important that the USMC and DLA embarked on a series of integrated process teams (IPTs) to determine if increased USMC-DLA logistics integration could improve customer wait times and decrease inventory forecasting errors (Hakola 2018a). The IPTs were mutually beneficial as the USMC were able to reduce inventory costs by leveraging DLA's expertise in logistics IT, parts forecasting, transportation, and inventory management. DLA benefited working more closely with USMC by having more direct access to information on USMC demand for Class IX repair parts. To provide insights on how to improve CWT, this thesis develops a modeling and simulation tool to analyze the USMC logistics system from the SMU perspective and its interaction with the regional DLA supply depots.

The thesis examines the advantages and disadvantages of possible modifications to the current system by varying the inventory policies of a select number of Class IX repair parts and analyzing the effects of those inventory policies on CWT. We use Simio, a discrete-event simulation program, to simulate orders and resupply operations related to 1st MEF (I MEF) and 2nd MEF (II MEF) units during one year. The simulation, which is based on data provided by the I MEF SMU, analyzes the effects of changes in inventory policies on CWT and on inventory.

This thesis uses RO as a proxy figure to show how much of an SMU's funds are held as inventory. Given similar CWTs between several inventory policies, the policy that has a lower RO signifies that a given inventory policy is more efficient than others with the same CWT. By using different levels of ROPs and ROs at the SMU, this thesis examines if there are more efficient inventory policies that might improve the SMU's performance.

Success can occur if the model shows a feasible inventory policy where an SMU has a decrease in RO with an only a marginal increase in CWT. Decreased inventory costs lead to less time wasted inventorying excess material, less space required to store unneeded parts, and less budget wasted in over-ordering parts. Budget saved by improving the ordering process can be used to order the parts the customers actually need, thereby improving CWTs. Reduced CWTs will lead to increased readiness overall for the Marines; the faster a critical part can be delivered to the customer, the faster that customer can deploy for its mission.

B. SMU AND DLA COLLABORATION

From August 2015 to January 2019, the USMC partnered with DLA to examine how they could improve the effectiveness of their current inventory system (Johnson 2019). With its massive logistics footprint and multiple distribution centers worldwide, DLA provides a single centralized management entity to assist the USMC in its logistics requirements. DLA seemed to provide a solution that would both potentially decrease budgetary waste and improve customer wait times. The USMC and DLA established four integrated process teams (IPTs) for studying the effect of possible collaborations. The first three were assigned to each of the existing MEFs to test various levels of integration with DLA. According to the USMC Business Case Analysis report dated 15 May 2018 provided by Hakola, while the fourth IPT concerned a USMC version of a Navy Working Capital Fund (NWCF), the USMC discovered that “capitalizing SMU inventories into a Marine Corps Logistics Command managed NWCF is not feasible” (2018b, p. 4).

The three IPTs operated with the SMUs of the corresponding MEFs according to different levels of cooperation. The IPT at I MEF implemented a tailored version of DLA’s inventory optimization system to recommend stock levels for the SMU based on demands, current wholesale performance, and distribution times from DLA. In April 2019, an interview with Matthew Hubbard, the officer in charge of the Combat Logistics Regiment 15, the 1st Supply Battalion’s Supply Company, was conducted regarding IPT 1 and the operations at the I MEF SMU at Camp Pendleton in southern California. Hubbard says that the I MEF SMU logisticians managed part of their inventory with a DLA forecasting

algorithm while DLA provided Class IX parts support for nine major platforms used by I MEF Marines (2019a). DLA also continued to provide dedicated transportation from the nearest major DLA distribution center to Camp Pendleton, DLA San Joaquin (Hakola 2018b).

DLA implemented IPT 2 with the II MEF SMU at Camp Lejeune, North Carolina. DLA established a physical presence by positioning Marine high demand items from DLA Susquehanna to the II MEF SMU warehouse. The II MEF SMU and DLA administratively controlled their own materiel. However, all materiel at the II MEF SMU warehouse, regardless of ownership, was physically managed by SMU Marines as DLA only brought inventory and not personnel to Camp Lejeune (Hakola 2018b). The II MEF SMU Marines were trained to use DLA's Distribution Standard System, an automated information system that manages all functional business processes of DLA's warehouse operations, to assist DLA (Defense Logistics Agency [DLA] 2015). During the IPT, DLA still delivered parts from its East Coast distribution center at DLA Susquehanna.

The Third MEF (III MEF) hosted IPT 3 at the III MEF SMU at Camp Butler in Okinawa, Japan. This IPT leveraged SMU initiatives and a collaborative relationship with DLA Distribution Yokosuka Japan, Detachment Okinawa for lateral support across a range of 10,000 Class IX repair part items. Emphasis was placed on combat-critical spares supporting principal end use items (PEIs) on the MEF commander's top 25 list (Hakola 2018b). Since the III MEF SMU warehouse and DLA's detachment in Okinawa were near to each, the local SMU and DLA continued to work closely together to support III MEF operations.

All three options tested by the IPTs showed that a more integrated approach with DLA results in improvements to the USMC logistics system. In all cases, CWT and customer order fulfilment (or net effectiveness) increased while inventory size decreased. The USMC discovered that a "collaborative demand planning and replenishment approach between DLA and SMUs demonstrated increased material availability while reducing inventory levels and costs" (Hakola 2018b, p. 3). Still, the USMC did not want to further pursue integration with DLA and in 2018, the IPTs ceased operations (Johnson 2019). Despite their results, the level of integration shown in the IPTs with DLA (i.e., using DLA

forecasting tools, DLA's physical stock at the SMUs) did not seem to provide the USMC sufficient results to warrant increased collaboration with DLA in that manner. Moreover, the IPTs did not answer how much and what type of inventory the SMUs could shift to DLA without increasing customer wait times. While we do not attempt to answer what inventory the SMUs could shift, we do investigate how much inventory the SMUs could shift to DLA.

C. OUT-OF-SCOPE ISSUES

While this thesis examines if more efficient inventory policies for USMC SMUs are possible, there are several issues that are out of scope. First, repair part orders are only considered complete in the USMC supply system when the customer electronically acknowledges the receipt of a requisition. Unfortunately, customers tend not to send this receipt until after the repairs have been used by the maintenance team. Per Hubbard (2019a), this erroneously lengthens customer wait by 3.5 days or more. SMUs such as the I MEF SMU have launched various "lean-forward" initiatives to have the receipt of Class IX materiel be acknowledged upon physical receipt of a requisition. Hubbard also stated that approximately 14% of overdue receipts are due to customers not posting the requisition receipt in a timely manner (2019a). While this is an important issue, the thesis is mainly concerned with the inventory policies that might reduce CWT. It is not concerned with SMU logistics receipt policies.

Another issue is that of "logistics sociology." The I MEF SMU Operations Overview states that the I MEF SMU has over 90 customers in a relatively broad area in the southwestern United States (Hubbard 2019b). In contrast, DLA San Joaquin must supply diverse customers from all branches located west of the Mississippi River. While personal intervention might work in smaller DLA distribution centers, the customer cannot expect to always receive this same level of service at distribution centers the size of San Joaquin or Susquehanna. Due to the sheer scale of DLA, it is highly unlikely an individual customer's order would get the same level of attention as an order at the SMU. The only way to consistently ensure that the customers' requirements are met with a reasonable CWT is to have effective inventory policies for the parts demanded.

A further issue is that the SMUs try to assist customers by checking outstanding parts requests against newly arrived stock or at other available supply sources. They are not obligated to do so; customers must track their own parts request from initial order to final delivery, and the SMUs will not hold backorders. While the SMUs' actions can reduce CWT, these are also out of scope. Assisting the customer to find other sources of supply will not help the SMU in finding the best inventory policies.

While receipt procedures, "lean forward" initiatives, and personal commitment can and often do lead to reduced customer wait times, these issues do not result in changes in an SMU's inventory policy. As such, these logistics issues, while important, are beyond the scope of this thesis and will not be examined further.

D. USMC SMU

Since a major part of this thesis deals with the SMUs and how they manage their inventory, this section will provide more detail into their operations. SMUs are the hubs of the USMC logistics system and are present in every MEF and any region where there is a significant Marine presence. The I MEF SMU supports Camp Pendleton on the West Coast while the II MEF SMU supports Camp Lejeune on the East Coast. The III MEF SMU supports Camp Butler and Marine Units forward deployed in the Western Pacific. Other SMUs have been established to support Marine operations abroad such as in Afghanistan. The SMUs are primarily engaged in the retail distribution of Class IX repair parts and are stocked to provide the maximum support for their USMC customers.

1. I MEF SMU at Camp Pendleton

Since this thesis models the life cycle of a Class IX parts requisition, our focus is on the I MEF SMU at Camp Pendleton in southern California. Under Combat Logistics Regiment 15, the 1st Supply Battalion's Supply Company's top priority is to always help Marines whenever needed. They view the SMU as a buffer force against adverse CWT. Hubbard states that while the SMU is concerned with filling every incoming customer requisition, a focus on filling every requisition is ineffective if the customers cannot get the required parts when they need them (2019a).

According to Hubbard, the I MEF SMU manages over 16,000 line-items, totaling a value of \$35 million, to provide general Class IX (repair parts) and Class I (rations/MREs) support to over 90 unique customers stationed mostly throughout the southwestern United States (2019a). Of these, 72 customers are I MEF-supported units located in four regions: Camp Pendleton (including both the Camp Pendleton North and Camp Pendleton South), Marine Corps Air Station (MCAS) Miramar, Marine Corps Air Ground Combat Center (MCAGCC) also known as Twenty-nine Palms, all located in southern California, and MCAS Yuma in Arizona. Per Hubbard, the I MEF SMU arranges truck deliveries to all these locations, even to MCAS Yuma, 202 miles away (2019a).

2. SMU Order Processing and Demand

According to Hubbard, since the I MEF SMU is the initial point of entry for customer requisitions in I MEF, its staff handles approximately 1,000 customer requisitions daily (2019b). In any case where the SMU cannot entirely fulfill a customer requisition, the SMU defers the unfulfilled portion to DLA for fulfillment. Although the SMU serves over 90 customers, most of the customer requisitions are from one of the 72 units located in southern California or in Arizona. Per Hubbard, these customers make up an estimated 97% of the value, or \$28 million of the nearly \$29 million, in annual Class IX parts issues from the I MEF SMU (2019a). To support this level of demand, the SMU must set its inventory levels properly to avoid both shortages and overages. While the overages result in funds frozen on the shelf in inventory that might not sell, the shortages cause an increase in customer wait time, hurting the customer's operational readiness.

3. Frequency of Orders and Amount Ordered

While interviewing Hubbard after our tour of his operations, he explains that the I MEF SMU bases its inventory policies on the amount of demand received (2019a). The USMC logisticians track two parameters related to demand: frequency of order and amount ordered. The frequency of order is the number of times that a part is requisitioned in any amount over a certain time period. The SMU typically focuses on items frequently ordered within the previous six months. The frequency of order helps the SMU determine if a part should be stocked at the SMU or whether customer orders for such parts be referred to

DLA. Parts that are not frequently ordered might have minimal stock on the shelf or might not be stocked at all. Hubbard further stated that although the SMU has a large storage capacity, any item that has not been ordered at least once in the past 36 months, unless required by regulation, is marked to be offloaded to DLA as excess materiel (2019a). The SMU also adjusts its stock posture based the quantity of an item the customer requires whenever a requisition arrives. Through examining the I MEF SMU database, some parts, such as setscrews, are ordered in even pairs while others, such as night vision goggles, must always be individually requisitioned. The SMU ensures that its inventory can also handle seasonal demand spikes when Marine deployments or vehicle maintenance operations occur.

4. Non-I MEF SMU Customers

While the I MEF SMU supports non-I MEF customers, mostly II MEF and III MEF units training at a I MEF site, such lateral support requests are relatively rare, comprising 3% of all requisitions in 2019. According to Hubbard, such demand is not included in I MEF SMU forecasting and has little effect on inventory policies (2019a).

5. I MEF SMU Stock Replenishment

Periodically, SMU personnel conduct stock replenishment orders whenever inventory reaches a certain level. Hubbard explains that while the I MEF SMU purchases an average of \$1 million worth of weekly reorders, they are cautious of ordering inventory that will remain on the shelf unsold (2019a). Unlike Navy supply departments which receive periodic grants to restock their shelves, Hubbard also states that USMC SMUs operate under a “pay-go” system (2019a). Their ability to restock is directly limited to the amount of inventory they “sell.” Although the SMU has stock reorders on quarterly, annual and on as-required bases, errors in forecasting can severely impact the reorder cycle. Overstocked items take up shelf space and prevent funds from being used to purchase more frequently demanded items. Under-ordered parts can cause disruptions in the SMU’s reordering plans as the SMU leadership must divert funds to purchase items where there is a shortage.

6. I MEF SMU Goals

There are several goals that the I MEF SMU strives to attain. The most important goal is to reduce overall CWT. Not having a critical repair part in stock might lead to deployed Marines waiting until the order is fulfilled by DLA, a delay of hours or even days. The staff at the SMU frequently review demand history for critical parts as to accurately forecast demand as much as possible. Another goal is for the SMU to increase its net effectiveness, which is the percentage of requisitions filled by the SMU versus the total number received. Requisitions the SMU cannot fill are passed to DLA for fulfillment, increasing CWT. To increase net effectiveness for any particular repair part, the SMU increases the amount of inventory held of that part. This can lower CWT as the SMU has more to issue, but at the expense of increasing inventory or ROP. According to Hubbard, while decreasing inventory is a goal, the SMU prioritizes reducing CWT over reducing inventory (2019a).

E. DLA DISTRIBUTION CENTERS

While the SMU is a retail distributor which directly fulfills requisitions to its customers, DLA is a wholesale distributor of parts for the various logistics requirements in the Department of Defense. DLA, through its distribution centers, ensures that the SMU is replenished with stock upon receipt of a reorder. The DLA distribution centers (DDC) also fill any customer requirements that the SMU passes to DLA, be it due to the SMU not carrying a part or the part in question being out of stock at the SMU.

DDCs are located throughout the United States, but for the purposes of this thesis, the two centers studied are DLA San Joaquin in Tracy, California, and DLA Susquehanna in New Cumberland, Pennsylvania. In support of this thesis, in July 2019, a tour of DLA San Joaquin was conducted with COL Andre Harrell, the commanding officer of DLA, and his staff. Due to their proximity to the MEF SMUs, these DDCs worked with the SMUs to implement the IPTs created when USMC partnered with DLA in 2017 (Hakola 2018b). These IPTs allowed USMC to test whether increased collaboration between the SMUs and DLA led to decreased customer wait times and more effective inventory forecasting.

F. BENEFITS OF THIS STUDY

The main benefit of this thesis is in discovering which combinations of current inventory, reorder point, and a requisitioning objective help the SMUs reduce their inventory and maintain acceptable CWTs. Simulating years of MEF customer requisitions and SMU reorders in Simio could model actual “sweet spots.” These spots are where different combinations of current inventory, reorder point, and requisitioning objective have either a similar CWT and/or similar inventory levels. This thesis aims to guide SMUs making tradeoffs between reducing their inventory and possibly increasing CWT. Through a reduction of inventory, the SMUs are effectively shifting the risks to DLA to forecast future demand. Any reductions in inventory while maintaining acceptable CWT help the SMUs to fill customer demand. These reductions also fulfill the sponsor’s, USMC HQ ILP, objective of finding more efficient ways to improve USMC logistics.

