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UNITED STATES MARINE CORPS MOTOR TRANSPORT MECHANIC-TO-EQUIPMENT RATIO

by

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March 2018

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This thesis provides a proof of concept for a method that relates changes in the number of Marines available to perform maintenance to the average time motor transport equipment remains in maintenance at the organizational command level. This thesis uses a discrete event simulation model of the workflow of first- and second-echelon maintenance actions at an organizational level ground command, less supply support. While the author models the maintenance systems based upon ground commands from First Marine Expeditionary Force (I MEF), the model is applicable to a variety of such commands across the Marine Corps. The method includes determining a range of staff levels to include in the optimization model using the workload evaluation method developed by Rex E. Nelsen in 2010. The optimization model produces outputs that allow planners to select optimal staffing levels based upon the objective function and constraints of the model. After analyzing the outputs of the primary and secondary responses, a staffing level is selected and applied to a single experiment that allows for assessment of risk of not achieving the objective. Inter-arrival time, processing time, work schedule, entities per arrival, and number of maintainers represent the primary factors of the model.

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UNITED STATES MARINE CORPS MOTOR TRANSPORT MECHANIC-TO-EQUIPMENT RATIO

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This thesis provides a proof of concept for a method that relates changes in the number of Marines available to perform maintenance to the average time motor transport equipment remains in maintenance at the organizational command level. This thesis uses a discrete event simulation model of the workflow of first- and second-echelon maintenance actions at an organizational level ground command, less supply support. While the author models the maintenance systems based upon ground commands from First Marine Expeditionary Force (I MEF), the model is applicable to a variety of such commands across the Marine Corps. The method includes determining a range of staff levels to include in the optimization model using the workload evaluation method developed by Rex E. Nelsen in 2010. The optimization model produces outputs that allow planners to select optimal staffing levels based upon the objective function and constraints of the model. After analyzing the outputs of the primary and secondary responses, a staffing level is selected and applied to a single experiment that allows for assessment of risk of not achieving the objective. Inter-arrival time, processing time, work schedule, entities per arrival, and number of maintainers represent the primary factors of the model.

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LIST OF ACRONYMS AND ABBREVIATIONS

1st TSB	First Transportation Support Battalion
5/11	Fifth Battalion, Eleventh Marine Regiment (5th Bn,A 11th Mar)
ACE	aviation combat element
ALIS	automated logistics information system
CMC	Commandant of the Marine Corps
DC	Deputy Commandant
DC, I&L	United States Marine Corps Deputy Commandant for Installations and Logistics
FLMMP	field-level maintenance management policy
FRAGO	Fragmentary Order
GCE	ground combat element
HIMARS	high mobility artillery rocket system
HQMC	Headquarters Marine Corps
I MEF	First Marine Expeditionary Force
LCE	logistics combat element
MAGTF	Marine air ground task force
MARADMIN	Marine administrative message
MARCORLOGCOM	Marine Corps Logistics Command
MARCORSYSCOM	Marine Corps Systems Command
MC	mission capable
MCO	Marine Corps Order
MDR	master data repository
MEF	Marine expeditionary force
MHET	medium heavy equipment transporter
MMRC	Marine Corps maintainers requirement criteria
MOS	military occupational specialty
MTVR	medium tactical vehicle replacement
MWSS-371	Marine Wing Support Squadron Three Seven One
NCO	non-commissioned officer
NMC	not mission capable
NMCM	not mission capable maintenance

NMCS	not mission capable supply
O/H	on-hand
PEI	principle end item
PMCS	preventive maintenance checks and services
POL	petroleum, oils, lubricants
QCNCO	quality control non-commissioned officer
TAMCN	table of authorized materiel control number
TLCM–OST	Total Life-Cycle Management Operational Support Tool
T/O	Table of Organization
T/O&E	Table of Organization and Equipment
UIC	unit identification code
USMC	United States Marine Corps

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I. INTRODUCTION

> We continue to accelerate our purchases of new systems while maintaining current equipment. Right now, our "ready bench" is not as deep as we need it to be for crises and contingencies. As we address our readiness shortfalls, we must simultaneously modernize our Corps. This is a tough, but necessary balancing act. We must be prepared to fight today *and* in the future.
>
> —General Robert B. Neller
> 37th Commandant of the Marine Corps
> (Headquarters Marine Corps, 2017, pp. 2–3)

A. OVERVIEW

The 37th Commandant of the Marine Corps (CMC) published a fragmentary order (FRAGO) identifying five areas critical to achieving our future success (Headquarters Marine Corps, 2016). Readiness made number two on the Commandants' list of focus areas. Although the scope of readiness identified by the CMC extends beyond equipment, the emphasis the CMC places on equipment readiness in the *Message to the Force 2017: "Seize the Initiative,"* the *U.S. Marine Corps Service Strategy 2016*, and other documents published that provide the way ahead for the Marine Corps make it clear that readiness is of the highest concern to the Enterprise. This thesis provides a method to determine staffing goals at the organizational level for maintenance personnel within the United States Marine Corp motor transport community.