The remaining chapters of this thesis are arranged as follows. Chapter II discusses the background of the thesis and includes a literature review of similar inventory management and event-based simulation theses. It also discusses how the USMC SMUs determine their inventory policies. Chapter III shows how the model is constructed and compares this to what happens in the SMU-DLA logistics system in real life. Chapter IV tests the model with different inventory parameters derived from actual Class IX repair part data. This chapter discusses the results in detail. Finally, Chapter V concludes this thesis by presenting recommendations for the SMU and possible future work for the model.

II. BACKGROUND

A. INTRODUCTION

Prior to constructing a model of the MC-DLA logistics system, this section reviews previous related studies to see how these relate to the current work. In addition, the life cycle of the USMC customer requisition is examined.

B. LITERATURE REVIEW

This thesis examines different inventory policies and their effects on the USMC-DLA logistics system. While there were many theses that also studied logistics or simulation, due to the large number of similar works, this thesis considers the following three: “*Analysis of I Marine Expeditionary Force Support Team Reset Operations*” written by Roque Graciani in 2013, “*Measuring the Impact of Business Rules on Inventory Balance*” written by Andrew Oswald in 2013, and “*Improving Aircraft Refueling Procedures at Naval Air Station Oceana*” written by Matthew Geiser in 2012. Below are the synopses from each of these theses and how they relate to the current thesis.

1. Graciani

Graciani examined the time required for the USMC “to repair an equipment item received from Afghanistan and be sent to a non-deployed unit” (2013, p. xvi). Using queuing theory and actual data from the 1st Marine Expeditionary Support Team, Graciani was able to develop an analytical model to analyze the “amount of time required to repair ground equipment and identify the factors most affecting this time” (p. v). Graciani’s work is similar to mine, in that we are both interested in computing (and reducing) CWT. However, Graciani’s focus is on items going through multiple repair and processing points, and accounting for the potentially significant idle time when an item must wait in a queue. Instead of solving queueing equations to determine CWT, this thesis uses I MEF SMU data to simulate CWT for customer requisitions in the USMC-DLA logistics environment.

2. Oswald

Oswald (2013) examined the concept of inventory balancing to enhance the performance of inventory systems. His thesis studied the effect of shifting inventory from locations where the quantity of parts exceeded the quantity demanded to locations where there were shortages. He aimed to “balance demand” in locations by using business rules to move materiel where it is required. To study this movement of materiel caused by inventory balancing and how that process leads to a decrease in inventory costs, Oswald constructed a model to simulate this process. Per Oswald, “A simulation model comprising a two-echelon supply network with three warehouse locations is used to evaluate the various business rules for several items with varying unit prices and demand frequencies” (2013, p. v). Oswald’s work is similar to this thesis, except his thesis aims to construct a model that examines different inventory policies and the effect these policies have on CWT. The primary difference between the two theses is that Oswald focuses on transshipment between locations, whereas we do not allow transshipment between SMU inventories.

3. Geiser

Geiser (2012) analyzed how to reduce aircraft refueling time by creating a simulation of airfield operations at Naval Air Station (NAS) Oceana, Virginia. According to Geiser, he developed “a computer-assisted discrete-event simulation to model refueling at NAS Oceana using airfield data from October 2011” (2012). Using this model, his thesis examined the different options NAS Oceana had available to reduce the time spent refueling aircraft. This thesis is similar to Geiser’s as the Simio model in this research is also a discrete-event simulation analyzing different parameters’ effects on reducing wait time.

4. Other Theses Reviewed

Since this thesis primarily deals with inventory management as applied to the USMC-DLA logistics system, we also considered other papers relevant to inventory management. Zheng and Federgruen (1991) discussed how to determine optimal reorder points and maximum levels of inventory using a computer algorithm instead of simulation.

Deibler (2018) investigated inventory policy setting at a Naval expeditionary logistics warehouse. Through a linear optimization model called SQID (*s and Q Unit Identification Model*), Deibler (2018) researched how to set efficient inventory policies using different reorder points, s , and reorder quantities, Q . Similar to Deibler, Roth (2016) researches inventory reorder policies by using a linear optimization model to find the most efficient reorder point. Hays (2018) studied inventory policies by using simulation in his thesis. By using the Wholesale Inventory Optimization Model (WIOM), Hays (2018) investigates optimum reorder inventory quantities for Class IX repair parts. Lastly, Wray (2017) created a model to assess inventory policy naval aviation weapon systems. His utilization of a discrete event simulation aimed to minimize costs while optimizing readiness and inventory levels for naval aviation parts.

C. LIFE CYCLE OF A CLASS IX PARTS REQUISITION

We now focus on how a customer requisition is processed. The requisition is the starting point for all interactions between the customers, the SMUs, and DLA. On 25 April 2019, Matthew Hubbard, the I MEF SMU Officer-in-Charge, provided a tour of the I MEF SMU facilities at Camp Pendleton in southern California. He also furnished some documents regarding SMU operations and a copy of the I MEF SMU inventory database. Hubbard explained how the USMC supply system is structured so that every repair part requisition is first sent to the local SMU for processing (2019a). Hubbard continues that the customer's requisition is electronically sent to the SMU via the Global Combat Support System-Marine Corps, a USMC logistics computer program. Upon receipt, the SMU either processes the requisition for issue from its stock or refers the requisition to DLA for further processing. Hubbard also provided the checklist below for how an in-stock part is issued at the Camp Pendleton SMU (2019a).

SMU Checklist for In-Stock Parts:

- Customer requisition received and verified by SMU
- Item is removed from the SMU inventory (as early as 0500 in the morning) and scanned for a specific requisition number

- USMC logisticians package requisition for delivery
- USMC transports part to requesting unit if the part is not being held for pickup by the requesting unit
- Local unit supply receives the part
- Local unit supply gives the part to the customer

The SMU prepares to ship stocked requisitions within 24 hours of receiving the requisition. During the tour at the I MEF SMU, we observed that most requisitions for stocked material received prior to 1200 were processed that day for shipment to the customers. As part of the shipping and handling process, the SMU bundles together all requisitions going to the same customer and then ships these out using locally scheduled trucks. According to Hubbard, any parts received after 1200 are processed for shipment the following day (2019a). If the requisition is referred to DLA, the customer will receive a status update from DLA with an estimated delivery date if applicable. Per Jeff Lambert, DLA J343, Center of Planning Excellence Logistics Operations–Stocking Positioning, while DLA does have a vast inventory of Class IX items, DLA is unable to directly fulfill approximately 5% of request (2019). This occurs when DLA does not have the item in stock or DLA does not carry the item. In these cases, any orders for those parts are contracted to a vendor for delivery. In either case, parts referred to DLA are shipped directly to the customer.

D. SMU REORDER PROCESSES

One of the key responsibilities of the SMU leadership is to manage their inventory effectively. Similar to how a Navy material stock division manages its inventory, the SMU adjusts its inventory policies for items according to the demand for each part. As described in Chapter I, the SMU relies on both the frequency of demand and the amount demanded for each part to calculate what inventory levels it should hold. To do so, the SMU uses two key parameters, reorder point and requisitioning objective.

1. Reorder Point

The P4400.151B, the USMC Intermediate-Level Supply Management Policy Manual defines reorder point as “that point in time in which a stock replenishment requisition would be submitted to maintain the predetermined or calculated stockage objective” (Department of the Navy [DoN] 2013). Another way to define the reorder point (ROP) is the inventory level at which a parts reorder is triggered. Each part has its own unique ROP determined by its demand.

2. Requisitioning Objective

Another key part is the requisitioning objective (RO). Per the P4400.151B, this is defined as “the maximum quantities of materiel to be maintained on hand and/or order to sustain peacetime support objectives for current operations” (DoN 2013). The requisitioning objective determines the maximum amount of inventory that the SMU will carry for a part. Similar to ROPs, the RO for each Class IX repair part is unique and determined by the part’s demand. Whenever the SMU creates a replenishment order or a reorder requisition, the reorder quantity is determined as follows:

$$\text{Reorder Quantity} = RO - \text{current inventory} - \text{inventory now on order}$$

Ignoring the current SMU inventory or the amount on order through outstanding reorder requisitions can cause the SMU to over-order parts. This might lead to excess inventory, tying down SMU funds to stock on the shelf.

Consider the following example: The SMU currently has 140 setscrews on the shelf. This repair part has an ROP of 100 and RO of 200. The SMU then receives a customer requisition for 45 setscrews, decreasing its current inventory from 140 to 95. Since 95 is below the SMU’s ROP for setscrews, the SMU places a reorder requisition for 105 setscrews to bring its inventory back to RO. Before that reorder requisitions arrives, a second customer requisition depletes the inventory from 95 to 60. The SMU will submit a second reorder, this time for only 35.

3. ROP and RO Determination

Every SMU conducts at least an annual review of the ROP and the RO for each of its stocked Class IX parts. I MEF SMU manages its inventory using a Microsoft Access Database. This database contains information not only on all 16,000 repair parts in the I MEF SMU inventory, but also all requisitions related to these parts from October 2017 to May 2019. According to Hubbard, the ROP and the RO for each part is calculated using a moving average of each parts' demand (2019a).

Each repair item in the SMU's inventory has sufficient stock to support operational usage for 60 days. As specified in the P4400.151B, the USMC Intermediate-Level Supply Management Policy Manual, "Operating level is that quantity of materiel required to sustain operations during the interval between the initiation of replenishment action and the arrival of successive replenishment shipments into the supply system.... Intermediate-level activities are authorized a 60-day operating level of materiel" (DoN 2013). The SMU has a combination of an ROP and RO for each item sufficient to maintain at least this demand.

Hubbard explained that the moving average method the SMU management team uses is based on the past three years of demand data with an emphasis on the last 12 months. Parts that do not have more than one requisition in the past three years might have both their ROPs and ROs adjusted to 0 and be slated to offload to DLA (2019a). Other parts that have had more frequent requisitions and higher demand might have their ROPs and/or their ROs increased to ensure that the SMU can accommodate their customers' requirements. Reviews might happen on a more frequent basis such as when a new Class IX part is made available or when there is a dramatic increase in demand for a part. According to Hubbard, most of the reviews that adjust ROPs and ROs are done in response to a large change in the moving average of demand (2019a).

4. SMU Safety Level of Supply

Another consideration for SMU inventory policies is that SMU is required to keep a minimum inventory of certain Class IX parts on hand at all times. This safety level of supply is defined by the P4400.151B as "the quantity of materiel, in addition to the

operating level of supply, required to be on hand to permit continued operations during a minor interruption of normal replenishment or unpredictable fluctuations in issue demand” (2012). This safety level or “reserved” stocking level is to ensure that there is always some minimum stock remaining to satisfy war contingency requirements or to have enough parts to support deploying USMC units. Once the current inventory reaches the safety level, the SMU will have to both reorder for stock and refer customer requisitions to DLA. The SMU has to choose values of ROP and RO to manage its inventory carefully and ensure both its customer demand and safety stock levels are met.

5. Time between Inspections

Finally, time between inspections (TBI) plays a critical role for the SMU’s reordering process. TBI determines how much time passes between the SMU review of inventory levels. For any part at or below their ROPs, the SMU places a reorder requisition. Using the setscrew example again, the SMU has 140 setscrews with an ROP of 100. There is a TBI of 1 week between the SMU’s reviews. Assuming the review has just been completed, if the SMU’s inventory decreased from 140 to 95, it cannot reorder until another a week has passed. If the ROP is set low enough or if the TBI is too high, this can result in periods where the SMU is out of inventory waiting to either send or receive a reorder requisition.

While inventory levels can be known on demand, the SMU’s ability to reorder parts is constrained both by available funding and by administrative concerns. Hubbard states that since the SMU operates on a “pay-go” system, the SMU might not have the funds to reorder parts every time inventory drops below ROP, especially if parts have a minimum reorder requirement (2019). Moreover, per the SMU Operations Overview, the staff must process 1,000 requisitions daily and keep track of 16,000 unique Class IX parts (Hubbard 2019b). Tracking reorder requisitions generated every time a part is below ROP might become an administrative burden.

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III. MODELING

This chapter defines the major components of the MEF customer requisition model, the underpinning assumptions, and its limitations. This chapter also reviews how the model is implemented in the simulation package Simio. An important part of constructing a Simio model is defining the model's output. The model's output forms an important part of the analysis that is described in Chapter IV.

A. SIMULATION OF REPAIR PARTS ORDERS

To build an accurate MEF customer requisition model, this section describes how the USMC-DLA supply network works.

1. Supply Nodes and Edges

Simio is a simulation program that can model a customer requisition's flow through a complex network such the USMC-DLA supply system we are studying. A network created in Simio to model the USMC-DLA supply system is comprised of nodes, edges, severs, and the requisitions that flow through them. Nodes are places such as the SMUs or DLA which can process customer requisitions. These actions include routing requisitions to other nodes or even removing the requisitions from the network. Edges are pathways on which requisitions travel between nodes.

The nodes in this model are in three groups: the MEF customers, the SMUs, and DLA. The MEF customers are the generators and receivers of all customer requisitions. A requisition is still outstanding if the MEF customer has not received it. The SMU nodes have two roles. The first role is that the SMU nodes, depending on the SMUs' inventory, either fill customer requisitions or refer those requisitions to DLA. The SMUs' second role is to generate and receive reorder requisitions whenever the SMUs' inventory level is below the ROP for a particular part. DLA is the last set nodes which fill all reorder requisitions from the SMUs and any customer requisitions the SMUs cannot fill.

In the model, edges represent links between the nodes that can be either physical or electronic. For example, if a customer submits requisitions to an SMU electronically, this

connection is modeled in Simio with an edge connecting the I MEF customer requisition creation node to the SMU node. If a DLA Distribution Center (DDC) is shipping a requisition to a customer, in Simio this connection is also an edge. The difference is that a customer requisition traveling on a physical edge connecting a DDC node to a customer node must take time to do so. On an electronic edge (i.e., modeling e-mail, etc.), travel time is considered instantaneous. Nodes and edges are defined in more detail in the following sections.

2. Customer Requisition Generation

Requisition generation is unique for each repair part in our model. The I MEF SMU carries over 16,000 parts, with each part having a unique distribution for its requisition frequency and requisition quantity (Hubbard 2019a). For example, per the I MEF SMU data, setscrews are used quite often for routine repairs and are requisitioned frequently. Despite their high frequency, the quantity of each requisition is usually small (e.g., requisitioning two or four setscrews). Other parts are requisitioned far less often, but sometimes in large quantities. To better test the model, this thesis examines six different repair parts that have different requisition frequencies and quantities.

High frequency parts, are defined as those repair parts in the I MEF SMU database that had at least seven requisitions per week arriving at the SMU. Two of these: setscrews and diesel parts are examined. Medium frequency parts are those repair parts that had at least one requisition per week arriving at the SMU. Two of these: filters and batteries are examined. Low frequency part are those repair parts that had less than one requisition per week arriving at the SMU. Two of these: caps and bolts are examined.