B. PROBLEM

In the *2017 CMC Institutional-Level Task List for Deputy Commandants and Commanders*, the 37th CMC assigned multiple tasks to each Marine Corps Deputy Commandant (DC). Each task supports the successful achievement of the five objectives identified in his FRAGO. The Commandant tasked the Deputy Commandant for Installations and Logistics (DC, I&L) to "reinforce and sustain ground equipment readiness efforts across the Marine Corps" and to "look for areas of improvement within each ground unit” (Headquarters Marine Corps, 2017, p. 5). This thesis provides an opportunity for the Enterprise to improve the manpower requirements development process at the program acquisition level for new programs of record. This in turn improves the table of organization (T/O) development process, which affects ground equipment readiness.

Currently, there exists little to no quantitative rigor applied to justify the number of maintenance Marines on the T/O at the organizational level throughout the Marine Corps. Existing publications (i.e., *Marine Corps Order (MCO) 5320.5E Personnel Requirements Manual*) employ algorithms that are wildly outdated (July 1983) or otherwise overly complicated. As such, requirements decisions tend to be made on the basis of other criteria, such as status quo, personal experience or other non-standard methods.

C. RESEARCH OBJECTIVE

The desired end state is to provide a proof of concept for a manpower planning method that relates changes in the number of Marines available to perform maintenance to materiel readiness of motor transport equipment at the organizational command level. This thesis uses a discrete event simulation model of the workflow of first and second echelon maintenance actions at an organizational level ground command, less supply support. While the author models the maintenance systems based upon ground commands from First Marine Expeditionary Force (I MEF), the model will be generalizable to a wide variety of such commands across the Marine Corps.

D. METHODS

To as thoroughly as possible achieve the research objective presented in this thesis, I employ several methods to gain insight into the topic and create the requisite method. First, I survey existing doctrine and publications within the Marine Corps and from other United States military services to identify current methods used to determine motor transport mechanic manpower requirements. Next, I conduct a review of relevant academic literature to determine what analytical techniques, if any, best support analysis of the data used in this thesis. Finally, I interview several motor transport maintenance officers and maintenance chiefs to ensure the simulation model closely resembles the realities present within the current motor transport maintenance system. I develop a discrete event simulation model of the workflow of maintenance actions at an organizational level ground command. In addition to developing a simulation model, I use the workload evaluation method developed by Nelsen (2010) to develop alternative staffing levels to the current table of organization (T/O) levels for inclusion into the model experiments.

E. SCOPE AND LIMITATIONS

This study focuses on mechanic-to-equipment ratio within the United States Marine Corps motor transport community at the organizational level. The study is further restricted to I MEF ground commands possessing motor transport equipment. Both reportable and non-reportable equipment are included in the analysis of this thesis. Two factors cause a weapon system or item to remain in a not mission capable (NMC) status, supply shortage or maintenance capacity shortage. The simulation model in this thesis only includes the element of maintenance capacity shortage. Provided more time, the author would broaden the scope of the study to the intermediate and organizational levels across each of the three active duty Marine Expeditionary Forces (MEF) and add the element of supply support to the model.

Measurement error bias exists within the data set for some of the variables such as military labor hours performed on an equipment set. Some observations within the data set show “0” for man-hours and/or labor hours, indicating erroneous data entry or an errant entry caused by the system. Other limitations to this thesis exist by way of time. Only the past five to seven years of maintenance data exist for research, decreasing the analytical power when conducting analysis of past and current T/Os to determine their effects on the average time motor transport equipment spends in the maintenance system.

F. ORGANIZATION OF STUDY

This thesis consists of six chapters. Chapter II provides background on the Marine Corps ground equipment maintenance system as well as a brief literature review of studies similar to this thesis. Chapter III discusses methods used by the author to address the primary research objective. Chapter IV provides information on the data used in this thesis to support analysis. Chapter V provides results of the simulation analysis. The final Chapter

VI summarizes the thesis, provides conclusions, and recommends follow-on action and research.