For modeling the six types of repair parts, which all have different requisition frequencies and quantities, we could have fit a parametric distribution to the data to simulate requisition creation; for example, the Poisson distribution for the requisition quantity. However, using the empirical data from the I MEF SMU database avoids having to make assumptions about the underlying parametric distribution and bolsters the model's fidelity and legitimacy. To model requisition frequency and requisition size, we construct

two different statistical distributions from the empirical requisition data obtained from the I MEF SMU database per part.

The first distribution relates to requisition frequency. Using the I MEF SMU data, it is possible to tabulate the daily requisition distribution. Table 1 is constructed using the filter repair part requisition data. Table 1 shows, over a 566-day period, how many requisitions for filters arrive at the SMU daily. About 64.3% of the time, the SMU does not have a requisition for this part. The other 36.4% of the time, the SMU fills or refers to DLA at least one or more requisitions. The model uses the empirical data in Table 1 to randomly generate customer requisitions for every day being simulated. Each repair part examined has their own unique requisition frequency distribution.

Table 1. Filter Requisition Frequency Distribution

| Number of Requisitions | Days | Percentage |
|------------------------|------|------------|
| 0 | 364 | 64.31% |
| 1 | 86 | 15.19% |
| 2 | 53 | 9.36% |
| 3 | 25 | 4.42% |
| 4 | 18 | 3.18% |
| 5 | 6 | 1.06% |
| 6 | 7 | 1.24% |
| 7 | 3 | 0.53% |
| 9 | 2 | 0.35% |
| 15 | 1 | 0.18% |
| 19 | 1 | 0.18% |
| Total | 566 | 100.00% |

The second distribution modeled is the requisition quantity. The quantity of each requisition is also based on the empirical data from the I MEF SMU database for the repair part being simulated. Table 2 is constructed with the filter repair part requisition quantity data. Studying the 988 requisitions available, Table 2 shows that nearly 90% of requisitions are for just one filter. While requisitions ordering four or more filters do occur, these happen only 6.2% of the time. Similar to the requisition frequency distribution, the model uses the data in Table 2 to randomly generate the quantity demanded by each

customer requisitions created. Each repair part examined has its own unique requisition quantity distribution.

Table 2. Filter Requisition Quantity Distribution

| Quantity Ordered | Number of Requisitions | Percentage |
|------------------|------------------------|------------|
| 1 | 430 | 88.84% |
| 2 | 17 | 3.51% |
| 3 | 7 | 1.45% |
| 4 | 3 | 0.62% |
| 5 | 3 | 0.62% |
| 6 | 2 | 0.41% |
| 7 | 1 | 0.21% |
| 8 | 2 | 0.41% |
| 10 | 1 | 0.21% |
| 11 | 1 | 0.21% |
| 12 | 1 | 0.21% |
| 14 | 1 | 0.21% |
| 15 | 5 | 1.03% |
| 19 | 1 | 0.21% |
| 22 | 1 | 0.21% |
| 26 | 1 | 0.21% |
| 35 | 4 | 0.83% |
| 36 | 2 | 0.41% |
| 40 | 1 | 0.21% |
| Total | 484 | 100.00% |

3. SMU Reorder Requisition Generation

SMU reorder requisitions are generated not through a frequency distribution, but rather through decision rules that capture the interaction of customer requisitions with the depleting SMU's inventory. As described in Chapter II, whenever current inventory reaches or falls below an SMU's ROP, a reorder requisition is generated. The model operates similarly. Whenever an SMU's inventory reaches ROP, an SMU reorder requisition is generated at the DLA Central node. The quantity of the reorder requisition is

determined by the RO minus both the current SMU inventory and the inventory the SMU already has on reorder.

As discussed in Chapter I, an SMU's inventory policy (i.e., setting the values of ROP and RO to meet customer demand), has a critical role in determining whether or not an SMU can fulfill incoming customer requisitions. An inventory policy with high ROPs and ROs leads to low customer wait times and frequent SMU reorder requisitions. This policy would also increase the inventory level on the SMU's warehouse shelves. The SMU must balance a tradeoff between having enough inventory to satisfy demand and avoiding having too much of its funds tied down in inventory.

4. Processing

After a customer requisition is generated at the MEF customer requisition node, the next step in the model is for those requisitions to go to the SMU for processing. The model simulates this process by routing all requisitions to their respective SMU node. I MEF orders go to SMU1 and II MEF orders are sent to SMU2. The edges connecting the MEF customer requisition node to the SMU node mimic the submission of customer requisitions to the SMU. Since the MEF customers usually send their requisitions electronically, the travel time on these edges is zero.

In real life, the SMUs check their inventory electronically upon receipt of a customer requisition to see if there is enough on hand to fulfill the requisition. If an SMU cannot fill a requisition due to insufficient inventory, the requisition is referred to DLA. The model assumes that this inventory check at the SMUs is instantaneous. Since requisitions are electronically referred to DLA, the edges connecting the SMUs and the DLA Central node have also travel times of zero. All requisitions arriving at the DLA Central node experience a processing time of one day to simulate the "dead" time that a requisition might spend waiting to be processed for handling.

5. SMU—Handling and Shipping

For requisitions that completed the processing phase at either the SMUs or DLA, the next step is the handling phase. Handling is defined as the time taken to physically

move the requisitioned items from the warehouse and prepare them for shipping to the customer. This includes not only the preparation and packaging, but also any “dead” time that a requisition might spend waiting to be shipped. For example, if a requisition went through the processing and handling phases, but misses the deadline for the next available shipping truck, it would encounter another period of “dead” time.

After a requisition has completed the processing phase at an SMU, there are two potential events. If the SMU has sufficient inventory to fill the order, the requisition is filled and the amount requisitioned is deducted from the current inventory. The requisition enters the shipping phase and is sent to the customer. During the tour of the I MEF SMU, it was observed that inventory shelves were in the same building as the shipping point. The SMU staff members locate the part on the shelf, package the requisition for shipping, and then deliver the requisition to the customer via truck.

In the model, due to the SMU’s close proximity to its customers, the handling phase for the SMUs is different from that of DLA. The edge connecting the SMU node with the MEF customer node represents both the handling and shipping phases. As stated in the I MEF SMU Overview, the SMU takes between 24 to 36 hours to prepare and ship a requisition to a customer (Hubbard 2019b). Moreover, Hubbard explains that while the SMU can fill some requisitions with 12 hours (i.e., same day), these were rare due to the “dead” time in the handling and shipping process (2019a).

To simulate the handling and shipping time, the model uses a triangular distribution. This distribution is used when the most likely outcome, the upper bound, and the lower bounds are known, but the shape is only somewhat known. The triangular distribution uses the most likely outcome as its mode for the peak of the triangle. We use the distribution here as we know the SMU’s upper and lower bounds for the time required for handling and shipping. Assuming the mean of the upper and lower bounds is the most likely outcome, the SMU’s handling and shipping time is defined as having a lower bound of 0.5 days, an upper bound of 1.5 days, and a mode of 1.0 day. This distribution is now abbreviated as triangular (0.5,1.0,1.5). Further triangular distributions are defined in the (lower bound, mode, upper bound) format.

If the SMU has insufficient inventory, then the SMU partially fills the requisition with its inventory on hand. The requisition quantity minus what the SMU supplied is then referred to DLA for fulfillment. The model simulates this situation by subtracting the SMU's inventory from the original requisition quantity, setting the SMU's inventory to zero, and passing the requisition on to DLA for further fulfillment. In either real life or in the model, if the SMU has no inventory, the entire requisition quantity is sent to DLA.

Despite the SMU filling some of the requested parts, CWT for any customer requisition only stops when the entire requested amount is filled by either SMU or DLA. For example, an SMU's current inventory of filters is 5. A requisition arrives requesting 10 filters. Although the SMU cannot fill all 10 requested, it first sends the customer the 5 filters remaining in its inventory. The requisition for the remaining 5 filters is sent to DLA for further fulfillment. Upon customer receipt of the 5 filters, the CWT time for the second customer requisition stops.

6. DLA Central—Handling

DLA sends all arriving customer and reorder requisitions to either a DDC on the same coast as the SMU, a DDC on the opposite coast, or, absent availability, to a contracting source. According to Lambert, approximately 84% of requisitions are filled at DLA distribution centers on the same coast as the requesting customer (2019). Part of the handling time is assumed to be moving the requisitioned repair part from its warehouse to the shipping area. Lambert further explained that 11% of requisitions are filled the opposite coast DDC and 5% are filled by contracting (2019). Contracting sources are the source of DLA's inventory replenishment. DLA also uses contracting as a means to fill customer or reorder requisitions whenever a DDC's inventory is insufficient to do so.

In Simio, the DLA Central node simulates DLA's sourcing process described above by forwarding requisitions to the next node randomly following a pre-set probability. Although DLA has several smaller distribution centers, we assume there is just one location per coast. Lambert stated that since DLA is the wholesale distributor of Class IX parts for the military, its policy is to try to have enough stock on hand to fulfill customer requisitions. Even so, about 5% will be referred to contracting (2019). While modeling contracting

would increase the accuracy of the simulation, it would also increase the complexity. We would be forced to model the inventories at the DDC nodes in the same way as the SMU nodes. To simplify the model and avoid tracking DLA reorder requisitions from a vendor, we assume no requisitions are sent to external contracting sources. The model has the DLA Central node send requisitions in an 84%-16% split to same/opposite coast distribution centers.

7. DLA Distribution Centers—Handling

The DLA distribution centers (DDC) play a critical role in the handling phase as they process SMU reorder requisitions and customer requisitions. While the processing phase does account for some “dead” time moving the requisitioned parts from the local warehouse to the shipping point, there is still time required for preparing the parts for shipment and onto the correct truck for shipping.

When we toured DLA San Joaquin, Mr. Matt Gomez, of the DLA San Joaquin Strategic Engagement Office, provided several documents to assist in the writing this thesis. According to an information brief received from Gomez (2019a), DLA San Joaquin manages over 400,000 repair parts stored in 19 warehouses on 453 acres at Tracy, California. During the tour, it was noticed that the trucks serving multiple locations followed strict delivery schedules. Retrieving a requisitioned part from its respective warehouse, preparing it for shipping, and then transporting it to the shipping point takes time. Any requisitions missing the departure time of the current truck were held until the next scheduled departure.

To model this behavior, unlike the SMUs, the DDC nodes have service times that are based on the time required to prepare a customer order for shipment. This handling time assumes that each DDC does not ship continuously, that there is “dead” time between receiving a requisition from a local warehouse and preparing the parts for shipment. This also accounts for cut-off times for the shipment of orders. The DDCs’ service times are given a triangular distribution of (0.5, 1.0, 1.5) days for handling requisitions. This is the same distribution used for the handling/shipping time at the SMU nodes. Due to the handling and the shipping locations being located in the same SMU building, the SMU

nodes can be modeled to have a combined handling/shipping time. Although the handling procedures are the same, due to the DDC's larger size, the service time only includes the handling time and not the actual shipment from the DDC to the customer. Still, using this distribution means that the DDC nodes can handle and prepare to ship customer requisitions and SMU reorder requisitions, within 36 hours of receipt.

8. DLA Distribution Centers—Shipping

For DLA filled requisitions, once the parts have completed the handling phases, the shipping times are now dependent on the location of the customer. The DDCs ship requisitions to their customers via commercial trucks; express shipments such as FedEx are ignored for the purposes of this model. According to Hubbard, the typical shipping time from DLA San Joaquin to Camp Pendleton can take between two to four days (2019a). Similarly, Lambert explains that opposite coast shipping from a DDC to a customer takes two to three days more to arrive than deliveries shipped from a same-coast DDC (2019).

The model simulates shipping times through a triangular distribution based on shipping destination on the edges leading from the DDC nodes to the customer or SMU receipt nodes. Based on Hubbard's experiences, the model uses a triangular distribution of (2, 2.5, 4) days to simulate same coast shipping times from a DDC to an SMU or MEF customer. The triangular distribution for opposite coast shipping is derived as follows. Taking Hubbard's and Lambert's estimates for opposite coast shipping time gives a range of four to seven days. The model uses the seven-day shipping time as a lower bound. According to DLA San Joaquin's Logistics Response Times (LRT) fact sheet provided by Gomez (2019b), a DDC must deliver a requisition within 14 days of receipt. Using the LRT figure as an upper bound, the model simulates opposite coast shipping with a triangular distribution of (7, 10, 14) days. This distribution uses the longer time periods based on the I MEF SMU's experiences as well as to use a worst-case scenario for receiving parts. A potential increase in customer wait time might have the SMUs consider inventory policies with higher ROPs and ROs ultimately leading to higher inventory costs.

B. LIMITATIONS OF THE MODEL

While this model simulates how a customer requisition is processed in the USMC-DLA logistics chain, there are several cases that are not covered by the model. These limitations are described below.

1. Transshipments between SMUs

First, while SMUs can check each other's inventory and ship parts to each other, there are no transshipments between SMU nodes in the model. Hubbard explained that transshipments are seldom done due to the separation of the logistics and the financial sides of the supply chain (2019a). Hakola concurs stating that, not only does the requesting SMU have to arrange for the parts transfer from the supplying SMU, but they must also request a transfer of funds (2019).

2. Expeditionary SMUs

Second, while there are three major USMC SMUs—Camp Pendleton in California, Camp Lejeune in North Carolina, and Camp Butler in Okinawa, Japan—the model only simulates the SMUs located in the U.S. Hakola states that the III MEF in Okinawa is considered a forward deployed Marine Air Ground Task Force (MAGTF) (2019). This status is different from the U.S.-based SMUs, which support both deployed and non-deployed units. Any SMU with a forward deployed status would normally not supply U.S. based units with parts. According to Hubbard, shipping priority is always the forward deployed unit (2019a). While the III MEF SMU could have been modeled, doing so would have increased the number of nodes and paths.

3. Simplification of DLA Distribution Centers

Third, Lambert states there are more DLA distribution centers than just DLA San Joaquin and DLA Susquehanna (2019). Although modeling these distribution centers could provide more detail to the model, this would also increase the number of parameters and data required to produce a working model. Making assumptions about the delivery time from DLA San Joaquin to the I MEF SMU is easier than trying to calculate the same delivery time for a delivery from a sub-unit of DLA San Joaquin to the DLA San Joaquin

shipping center and then to the I MEF SMU. The model avoids this unnecessary complexity by simulating deliveries from the DLA sub-distribution centers to the DLA shipping center under the handling phase of the DLA section of the model. The model assumes that sub-distribution centers sends requisitions to their main DDC for ultimate delivery to the customer.

4. DLA Inventories

Another limitation is that DLA's wholesale activities and inventories are only broadly simulated. Since this thesis is concerned with efficient inventory policies at the SMU, modeling DLA inventory at its DDCs is out of scope. Due the size and scale of its DDCs and associated sub-distribution centers, simulating DLA inventory would have added unnecessary complexity to the model, distracting from the thesis' main purpose. To bypass this limitation, the model assumes that DLA is never out of stock of inventory. According to Lambert, DLA maintains a vigorous stocking policy so that items are typically out of stock and are being reordered approximately 5% of the time (2019). Since DLA's not-in-stock rate of 5% rate is an average of all not-in-stock parts across DLA's vast inventory, it is plausible that many frequently ordered items are never out of stock when a customer order arrives. Therefore, we assume that the DDCs fill all requisitions.

5. Distribution Limitations

An additional limitation is that the distributions the model uses to simulate requisition frequencies, requisitions quantities, and shipping times do not account for extreme values. While the advantage of the empirical distribution is that results are based on real data, it cannot model what is not observed. For example, a requisition quantity distribution based on empirical data states that there is a 50% probability a requisition will request four parts, and the other 50%, twenty. This example does not allow for requisition quantities at the extremes, potentially underestimating demand and skewing CWT. The other distribution used, the triangular distribution, is based on observations from the I MEF SMU operations and from I MEF SMU data. The ranges also do not account for extreme values and likewise underestimate shipping times and CWT.

6. SMU Budgetary Considerations

The last limitation is that the model does not take into account budgetary considerations. Since all SMUs operate under a “pay-go” system to reorder their parts, the SMUs cannot reorder parts without receiving funds from their customers. The SMUs only receive funds from their customers by issuing or “selling” them parts from the SMU’s inventory. Hakola explained that these stock replenishments happen periodically on different intervals: weekly, monthly, quarterly, etc. (2019). An SMU balances and forecasts its purchases not just per line item but across the whole SMU inventory with future requirements in mind. The model, in contrast, only examines parts one at a time. This limitation is partially mitigated by using the RO parameter as a proxy to represent the opportunity cost of a part occupying space on the SMU’s shelf. The larger the RO is; the more funds an SMU has to devote to maintain that inventory. Accurately implementing budget-management considerations would require considering the entire array of repair-parts in the same simulation. This would add more complexity as, according to Hubbard, an SMU’s inventory is in excess of 16,000 parts and result in longer simulation times for each run of the model (2019a).

C. MODELING IN SIMIO

With the four major parts of the model (requisition generation, processing, handling, and shipping) defined, this section shows how the model is created in Simio.

1. Customer Orders

As described in Section III.A above, customer requisitions are generated according to distributions based on data from the I MEF SMU. They proceed to the SMU node for either fulfillment or referral to DLA. If filled by the SMU, the SMU’s inventory is decremented and the requisition is sent to the MEF Receipt node to both remove the requisition from the system (receipt) and to stop CWT (time in system). If referred to DLA, the DLA Central node sends the requisition to a DDC or contracting for fulfillment. Once filled by a DDC, the customer requisition is sent to the MEF Receipt node.

2. SMU Reorder Requisitions

SMU stock reorders are created whenever the current inventory level is at or less than the SMU's RO. The order amount for a stock reorder is determined by the SMU's ROP, current inventory, and amount currently on reorder. The reorder requisition is created at the DLA Central node, and from there, DLA processes the SMU stock reorder as if it were a MEF customer order. When the reorder requisition arrives at the SMU Receipt node, the SMU's current inventory is increased by the order amount of the stock reorder. The amount on order for the SMU is decreased by the order amount and the reorder requisition is then removed from the model.

B. RESPONSES FROM THE MODEL

The model's main purpose is to simulate customer orders within the SMU-DLA logistics system to determine if the current combination of TBI, ROP, and RO is efficient compared to the original ROP and RO. Comparing different inventory policies for a repair part can be accomplished by comparing the policies' respective CWT and stock outs. These are the two main responses the model generated when simulating an inventory policy.

1. CWT

The model measures CWT in hours starting from when a customer requisition is received at the SMU to when the requisition is finally received by the customer. Every inventory policy will have a different CWT associated with it. Although the SMU is interested in reducing inventory levels, having a high CWT can indicate the SMU does not have enough stock to meet demand. If so, the SMU might have to increase ROP, RO or both to decrease CWT. On the other hand, a low CWT might indicate that the SMU has excess inventory.

2. Stock Outs

Stock outs are occurring whenever an SMU does not completely fill a requisition in the model. Partially filled requisitions also count as stock outs. As the SMU's major goal is to fulfill as many requisitions as possible given its ROP and RO, stock outs are to be avoided as much as possible. An SMU operating with an ROP-RO combination fulfilling

100% of all customer requisitions would have zero stock outs. Any ROP-RO combination that has a CWT higher than the model's minimum CWT possible also has at least one stock out. Since CWT implies stock outs occur, the model's primary output is still CWT.

IV. EXPERIMENTATION

With the groundwork laid, we can use the model developed in Chapter III to see how different inventory parameters affect CWT. Key sections are the design of experiments, the results per type of demand, and the interpretation of the results.

A. SETUP OF THE EXPERIMENTS

We apply the simulation to six repair parts that vary in the frequency and size of their typical requisitions. The analysis examines the tradeoff between the RO, which is used as a proxy for inventory size, and CWT, which measures the effectiveness of the supply chain. Higher RO implies larger inventories that occupy storage space and lock in purchase funds. CWT is a measure of service quality: how long a customer waits to receive its requisition. This tradeoff is analyzed while varying several parameters: TBI, ROP, and RO. TBI is a control parameter that determines how often the SMU management reviews the inventory level of a repair part (e.g., 1 week, 2 weeks,) and creates a requisition reorder. The value of the ROP is defined as a percentage of the RO. While the specific tradeoffs between parameters might differ by repair part, some relations between the parameters are obvious. For example, large ROP and RO, and a small TBI lead to higher mean inventory and thus lower mean CWT. Conversely, small ROP and RO values and a large TBI result in lower mean inventories. These lower inventories imply a higher probability of stock-out and thus referral of requisitions to DLA. Such situations lead to increases in CWT.

B. PARAMETER LEVELS

For each repair part examined, the parameters of ROP, RO, and TBI are varied across different levels. Testing 7 levels of ROP (10%–70% of RO) and 11 levels of RO (20% -120% of current practice RO) results in 77 combinations of ROP and RO. The model also examines a policy relying entirely on DLA where RO is set to zero. Additionally, a base case policy representing the current levels of ROP and RO as found in the I MEF SMU database is also included. Altogether there are 79 policies that are examined under five different TBI settings, for a total of 395 different policies for each repair part.

1. TBI

The model has the SMU mimic in part how requisitions are done in a shipboard supply department. According to the *Operational Forces Supply Procedures*, revision 5 (P-485), “periodic stock replenishment on a regular basis is essential to maintaining proper stock levels. ... Every effort must be made to schedule stock item records for automatic reorder review at least twice monthly” (2015, p. 3-150). The P-485 also provides a sample monthly schedule for supply department activities that recommends conducting a weekly reorder review. Since ships in practice reorder on three intervals: daily, weekly, and bi-weekly, we evaluate TBI on those levels. In addition, to check for sensitivity, we also examine TBIs of 4 and 12 weeks.

2. ROP

The ROP for each of the policies examined is determined by a percentage of the current level of RO. Every repair part has different ROPs based on its ROs. These ROPs are normalized as a percentage of RO and in the model’s experiments are measured on seven (7) levels; from 10% to 70% of RO, in 10% increments.

3. RO

The RO for each of the policies examined is determined by a percentage of the original level of RO. The original level of RO is defined as the RO for the specific part found in the SMU database. These ROs are measured on eleven (11) levels from 20% of the original ROP to 120% of original RO in 10% increments.

4. Initial Inventory

The initial inventory for each combination of ROP-RO tested is set to the inventory level in the I MEF SMU database. This is done to reach a realistic steady state quickly. Initial inventory varies per repair part.

5. Simulation Runtime

The model simulates the flow of customer requisitions for each inventory policy for a repair part over the course of one simulated year. To ensure reasonable sample results, the experiments repeat this simulation 100 times. Since each repair part has 395 different inventory policies, a total of 39,500 years are simulated for each repair part. For six repair parts, 237,000 years are replicated in the model.

For items with higher requisition frequencies, such as setscrew and diesel parts, simulations take longer times to run. These high demand items require a mean of four to five hours of runtime per TBI. In contrast, low demand items require less than 20 minutes per TBI run. The runtime for medium demand items fell in between that of the high frequency and low frequency repair parts. To simulate all six pair parts at the levels listed above require approximately 79.5 hours.

C. TYPES OF DEMAND

The experiments are run on six repair parts, each with different customer requisition frequency distributions. For the purpose of this thesis, there are three classes of demand: high, medium, and low demand. High demand repair part items are defined as those repair parts in the I MEF SMU database that had at least seven requisitions per week arriving at the SMU. Two of these: setscrews (NSN 00-133-8276) and diesel engine parts (NSN 01-492-5709) are examined. Medium demand repair part items are those repair parts that had at least one requisition per week arriving at the SMU. Two of these: filters (NSN 01-588-0924) and batteries (NSN 01-548-7566) are examined. Low demand repair part items are those repair parts that had less than one requisition per week arriving at the SMU. Two of these: caps (NSN 00-449-6408) and bolts (NSN 01-212-4527) are examined.

D. SPECIFIC REPAIR PART RESULTS

From the six repair parts examined, there are two broad groups of results. The first group are those parts which have ROP-RO combinations that reach the model's minimum possible CWT. This indicates that the SMU might have more inventory than customer demand requires. The representative part for this group is the setscrew. The second group

are those parts which do not reach the minimum CWT. This indicates the SMU might have insufficient inventory to meet customer demand. The batteries represent the second group. Due to the other four repair parts having similar results as the setscrew, we moved these results to the appendix to avoid repetition. Another omission from the main thesis are the results from the DLA policy. It is sufficient to say that DLA's CWTs are significantly higher than even the worst non-DLA policies for every part examined and are omitted from the tables and graphs below.

1. Setscrews

Setscrews have the largest ROP and RO of any part examined in this model. Per the I MEF SMU database, setscrews have an ROP of 491 and an RO of 1,069. Over a 570-day period, there were 1,055 customer requisitions for setscrews, an average of 1.9 arriving at the SMU daily. The average size of each requisition is approximately 5.5 setscrews. Since 60 days of demand is approximately 627 items (1.9 requisitions * 5.5 setscrews * 60 days = 627), any valid SMU policy must meet or exceed this RO.

RO: Using the current RO from the I MEF SMU database as the base-line, we range the values of RO between a very risky value of 214 items (approximately 20% of RO) and a conservative value of 1,283 (120% of RO).

ROP: Since ROP, as a percentage of RO, range between a risky percentage of 10% and a conservative value of 70%, the actual ROPs tested range from 21 to 898.

Figures 1 and 2 below present the results of the mean CWT and the 90th percentile CWT, respectively. For both results, there are key similarities; increases in ROP or RO lead to decreases in CWT. The graphs show that increases in TBI from 0 to 2, generally do not result in an increase in CWT. When TBI is 4 or greater, however, CWT increases, especially if the 90th percentile results are examined. Still, despite the higher CWTs and range between the ROP-RO combinations, shape of the 90th percentile results closely follow those of the mean CWT results.

Another result is that both graphs show a limit to how much increases in ROP and RO can decrease CWT. Any combination of ROP and RO not meeting 100% of customer

demand would have a CWT greater than the model’s minimum CWT. If an SMU is meeting 100% of customer demand at a certain level of ROP and RO, any increase in RO would not decrease CWT. The graphs show that CWT can become insensitive to increases in RO once a ROP-RO curve has reached the minimum CWT.

Further analysis of the graphs reveals a potential “sweet-spot” for an efficient policy. First, the plots become closely clustered as ROP increases. Small to medium ROP values seem to be good enough; an ROP that is beyond, say, 30% of RO does not significantly affect the CWT. Second, while there is a dramatic decrease in CWT as RO is increases from its minimum level of 214, this decrease subsides when RO reaches the level of around 500.