II. BACKGROUND AND LITERATURE REVIEW

A. BACKGROUND

1. USMC Ground Equipment Maintenance

In this section, the author discusses three primary aspects of Marine Corps ground equipment maintenance. First, the author provides background information on the ground equipment maintenance program. Next, the author discusses ground equipment readiness. Finally, the author describes the motor transport maintenance system.

a. Ground Equipment Maintenance Program

The DC, I&L issued Marine administrative message (MARADMIN) 159/13 to establish new policy regarding levels of maintenance and source maintenance and recovery codes that promoted a more responsive ground equipment maintenance system. This MARADMIN foreshadowed the establishment of the ground equipment maintenance program published in January 2014 as *MCO 4790.25 Ground Equipment Maintenance Program*.

Marine Corps Order 4790.25 defines maintenance as the “recovery, assessment, troubleshooting, repair, replacement, overhaul, servicing, inspection, and corrosion prevention functions that preserve, or restore, ground equipment to a serviceable condition in which it is capable of performing the tasks as defined in each platform or weapon system's configured specifications” (Headquarters Marine Corps, 2014, 7–8). This thesis focuses on the repair portion of this definition. The order highlights the necessity for constant improvement in maintenance practices to ensure maintenance activities within the Marine Corps remain aligned with changing defense strategies and operational concepts. The Ground Equipment Maintenance Program forms the framework from which maintenance management policy is created.

b. Ground Equipment Maintenance Management

Marine Corps Order 4790.2 Field Level Maintenance Management Policy provides policy to commanders on effective maintenance management for ground equipment. This order emphasizes the high impact maintenance management has on equipment readiness. Various ground maintenance sections participate in the maintenance management process through maintenance actions defined in the previous paragraph. Chapter 3, Field Maintenance Production, of MCO 4790.2 provides details of the system modeled in this thesis. The elements of the maintenance system seen in the simulation model include the four maintenance phases. The nature of the data facilitates simulating maintenance cycle time, preventive maintenance checks and service (PMCS) maintenance as well as corrective maintenance (CM). A more detailed description of the system applicable to a motor transport section is provided in Chapter III of the thesis.

2. Ground Equipment Readiness

The following subsections describe ground equipment readiness. The two subsections define ground equipment readiness and discuss reporting of ground equipment readiness.

a. Ground Equipment Readiness Defined

The Marine Corps captures readiness in terms of three ratings. The “S” rating reflects readiness relative to supply/equipment possessed. The “R” rating reflects readiness relative to the maintenance/equipment condition. The “MR” rating reflects readiness relative to overall materiel readiness. These three ratings apply to a command’s overall equipment possessed, separate equipment commodities, and individual table of authorized materiel control number (TAMCN) items. A commander’s understanding of the three ratings allow him/her to prioritize funding for supply shortfalls based upon the “S” rating and/or maintenance shortfalls based upon the “R” rating. Understanding how the “S” and “R” ratings impact a command’s overall “MR” rating assists commanders in pursuing a balanced approach to increasing operational readiness. For the purpose of this thesis, the author focuses on the “R” rating and the readiness terms associated with it.

Two primary condition status codes describe the materiel condition of a Marine Corps ground command’s equipment. The MC equipment condition code indicates that an item or weapon system performs its specified mission. The NMC equipment condition code indicates that an item or weapon system fails to perform its specified mission. To indicate where shortfalls occur in returning a weapon system or item back to a MC status, two sub-categories under NMC assist with focusing a maintenance officer and/or maintenance chief’s attention where needed most. Not mission capable maintenance (NMCM) indicates that a shortfall in maintenance capacity exists causing a weapon system or item to not perform its specified mission. Not mission capable supply (NMCS) indicates maintenance delays due to supply shortage, also causing an item or weapons system to not perform its specified mission. With a focus on maintenance personnel and actions, the simulation model in this thesis excludes delays in a weapon system returning to a MC status due to NMCS.

b. Reporting Ground Equipment Readiness

Reporting ground equipment readiness serves as great of a purpose as performing maintenance actions in support of ground equipment readiness. The Global Combat Support System–Marine Corps (GCSS–MC) serves as the primary system to report ground equipment readiness. The system allows maintenance personnel to record maintenance actions performed on a weapon system or equipment item at each maintenance phase. Data input into the system remains indefinitely, which allows for retrieval of archived data for data analysis. Reports update in real-time on GCSS–MC allowing for instant updates to equipment status reports after data entry. The United States Marine Corps Concepts & Programs website provides the following description for GCSS–MC:

> GCSS–MC/Life–Cycle Management (GCSS–MC/LCM) family of systems serves as primary technology enabler for the Marine Corps Logistics Modernization strategy. GCSS-MC/LCM provides the backbone for all logistics information required by the Marine Forces and the Supporting Establishment. The core for GCSS-MC/LCM Increment 1 is a modern, commercial-off-the-shelf enterprise resource planning software (Oracle e-Business Suite). The Increment 1 design focused on enabling the warfighter to operate while deployed with reach back from the battlefield. Increment 1 replaced 5 legacy supply and maintenance information technology systems and currently supports ~22,000 users world-wide. (“U.S. Marine Corps concepts & programs,” 2017)

With such a system, commanders and maintenance staff personnel possess the ability to exercise greater command and control while greatly increasing situational awareness and reducing the decision cycle time during logistics planning.