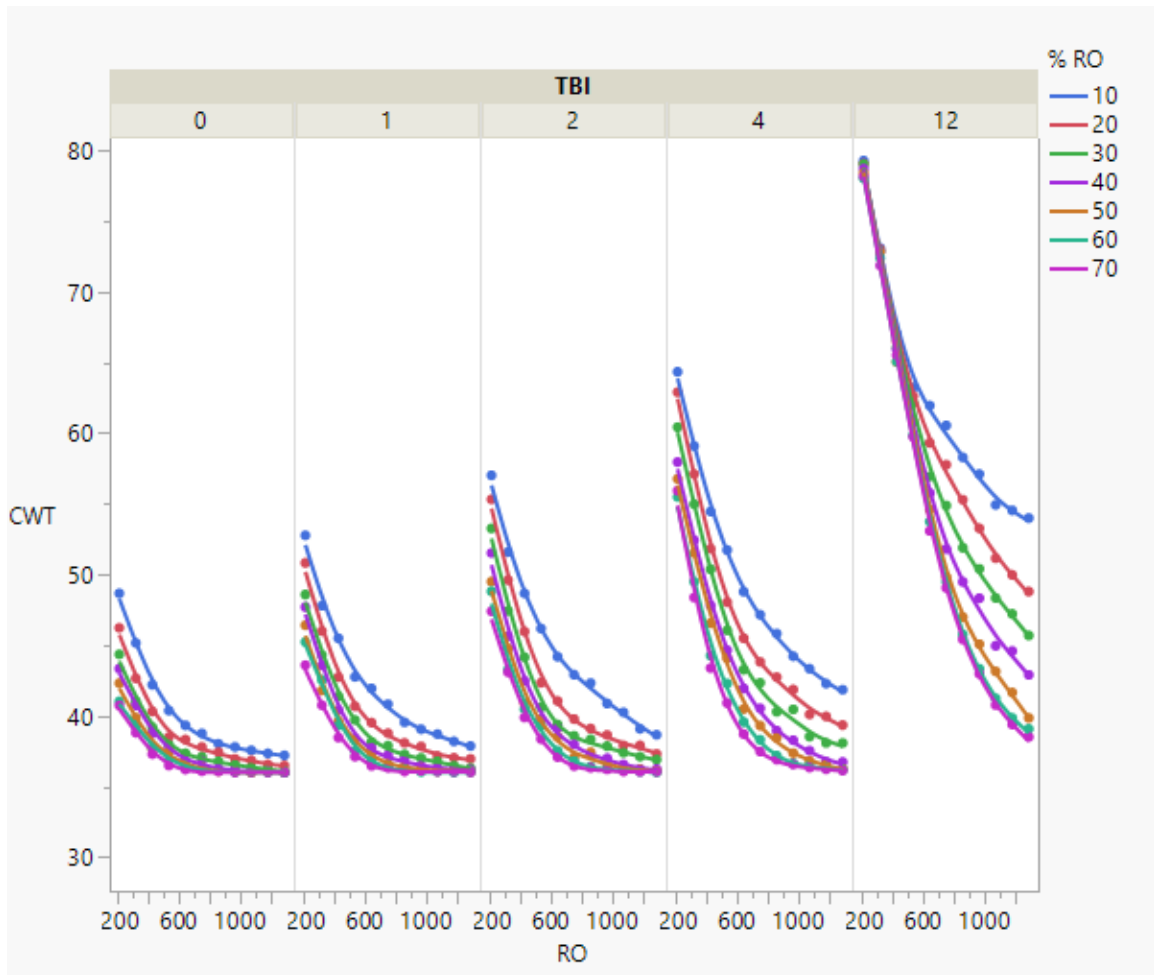


Figure 1. Setscrew CWT vs. RO by Inspection Period and by ROP as %RO

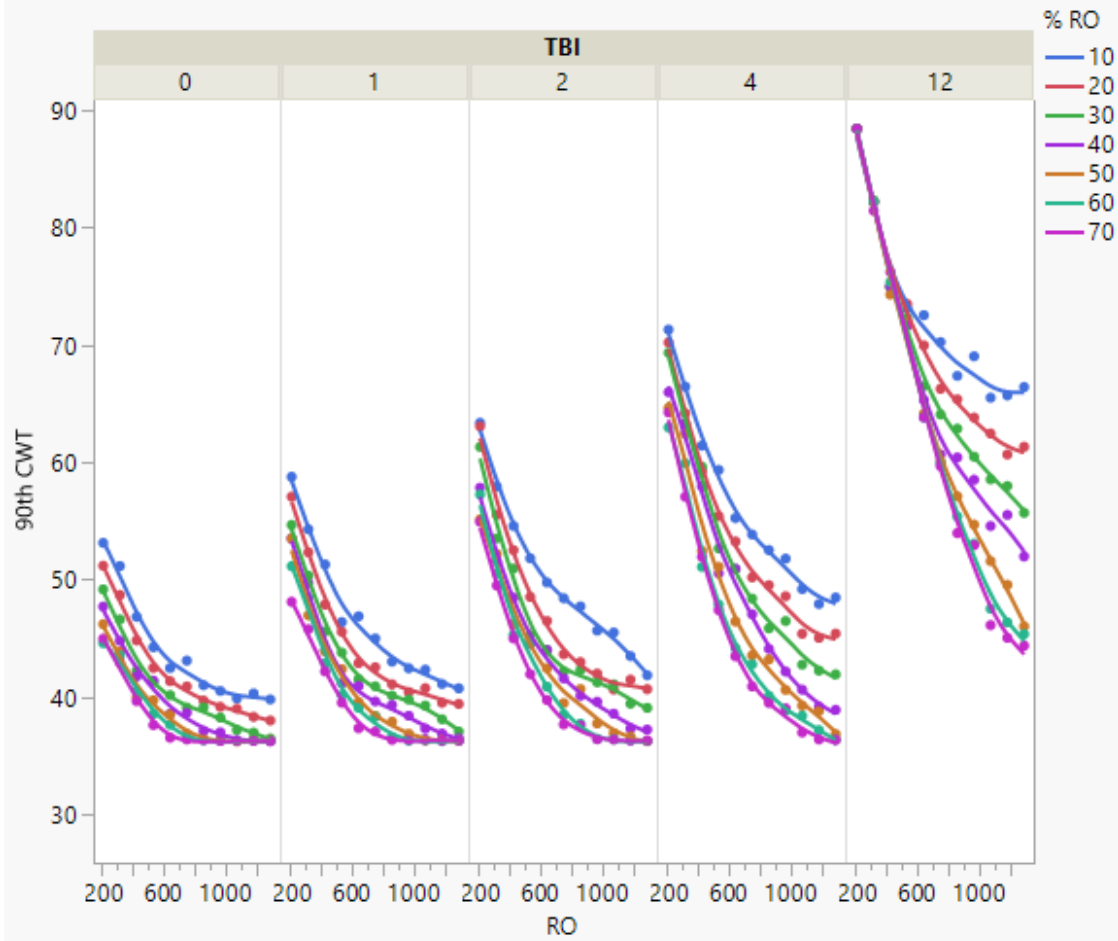


Figure 2. Setscrew 90th Percentile of CWT vs. RO by Inspection Period and by ROP as %RO

Tables 3 and 4 display feasible ROP as a percentage of RO (%RO) policies and the minimum level of RO required to meet a certain CWT within a certain TBI. A benchmark CWT is the CWT the model generates for the SMU’s current settings a given TBI. For example, in Table 3, the benchmark CWT is 36.2 hours for TBI = 1. Infeasible ROP-RO combinations are those that for a given ROP, there is no RO level within the range examined that can meet a certain benchmark CWT. These policies are marked as “N/A” and are marked in red in the tables below. Since the focus of the study is to reorder as a ship does, we focus on TBI = 1 and TBI = 2 weeks. To provide sensitivity analysis, the initial benchmark CWT is relaxed by 5% and 10%. For example, for setscrews, the initial

benchmark is 36.2 for TBI = 1, the 5% benchmark is 38 hours, and the 10% benchmark is 39.8 hours. The tables round all ROs to the nearest integer as SMU managers can only order in integers.

While the results show ROP-RO combinations providing the same CWT as the current practice ROP-RO, the USMC Intermediate-Level Supply Management Policy Manual mandates SMUs carry enough inventory to meet customer demand, and authorizes them to have enough stock to satisfy 60 days of demand (DoN 2013). A feasible policy must have less RO than current practice and enough inventory to satisfy 60 days of demand. Policies not meeting this minimum RO are also marked in red. The SMU can still use these policies, but it would have to increase its RO to the minimum RO level.

Tables 3 and 4 reveal several relationships between RO, ROP, and the benchmark CWTs. As ROP increases, the RO required to meet a benchmark CWT decreases. As TBI increases from TBI = 1 to TBI = 2, the benchmark CWT for all repair parts increases, but the RO required to meet the benchmark CWTs decreases. Relaxing the original benchmark by 5% and by 10% increases CWT, but decreases RO. The most important result is that the tables demonstrate that there are many ROP-RO combinations for setscrews that can both match the benchmark CWT and meet the RO requirements to be feasible for the SMU.

Table 3. Setscrew %RO and RO per CWT Benchmark for TBI = 1

| TBI = 1 | Current Practice CWT | Relaxed 5% | Relaxed 10% |
|-------------------------|-----------------------------|-------------------|--------------------|
| Hrs. | 36.2 | 38 | 39.8 |
| %RO | RO | RO | RO |
| 10 | N/A | 1233 | 841 |
| 20 | N/A | 870 | 610 |
| 30 | N/A | 690 | 528 |
| 40 | 1210 | 599 | 474 |
| 50 | 982 | 557 | 435 |
| 60 | 800 | 528 | 425 |
| 70 | 735 | 478 | 370 |
| | | | |
| Current Practice | 1069 | Minimum RO | 627 |

Table 4. Setscrew %RO and RO per CWT Benchmark for TBI = 2

| TBI = 2 | Current Practice CWT | Relaxed 5% | Relaxed 10% |
|-------------------------|----------------------|-------------------|-------------|
| Hrs. | 36.3 | 38.1 | 39.9 |
| %RO | RO | RO | RO |
| 10 | N/A | N/A | 1092 |
| 20 | 1161 | 1057 | 730 |
| 30 | 1118 | 845 | 605 |
| 40 | 1060 | 718 | 554 |
| 50 | 1041 | 636 | 515 |
| 60 | 1012 | 596 | 479 |
| 70 | 998 | 552 | 450 |
| | | | |
| Current Practice | 1069 | Minimum RO | 627 |

2. Batteries

In contrast to the setscrews, batteries have a lower demand, ROP, and RO. Per the I MEF SMU database, batteries have an ROP of 118 and RO of 286. Over a 566-day period, there were 314 requisitions, an average of 0.6 customer requisitions arriving at the SMU daily. Out of 314 customer requisitions in a 566-day period, 269 requisitions requested only 417 batteries. The remaining 45 requisitions amounted to 1,259 batteries requested, 75% of all batteries in that period. This indicates that the SMU might have to stock a large amount of batteries to satisfy periodic demand surges. Due to large spikes in demand, the average size of each requisition is approximately 5.3 setscrews (1,676 batteries / 314 requisitions). Since 60 days of demand is approximately 191 items (0.6 requisitions * 5.3 batteries * 60 days = 190.8), any valid SMU policy must meet or exceed this RO.

RO: Taking the current RO at the I MEF SMU as the base-line, we range the values of RO between 57 items (approximately 20% of the current practice) and 343 (120% of current practice).

ROP: The actual ROPs tested range from 6 to 240.

Figures 3 and 4 present the results of the mean CWT and the 90th percentile CWT, respectively. The results for the batteries show similarities with the setscrew analysis. The relationships between ROP and RO to CWT are still applicable. Moreover, the figures show that CWT is relatively insensitive to changes in TBI from 0 to 2. As with the

setscrews, when TBI is 4 or greater, CWT increases, especially if the 90th percentile results are examined.

The key difference between the setscrews and the batteries is that the curves in Figures 3 and 4 do not cluster around a 36-hour CWT. Increasing RO from its minimum level of 57 to the maximum of 343 does not cause the CWT to drop to the minimum CWT.

This is more pronounced in Figure 4 for the 90th percentile CWT where only ROPs that are at least 60% or more of RO have a sub-40-hour CWT. These results indicate that the SMU is not able to satisfy 100% of customer demand with any of the ROP-RO combinations examined. Further increasing ROP and RO will yield further reductions in CWT.

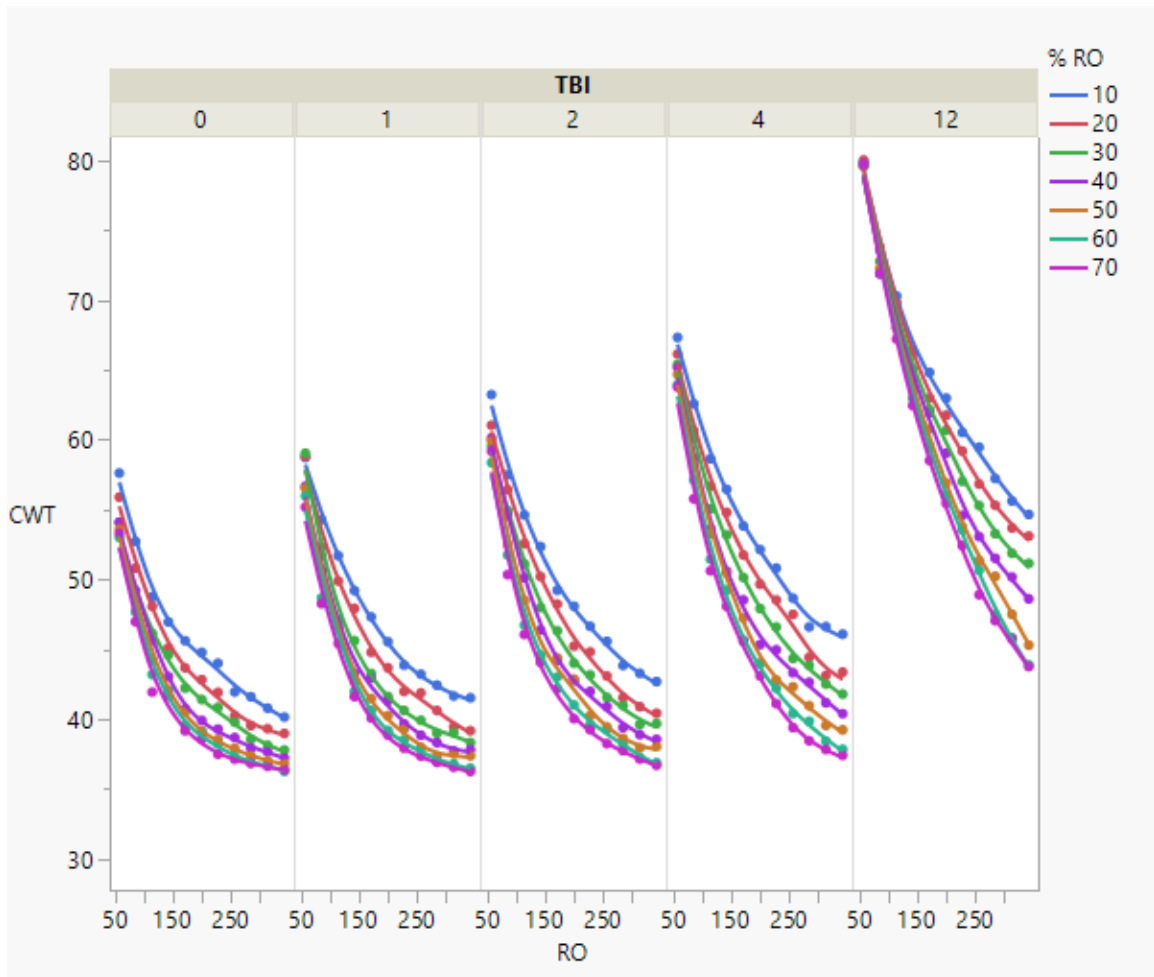


Figure 3. Battery CWT vs. ROP by Inspection Period and by ROP as %RO

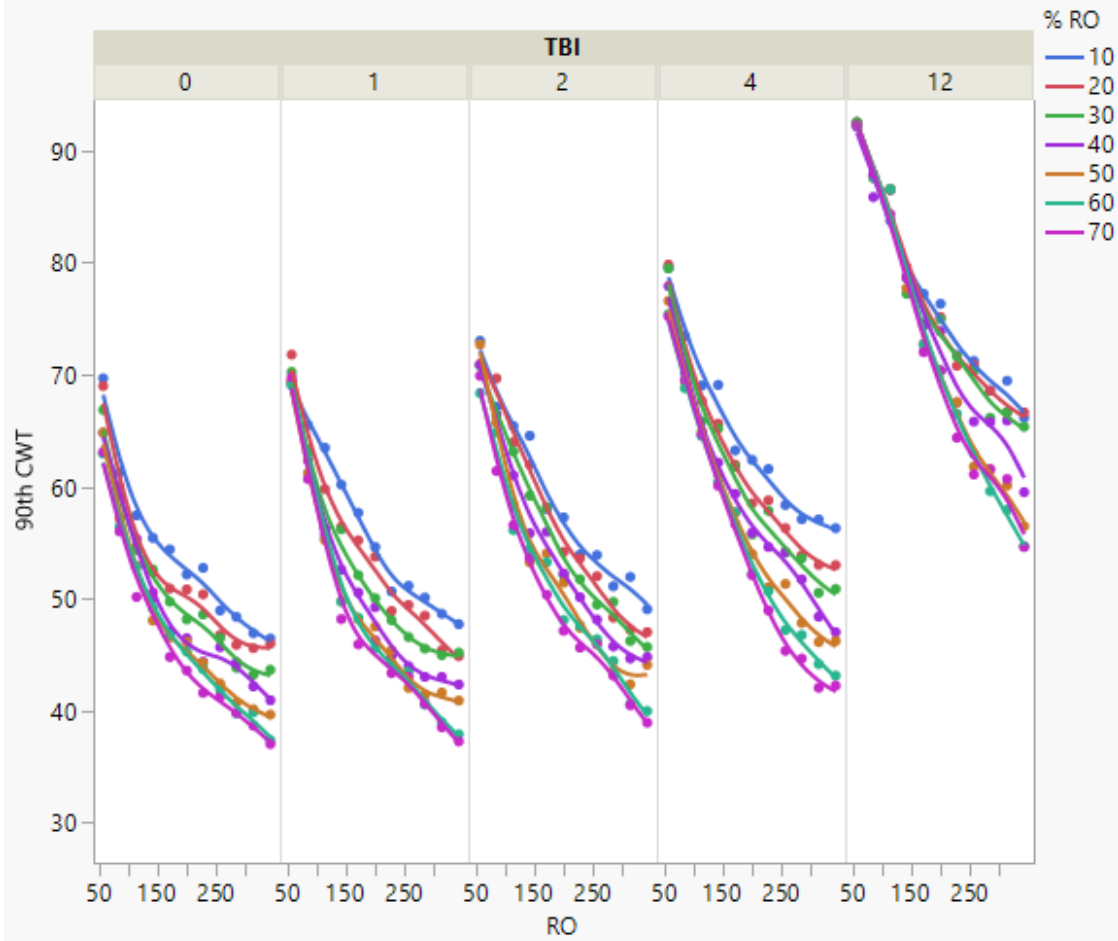


Figure 4. Battery 90th Percentile of CWT vs. ROP by Inspection Period and by ROP as %RO

Tables 5 and 6 show per TBI, the combinations of %RO and RO for batteries that meet the benchmark CWTs. As with the setscrew analysis, the tables point to multiple combinations of ROP and RO that both meet benchmark CWTs and the RO requirements. Several policies do not meet the minimum inventory, but the SMU can increase its RO to make use of those policies. Relaxing the benchmarks by 5% and 10% reveals that most ROP levels are feasible within the given range of ROs. Still, the minimum CWT for the model is approximately 36 hours, and none of the benchmark CWTs reach it. If the SMU desires to maintain its current practice CWT, it is recommended to use a ROP-RO combination from the TBI = 1 benchmark table. If the SMU, however, wanted to reduce its CWT, it must consider both raising RO and increasing %RO from its current practice.

Table 5. Battery %RO and RO per CWT Benchmark for TBI = 1

| TBI = 1 | Current Practice CWT | Relaxed 5% | Relaxed 10% |
|-------------------------|-----------------------------|-------------------|--------------------|
| Hrs. | 38.6 | 40.5 | 42.5 |
| %RO | RO | RO | RO |
| 10 | N/A | N/A | 281 |
| 20 | N/A | 286 | 225 |
| 30 | 326 | 231 | 184 |
| 40 | 270 | 211 | 170 |
| 50 | 241 | 188 | 155 |
| 60 | 219 | 173 | 148 |
| 70 | 204 | 164 | 140 |
| | | | |
| Current Practice | 286 | Minimum RO | 191 |

Table 6. Battery %RO and RO per CWT Benchmark for TBI = 2

| TBI = 2 | Current Practice CWT | Relaxed 5% | Relaxed 10% |
|-------------------------|-----------------------------|-------------------|--------------------|
| Hrs. | 39.3 | 41.3 | 43.2 |
| %RO | RO | RO | RO |
| 10 | N/A | N/A | 317 |
| 20 | N/A | 304 | 252 |
| 30 | N/A | 270 | 221 |
| 40 | 301 | 240 | 191 |
| 50 | 263 | 217 | 180 |
| 60 | 246 | 195 | 162 |
| 70 | 224 | 180 | 151 |
| | | | |
| Current Practice | 286 | Minimum RO | 191 |

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V. CONCLUSIONS AND FUTURE WORK

A. PROBLEM REVIEW

The main goal of this thesis has been to identify how to improve USMC Class IX repair parts management. USMC SMUs are critical to resolving this issue as these supply depots are tasked with providing Class IX parts support to the MEF customers. While the SMU inventories generally meet customer demand, forecasting errors can and do cause the SMUs to have inefficient inventory levels. These inefficiencies cause overages for some parts and shortages for others. The thesis explores how changes in inventory reordering and maximum inventory level can both reduce excess inventory and maintain current levels of customer wait time. More efficient inventory policies allow the SMUs to reduce inventory and reallocate funds to parts that their customers demand. By doing so, the SMU is able to avoid more shortages and reduce customer wait time even further.

With millions of dollars in inventory and thousands of repair parts, any improvement in the SMUs' inventory policies can lead to potentially millions of dollars saved. Moreover, any reduction in customer wait time improves the mission readiness for the SMU supported Marines.

B. CONCLUSIONS

We observe that the reordering policy at the SMU—setting the ROP, RO and TBI values—has a great effect on CWT. CWT is sensitive to the RO and experiences a sharp decline when one moves from very low RO to moderate values. This effect is ameliorated as one moves from moderate values of RO to large values. We also note that while shorter TBI leads to shorter CWT, for realistic values of TBI—0, 1, 2—the CWT is not very sensitive to TBI. CWT increases when TBI is unrealistically high (12 weeks).

Comparing the results of the repair parts analysis with current practices at the I MEF SMU, we conclude that the SMU has two types of repair parts. The first type are those parts that can maintain an acceptable mean CWT with a substantially smaller inventory for most of the repair parts examined. In some cases, such as the setscrews, the

SMU can reduce its RO by as much as 30% while still maintaining a 60-day operating supply of repair parts. This enables more funds to be allocated to other inventory items. The second type of parts are those which can attain lower CWTs if the SMU were to increase their RO. The battery repair part represents this group.

Overall, while reductions in inventory might lead to an increase in administrative work due to the increased number of reorder requisitions, the more frequent the reorder period, the greater the decrease in CWT. If the SMU is constrained in adjusting its reorder policy due to financial or operational reasons, the SMU can still consider decreasing the ROP while increasing its RO.

While parts with different levels of demand were examined, the changes in the demand patterns did not change the effect that ROP, RO, and TBI values had on CWT.

We recommend that the SMU investigate if a TBI of one or two weeks is feasible. We further recommend for most parts a reduction of 30% in RO and an increase of ROP to 70% of the new RO. This recommendation for RO and ROP should be increased if the SMU implements a TBI of 2 weeks.

C. FUTURE WORK

Future research will relax the assumption regarding vertical flow of supplies along the hierarchy: DLA (wholesale) to SMU (retail) to customer. While still more of an exception than a rule, lateral flow between SMUs is possible, and perhaps even desirable. As this flow is not captured in our model, it could be part of a model extension. A second extension would be to expand the scope of the model to include III MEF SMU, other forward deployed logistic units at the operational level, as well as modeling in detail the DLA operations with all its relevant installations. Finally, the current model touches on budgetary considerations only through the ROP proxy. Further research would involve estimations of inventory, handling and shipping cost so that the tradeoff between effectiveness (CWT) and efficiency (cost) will be more realistic.

APPENDIX. OTHER PARTS

D. DIESEL PARTS

Diesel parts are a high demand item, and have the second the largest ROP and RO of the parts examined in this model. According to the I MEF SMU database, diesel parts have an ROP of 245 and an RO of 643. Over a 575-day period, there were 1,886 customer requisitions for diesel parts, an average of 3.3 arriving at the SMU daily. The average size of each requisition is approximately 2.1. Since 60 days of demand is approximately 416 items ($3.3 \text{ requisitions} * 2.1 \text{ diesel parts} * 60 \text{ days} = 415.8$), any valid SMU policy must meet or exceed this RO.

RO: Taking the current RO at the I MEF SMU as the base-line, we range the values of RO between 129 items (approximately 20% of the current practice) and 772 (120% of current practice).

ROP: Since this parameter is a ROP as %RO, the actual ROPs tested ranged from 13 to 540.

Figures 5 and 6 below display the results from the decision parameters %RO, RO and TBI. These graphs are very similar to those in the setscrew results. The shape, the insensitivity of CWT to most levels of CWT, and the limits to decrease CWT by increasing RO all mirror those in the setscrew analysis. This applies to both the mean CWT and the 90th percentile graphs. As with the setscrews, there also seems to be a limit to how much increasing RO can reduce CWT. The results indicate RO can be reduced by 30% of current practice if the ROP is sufficiently high enough. Increasing RO from its minimum level of 129 reduces CWT, but this decrease subsides when RO reaches the level of around 400.

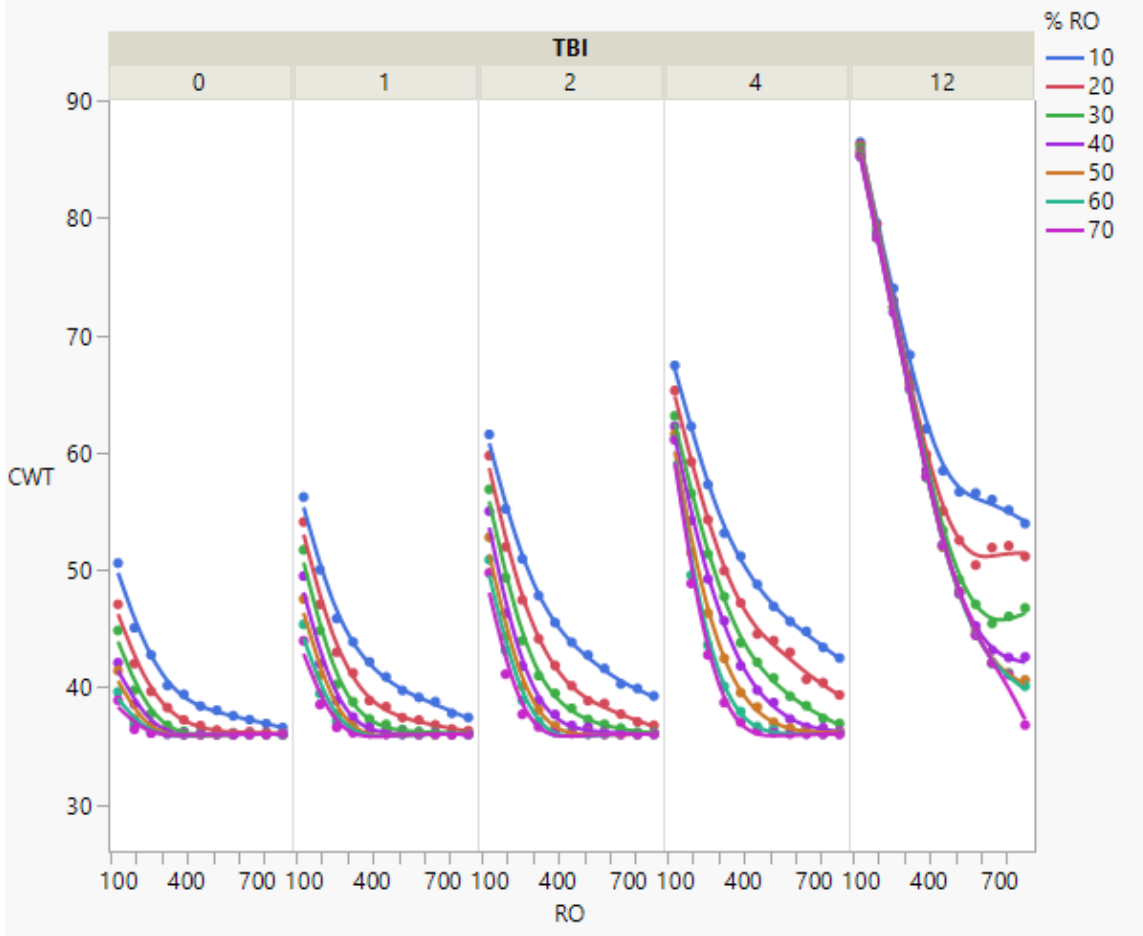


Figure 5. Diesel Part CWT vs. RO by Inspection Period and by ROP as %RO

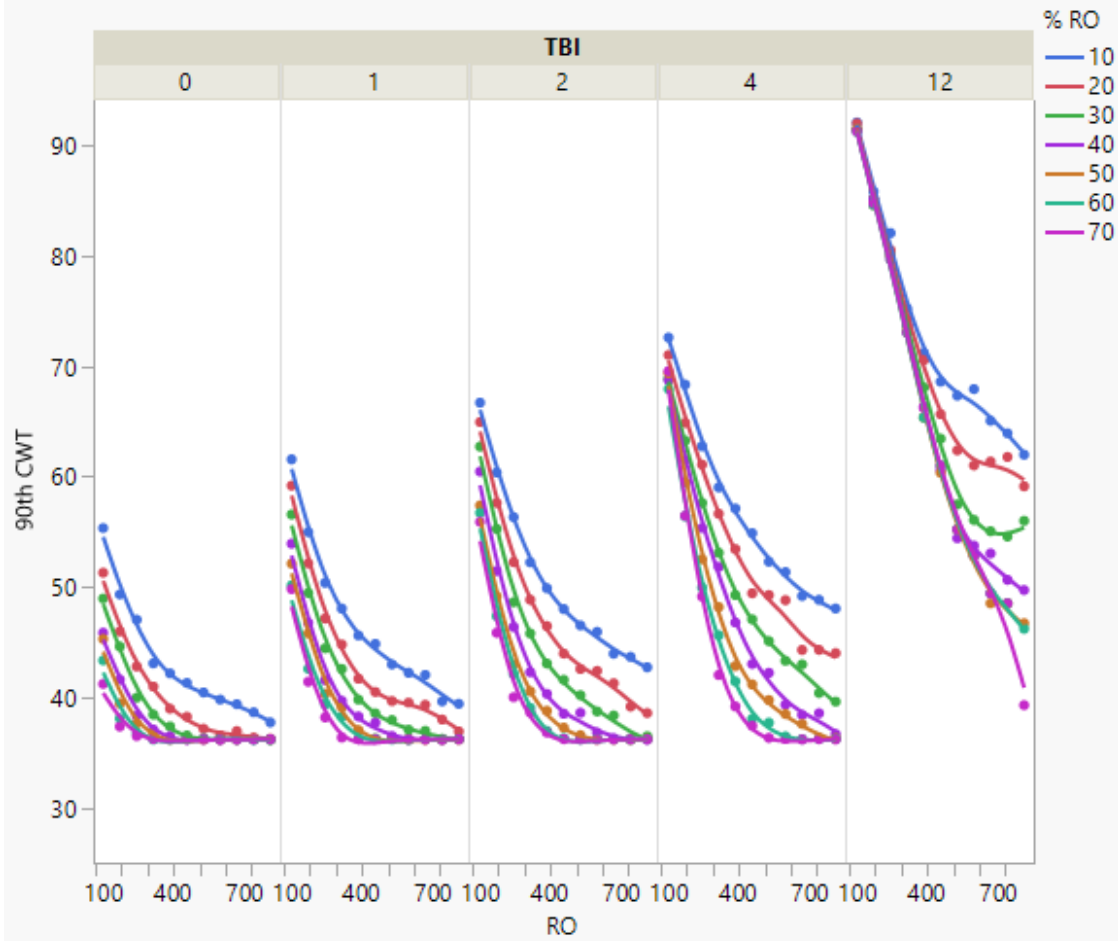


Figure 6. Diesel Parts 90th Percentile of CWT vs. RO by Inspection Period and by ROP as %RO

Tables 7 and 8 show per TBI the combinations of %RO and RO that meet the benchmark CWTs. Like the setscrew tables, it is apparent that multiple combinations of %RO and RO exist that both meet benchmark CWTs and RO requirements. The SMU can still utilize the higher percentage ROP policies marked in red by increasing the RO to meet the minimum RO required.