A more intuitive, user-friendly tool available to commanders and maintenance staff personnel is Total Life-Cycle Management Operational Support Tool (TLCM-OST). It provides faster access to reports tailored for a quick review of equipment readiness in terms of “S,” “R,” and “MR” ratings for commanders and maintenance staff personnel.

Readiness reports found on TLCM-OST come from the master data repository (MDR). Marine Corps Logistics Command (MARCORLOGCOM) manages the MDR where unfiltered data entered into GCSS-MC feeds into it (C. J. Hall, *Master data repository: Getting started*, personal communication, November 21, 2017).

3. Motor Transportation Maintenance System

This section of the thesis serves several purposes. First, the author describes the organizational structure (E5 and below) of three I MEF ground commands’ Motor Transport sections. The commands each come from one of the combat elements of the Marine air ground task force (MAGTF). From the aviation combat element (ACE) the author chose Marine Wing Support Squadron Three Seven One (MWSS-371) as a command to analyze and determine the appropriate quantity of motor transport mechanics. From the logistics combat element (LCE), the author selected First Transportation Support Battalion (1st TSB). For the ground combat element (GCE), the author uses Fifth Battalion, Eleventh Marine Regiment (5th Bn, 11th Mar (a.k.a. 5/11)). Next, the author describes the maintenance production process per *MCO 4790.2*. Integrated into the discussion of the motor transport maintenance system is a discussion of the system within the context of the commands analyzed. The author interviewed the motor transport maintenance officer and/or chief of each of the three commands to gain an understanding of their respective local procedures for each maintenance phase.

a. Motor Transport Section Organizational Structure

The Motor Transport organizational structure of the commands representing the ACE, GCE and LCE in this thesis differ. Common to each are the non-active maintenance billets required by the Field Supply and Maintenance Analysis Office (FSMAO). Prior to discussing the commands' structure, the following paragraphs describe the mission for each command and the equipment used to support it. This provides context to the problem this thesis attempts to address.

(1) MWSS-371

Marine Wing Support Squadron Three Seven One is an aviation ground command within the ACE. Its mission statement listed on the table of T/O&E sounds simple when read:

> a. Mission. Provide aviation ground support to enable a Marine aircraft group (MAG) or a composite MAG to conduct expeditionary operations. (Headquarters Marine Corps, 2017, p.1)

However, the tasks that follow begin to reveal the amount of effort required to accomplish its mission. To complete these tasks, MWSS-371 possesses more than 30 category "D" or "Delta" TAMCN items, totaling in excess of 200 individual end items. Figures 1–3 provide a visual of the types and sizes of equipment employed by this command critical to providing aviation ground support.

Figure 1. MK31/MK31A1 Tractor: Prime Mover for MK970/AMK970 5,000 Gallon Refueler. Source: Program Executive Officer, Land Systems (PEO LS) Marine Corps (2016).

Figure 2. A/S32P-19A: Aircraft Crash and Rescue Operations. Source: PEO LS Marine Corps (2016).

Figure 3. MK28/MK28A1: Large Capacity Troop and Medium Cargo Carrier. Source: PEO LS Marine Corps (2016).

The command's maintenance section has an authorized strength of 18 out of 19 motor transport mechanics, military occupational specialty (MOS) 3521. A simple ratio reveals an 11-to-1 equipment-to-maintainer ratio for MWSS-371's motor transport maintenance section. This ratio may suffice. However, the command's motor transport maintenance section has use of, on average, a third of its authorized strength to conduct vehicle maintenance (Chief Warrant Officer Collum, interview with author, January 17, 2018). Figure 4 displays the organizational structure of MWSS-371's motor transport maintenance platoon per the command's T/O&E report, current as of 30 August 2017. Missing from the official organizational structure are two quality control non-commissioned officers (QCNCOs), one platoon sergeant, and one shop chief all filled by sergeants and below. The portion of structure within the red box emphasizes structure and rank of interest in this thesis.