Table 7. Diesel Parts %RO and RO per CWT Benchmark for TBI = 1

| TBI = 1 | Current Practice CWT | Relaxed 5% | Relaxed 10% |
|-------------------------|----------------------|-------------------|-------------|
| Hrs. | 36 | 37.8 | 39.6 |
| %RO | RO | RO | RO |
| 10 | N/A | 720 | 531 |
| 20 | N/A | 474 | 363 |
| 30 | N/A | 356 | 293 |
| 40 | 528 | 307 | 257 |
| 50 | 388 | 278 | 234 |
| 60 | 363 | 257 | 211 |
| 70 | 332 | 237 | 191 |
| | | | |
| Current Practice | 643 | Minimum RO | 416 |

Table 8. Diesel Parts %RO and RO per CWT Benchmark for TBI = 2

| TBI = 2 | Current Practice CWT | Relaxed 5% | Relaxed 10% |
|-------------------------|----------------------|-------------------|-------------|
| Hrs. | 36.2 | 38 | 39.8 |
| %RO | RO | RO | RO |
| 10 | N/A | N/A | 713 |
| 20 | N/A | 615 | 468 |
| 30 | 750 | 455 | 367 |
| 40 | 594 | 363 | 308 |
| 50 | 443 | 328 | 280 |
| 60 | 384 | 300 | 259 |
| 70 | 356 | 274 | 237 |
| | | | |
| Current Practice | 643 | Minimum RO | 416 |

E. FILTERS

Filters are a medium demand item, having an ROP of 116 and an RO of 230. Over a 566-day period, there were 484 customer requisitions for filters, an average of 0.9 arriving at the SMU daily. The average size of each requisition is approximately 2.0. Since 60 days of demand is 108 filters (0.9 requisitions * 2.0 filters * 60 days = 108), any valid SMU policy must meet or exceed this RO.

RO: Taking the current RO at the I MEF SMU as the base-line, we range the values of RO between 46 items (approximately 20% of the current practice) and 276 (120% of current practice).

%RO: Since this parameter is a ROP as %RO, the actual ROPs tested ranged from 5 to 193.

Figures 7 and 8 below display the results from the decision parameters %RO, RO and TBI. Like the diesel parts above, these graphs are very similar to those in the setscrew results. The results indicate that RO can be reduced by 30% of current practice if the ROP is sufficiently high enough. Increasing RO from its minimum level of 46 reduces CWT, but this decrease subsides when RO reaches the level of around 151.

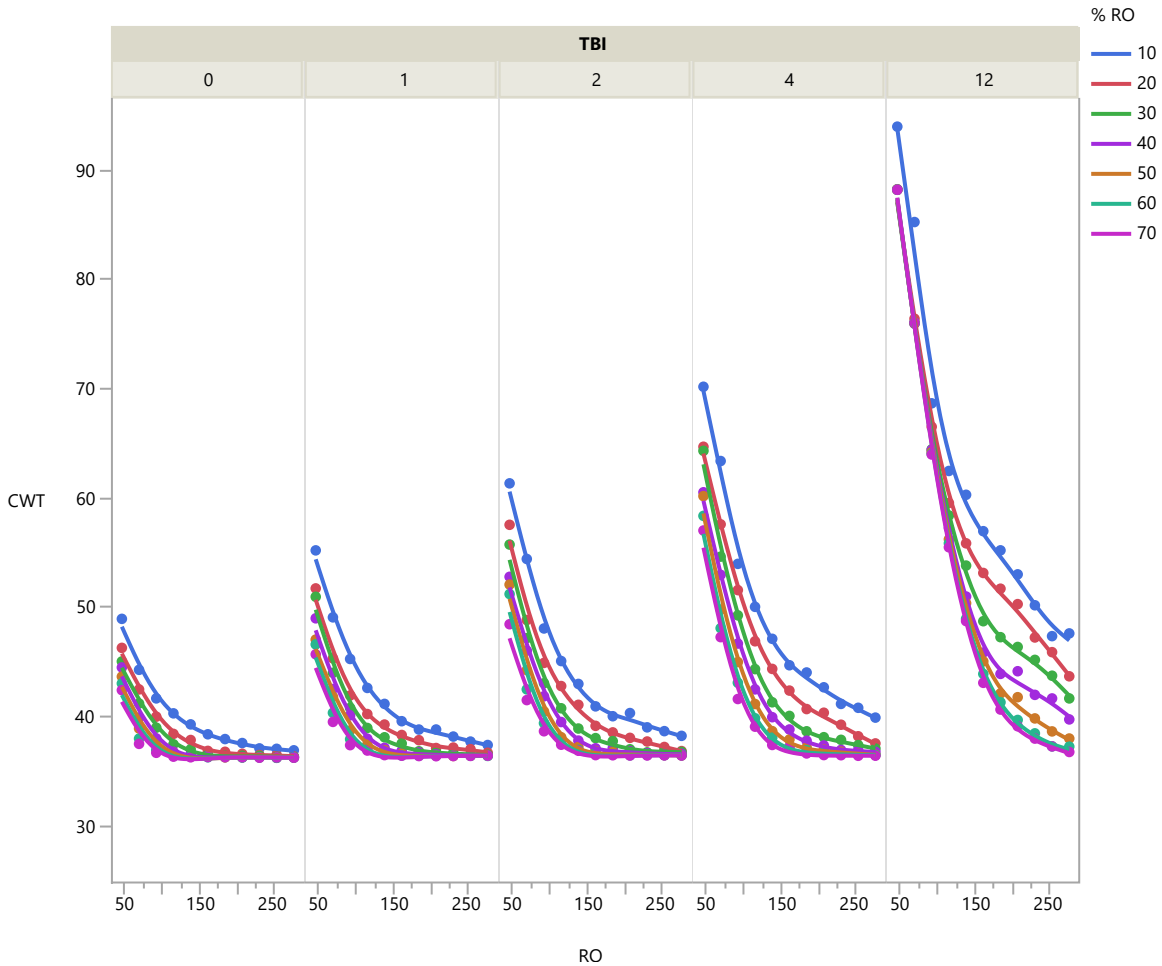


Figure 7. Filter CWT vs. ROP by Inspection Period and by ROP as %RO

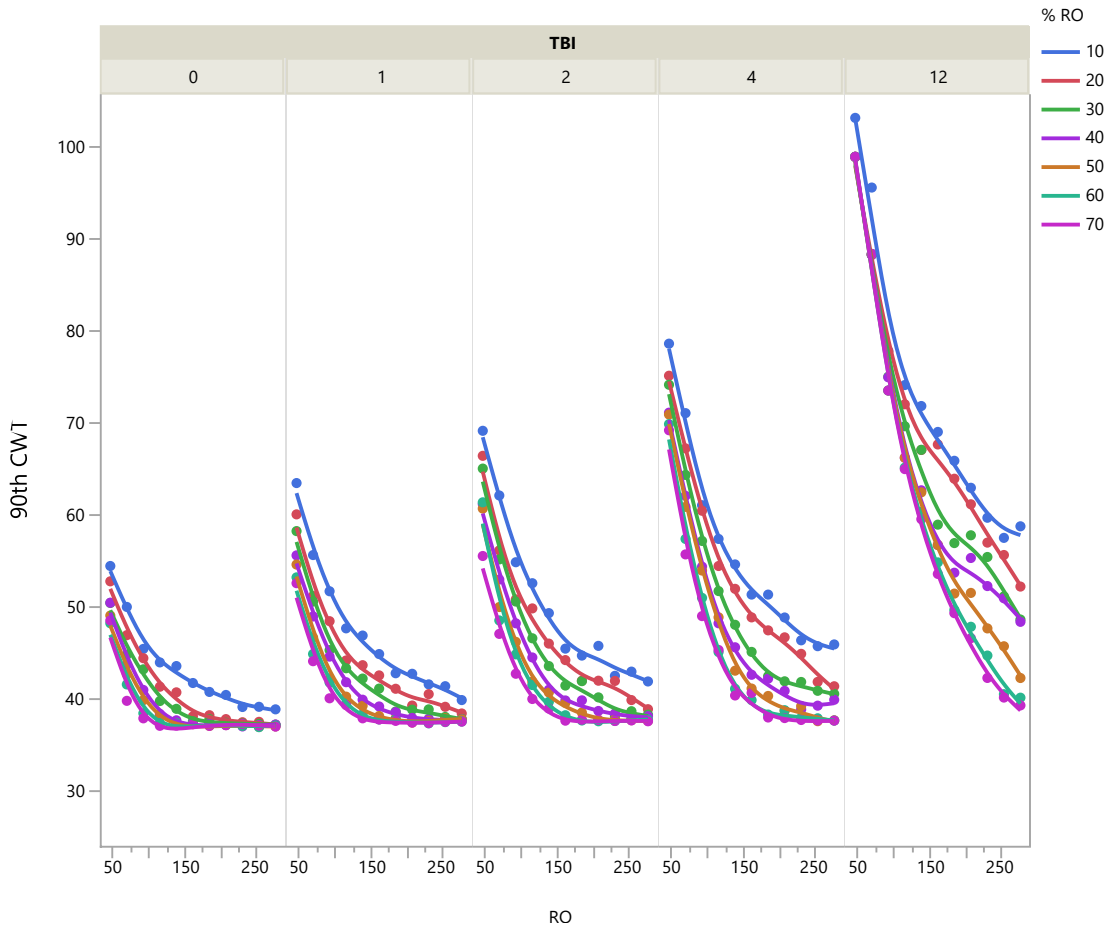


Figure 8. Filter 90th Percentile of CWT vs. ROP by Inspection Period and by ROP as %RO

Tables 9 and 10 show per TBI the combinations of %RO and RO that meet the benchmark CWTs. Like the setscrew RO tables, it is apparent that multiple combinations of %RO and RO exist that both meet benchmark CWTs and RO requirements. The SMU can still utilize the higher percentage ROP policies that are marked in red by increasing the ROs to meet the minimum RO required.

Table 9. Filter %RO and RO per CWT Benchmark for TBI = 1

| TBI = 1 | Current Practice CWT | Relaxed 5% | Relaxed 10% |
|-------------------------|-----------------------------|-------------------|--------------------|
| Hrs. | 36.4 | 38.2 | 40 |
| %RO | RO | RO | RO |
| 10 | N/A | 225 | 153 |
| 20 | N/A | 161 | 119 |
| 30 | N/A | 131 | 104 |
| 40 | N/A | 116 | 95 |
| 50 | 184 | 106 | 86 |
| 60 | 141 | 97 | 79 |
| 70 | 130 | 91 | 74 |
| | | | |
| Current Practice | 230 | Minimum RO | 108 |

Table 10. Filter %RO and RO per CWT Benchmark for TBI = 2

| TBI = 2 | Current Practice CWT | Relaxed 5% | Relaxed 10% |
|-------------------------|-----------------------------|-------------------|--------------------|
| Hrs. | 36.5 | 38.3 | 40.2 |
| %RO | RO | RO | RO |
| 10 | N/A | 270 | 187 |
| 20 | N/A | 192 | 146 |
| 30 | N/A | 150 | 121 |
| 40 | N/A | 131 | 110 |
| 50 | 230 | 116 | 99 |
| 60 | 157 | 108 | 92 |
| 70 | 147 | 103 | 86 |
| | | | |
| Current Practice | 230 | Minimum RO | 108 |

F. BOLTS

Bolts are a low demand item, having an ROP of 22 and an RO of 56. Per the I MEF SMU database over a 436-day period, there were 81 customer requisitions for filters, an average of 0.2 arriving at the SMU daily. The average size of each requisition is approximately 3.5. Since 60 days of demand is 42 bolts (0.2 requisitions * 3.5 bolts * 60 days = 42), any valid SMU policy must meet or exceed this RO.

RO: Taking the current RO at the I MEF SMU as the base-line, we range the values of RO between a very risky value of 11 items (approximately 20% of the current practice) and a conservative value of 67 (120% of current practice).

%RO: Since this parameter is ROP as %RO, the actual ROPs tested ranged from 1 to 47.

Figures 9 and 10 display the results from the decision parameters %RO, RO and TBI. Similar to the other parts in this appendix, these graphs are very similar to those in the setscrew results. The results indicate that RO can be reduced by 30% of current practice if the ROP is sufficiently high enough. Increasing RO from its minimum level of 11 reduces CWT, but this decrease subsides when RO reaches the level of around 40.

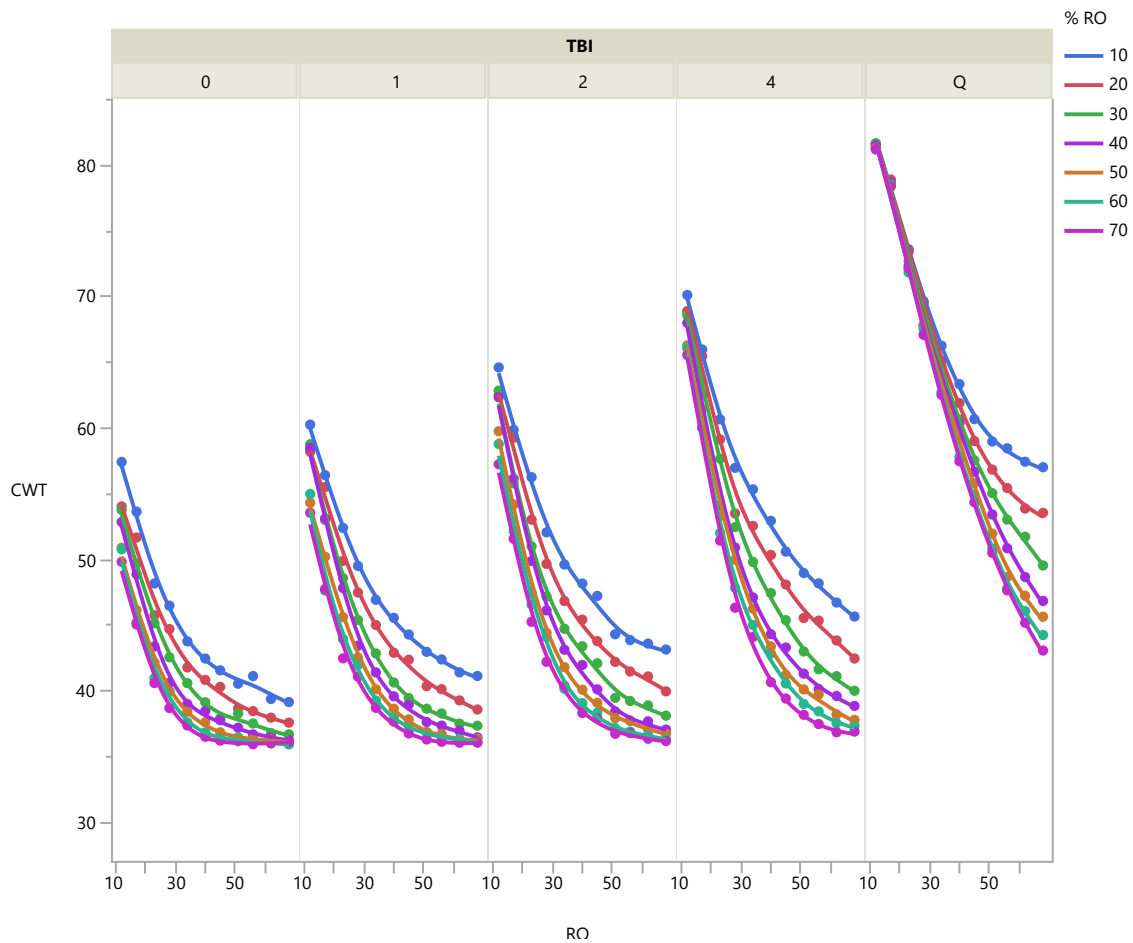


Figure 9. Bolt CWT vs. RO by Inspection Period and by ROP as %RO

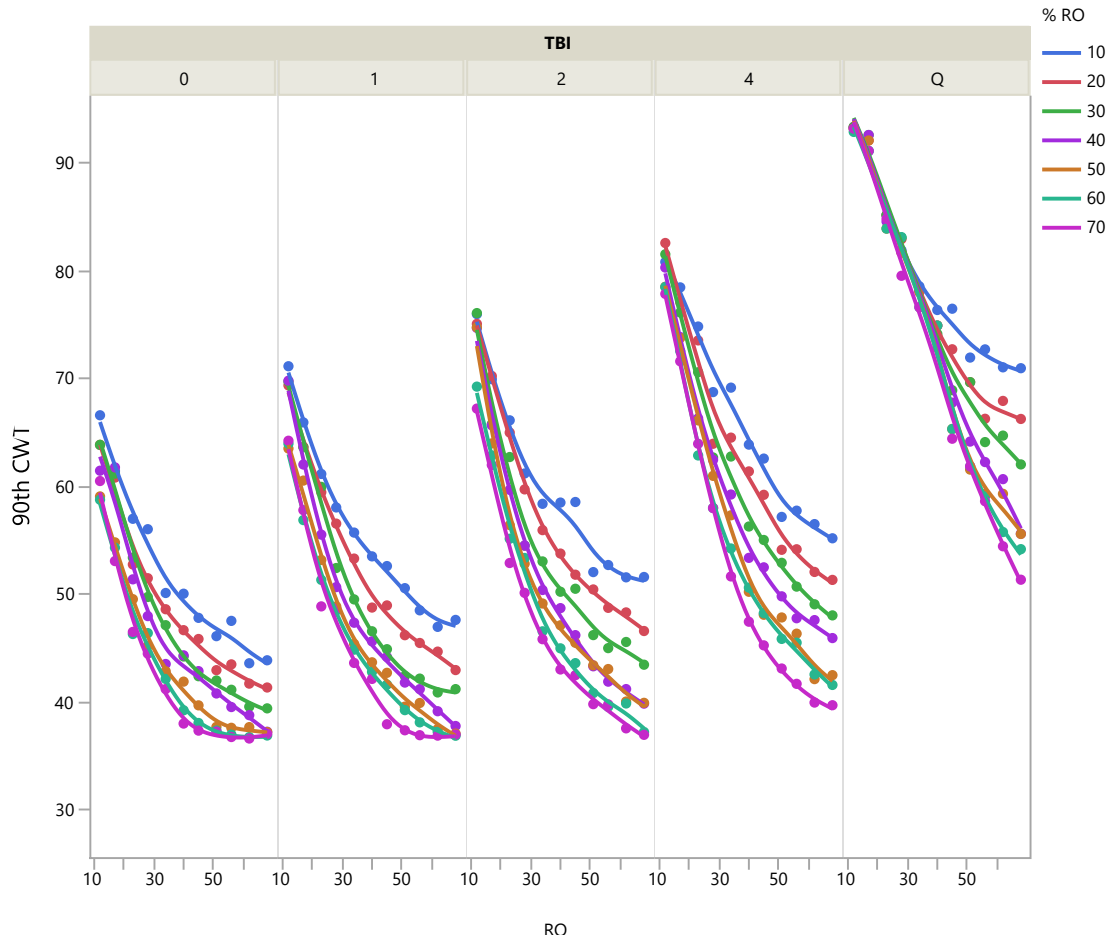


Figure 10. Bolt 90th Percentile of CWT vs. RO by Inspection Period and by ROP as %RO

Tables 11 and 12 show per TBI, the combinations of %RO and RO that meet the benchmark CWTs. Like the setscrew RO tables, it is apparent that multiple combinations of %RO and RO exist that both meet benchmark CWTs and RO requirements. The SMU can still utilize the higher percentage ROP policies that are marked in red by increasing the ROs to meet the minimum RO required.

Table 11. Bolt %RO and RO per CWT Benchmark for TBI = 1

| TBI = 1 | Current Practice CWT | Relaxed 5% | Relaxed 10% |
|-------------------------|----------------------|-------------------|-------------|
| Hrs. | 37.4 | 39.3 | 41.1 |
| %RO | RO | RO | RO |
| 10 | N/A | N/A | 67 |
| 20 | N/A | 62 | 49 |
| 30 | 66 | 47 | 39 |
| 40 | 56 | 42 | 35 |
| 50 | 48 | 38 | 32 |
| 60 | 44 | 35 | 30 |
| 70 | 41 | 33 | 28 |
| | | | |
| Current Practice | 56 | Minimum RO | 42 |

Table 12. Bolt %RO and RO per CWT Benchmark for TBI = 2

| TBI = 2 | Current Practice CWT | Relaxed 5% | Relaxed 10% |
|-------------------------|----------------------|-------------------|-------------|
| Hrs. | 37.9 | 39.8 | 41.7 |
| %RO | RO | RO | RO |
| 10 | N/A | N/A | N/A |
| 20 | N/A | 56 | 56 |
| 30 | N/A | 53 | 45 |
| 40 | 57 | 46 | 39 |
| 50 | 53 | 41 | 35 |
| 60 | 47 | 37 | 32 |
| 70 | 44 | 35 | 30 |
| | | | |
| Current Practice | 56 | Minimum RO | 42 |

G. CAPS

Caps are also a low demand item, having an ROP of 51 and an RO of 130. Per the I MEF SMU database over a 544-day period, there were 105 customer requisitions for caps, an average of 0.2 arriving at the SMU daily. The average size of each requisition is approximately 5.4. Since 60 days of demand is approximately 65 caps (0.2 requisitions * 5.4 caps * 60 days = 64.8), any valid SMU policy must meet or exceed this RO.

RO: Taking the current RO at the I MEF SMU as the base-line, we range the values of RO between a very risky value of 26 items (approximately 20% of the current practice) and a conservative value of 156 (120% of current practice).

%RO: Since this parameter is a ROP as %RO, the actual ROPs tested ranged from 3 to 109.

Figures 11 and 12 below display the results from the decision parameters %RO, RO and TBI. Again, these graphs are very similar to those in the setscrew results. The results indicate RO can be reduced by 30% of current practice if the ROP is sufficiently high enough. Increasing RO from its minimum level of 26 reduces CWT, but this decrease subsides when RO reaches the level of around 91.

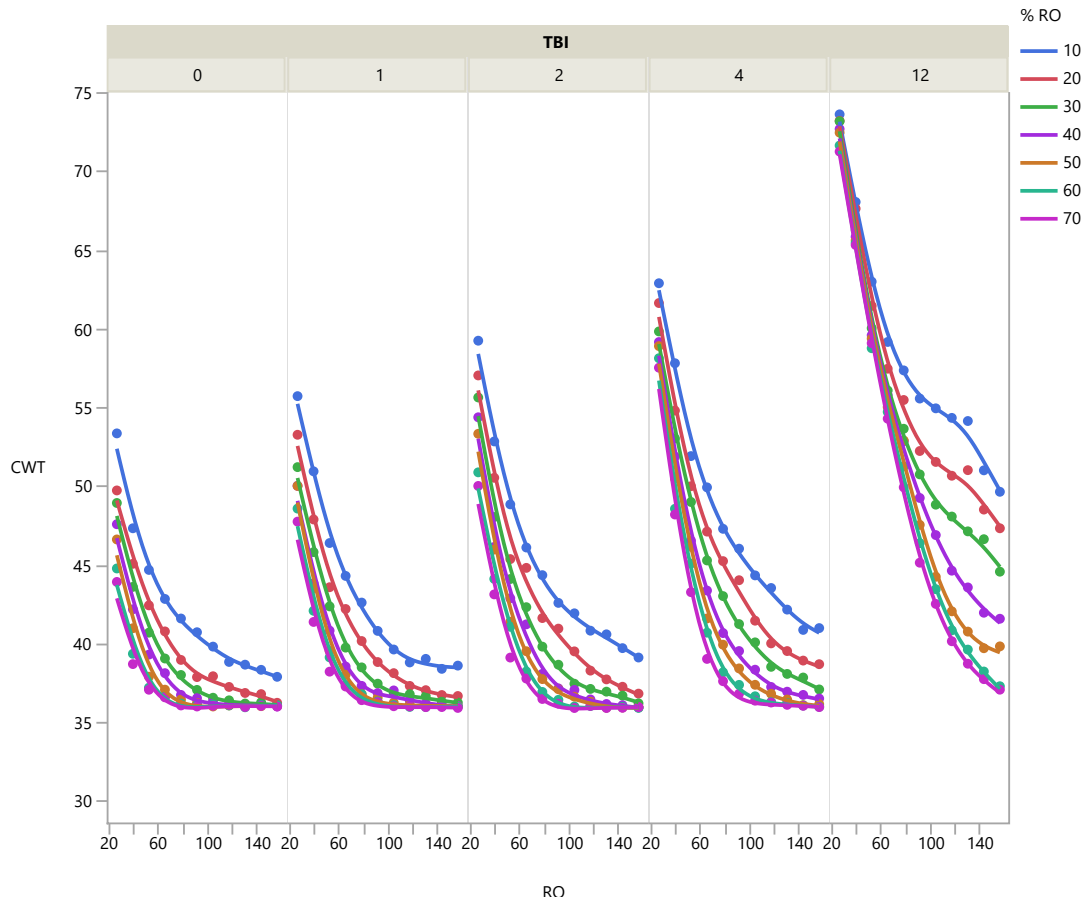


Figure 11. Cap CWT vs. ROP by Inspection Period and by ROP as %RO

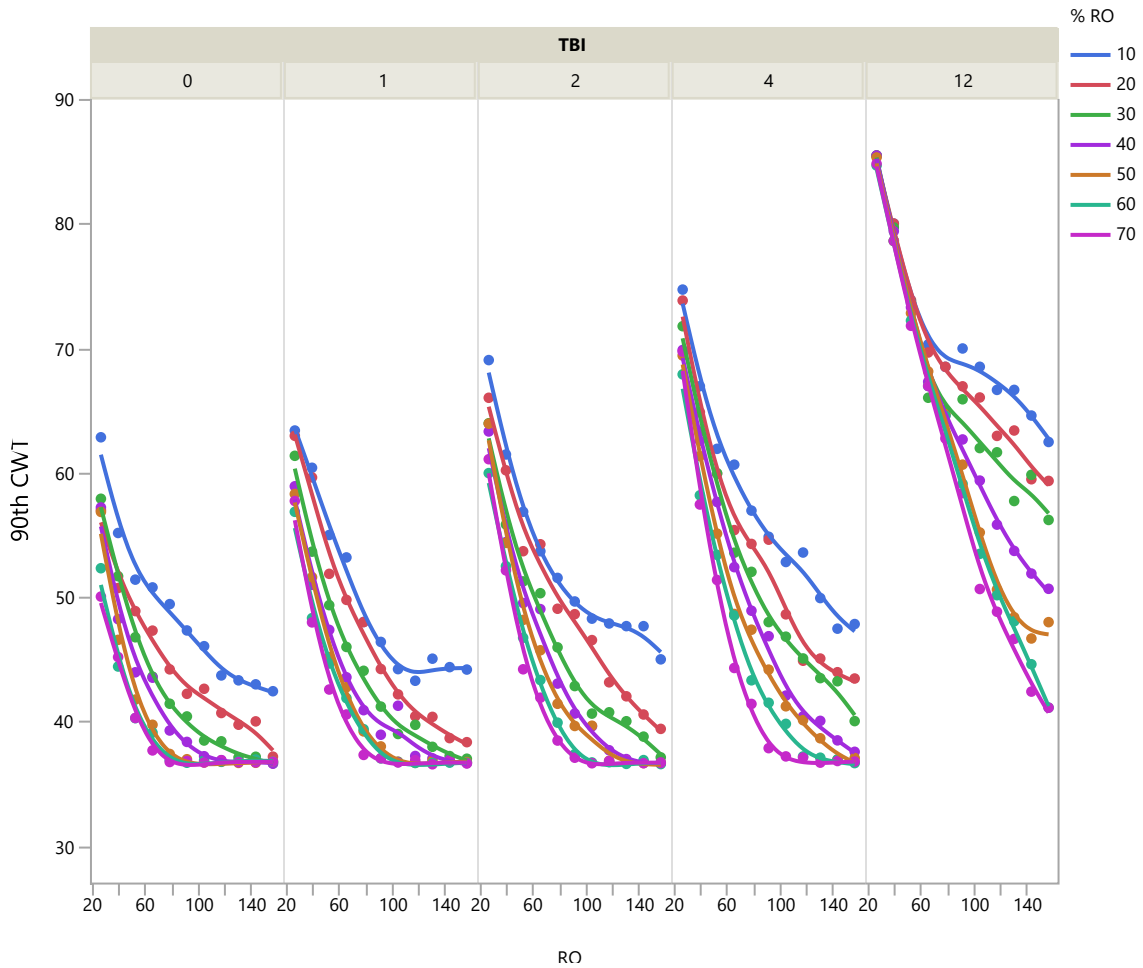


Figure 12. Cap 90th Percentile of CWT vs. ROP by Inspection Period and by ROP as %RO

Tables 13 and 14 show per TBI, the combinations of %RO and RO that meet the benchmark CWTs. Like the setscrew RO tables, it is apparent that multiple combinations of %RO and RO exist that both meet benchmark CWTs and RO requirements. The SMU can still utilize the higher percentage ROP policies that are marked in red by increasing the ROs to meet the minimum RO required.

Table 13. Cap %RO and RO per CWT Benchmark for TBI = 1

| TBI = 1 | Current Practice CWT | Relaxed 5% | Relaxed 10% |
|-------------------------|-----------------------------|-------------------|--------------------|
| Hrs. | 36.2 | 38 | 39.8 |
| %RO | RO | RO | RO |
| 10 | N/A | N/A | 102 |
| 20 | N/A | 104 | 81 |
| 30 | N/A | 82 | 67 |
| 40 | 132 | 71 | 59 |
| 50 | 97 | 66 | 55 |
| 60 | 89 | 62 | 52 |
| 70 | 83 | 58 | 49 |
| | | | |
| Current Practice | 130 | Minimum RO | 65 |

Table 14. Cap %RO and RO per CWT Benchmark for TBI = 2

| TBI = 2 | Current Practice CWT | Relaxed 5% | Relaxed 10% |
|-------------------------|-----------------------------|-------------------|--------------------|
| Hrs. | 36.2 | 38 | 39.8 |
| %RO | RO | RO | RO |
| 10 | N/A | N/A | 142 |
| 20 | N/A | 125 | 100 |
| 30 | N/A | 98 | 79 |
| 40 | 130 | 83 | 69 |
| 50 | 118 | 76 | 63 |
| 60 | 93 | 69 | 58 |
| 70 | 84 | 63 | 53 |
| | | | |
| Current Practice | 130 | Minimum RO | 65 |

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