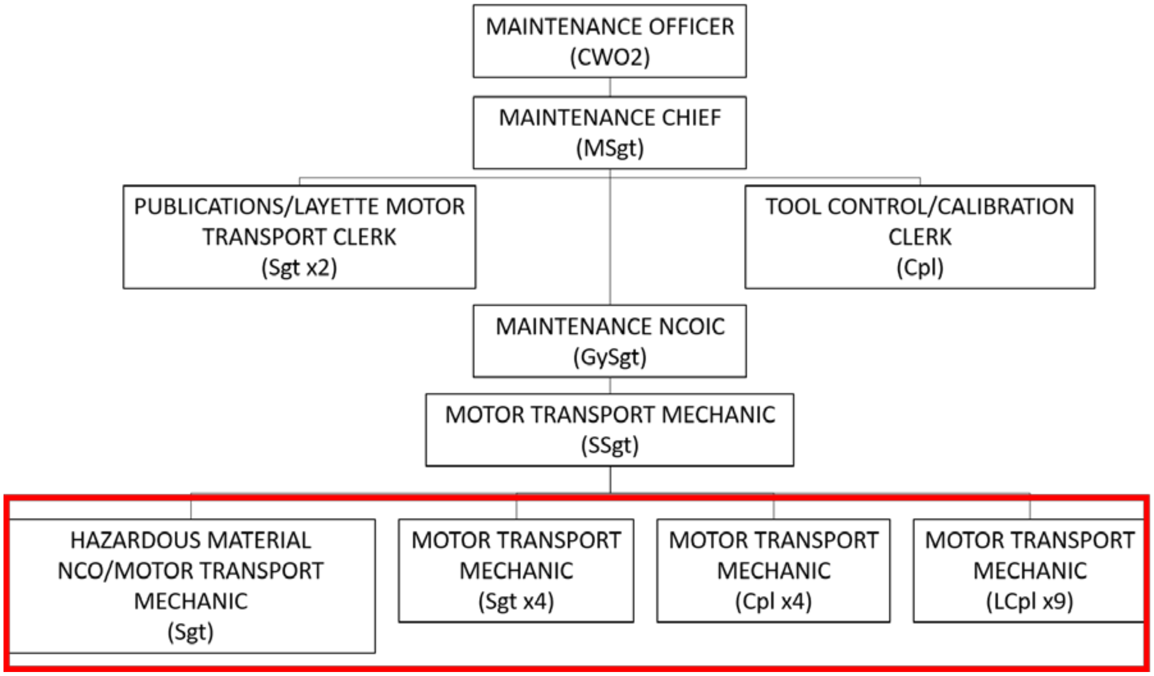


Figure 4. MWSS-371 Motor Transport Maintenance Platoon

(2) Fifth Battalion, Eleventh Marine Regiment (5th Bn, 11th Mar)

Fifth Battalion, Eleventh Marines is an artillery rocket battalion within the GCE. Its assigned mission is to provide timely and accurate rocket/missile fires in support of a MAGTF (Headquarters Marine Corps, 2017). The command possesses a little less than 30 category "D" or "Delta" TAMCN items, totaling in excess of 200 individual end items (TLCM-OST, 2018). Figures 5 and 6 provide a visual of the types and sizes of equipment employed by this command critical to providing fires support to the MAGTF.

Figure 5. Medium Tactical Vehicle Replacement (MTVR) MK38 HIMARS Re-Supply Trailer. Source: POE LS Marine Corps (2016).

Figure 6. MTVR AMK37 HIMARS Re-Supply Vehicle. Source: POE LS Marine Corps (2016).

Fifth Battalion, Eleventh Marines motor transport maintenance organizational structure differs drastically from that of MWSS-371, in which all mechanics structurally and physically fall under direct control of the squadron motor transport maintenance officer and chief. The command possesses multiple T/O&E reports. Also, 5th Bn, 11th Mar motor transport section falls under the command's service platoon. Its motor transport maintenance section is embedded within the command's motor transport section. Finally, each battery within 5th Bn, 11th Mar possesses its own motor transport automotive maintenance technicians, as listed on the T/O&E report. Though on the T/O&E the mechanics are disbursed, the battery motor transport maintenance officer exercises control over all mechanics. Of the 39 automotive maintenance technicians on the morning report, the command experiences an average on-hand (O/H) rate of approximately 20 technicians. Of the 20 O/H, only 12 perform actual vehicle maintenance on average (Chief Warrant Officer Palmer, interview with author, January 17, 2018). Figures 7–11 provide a visual of 5th Bn, 11th Mar motor transport section's organizational structure.

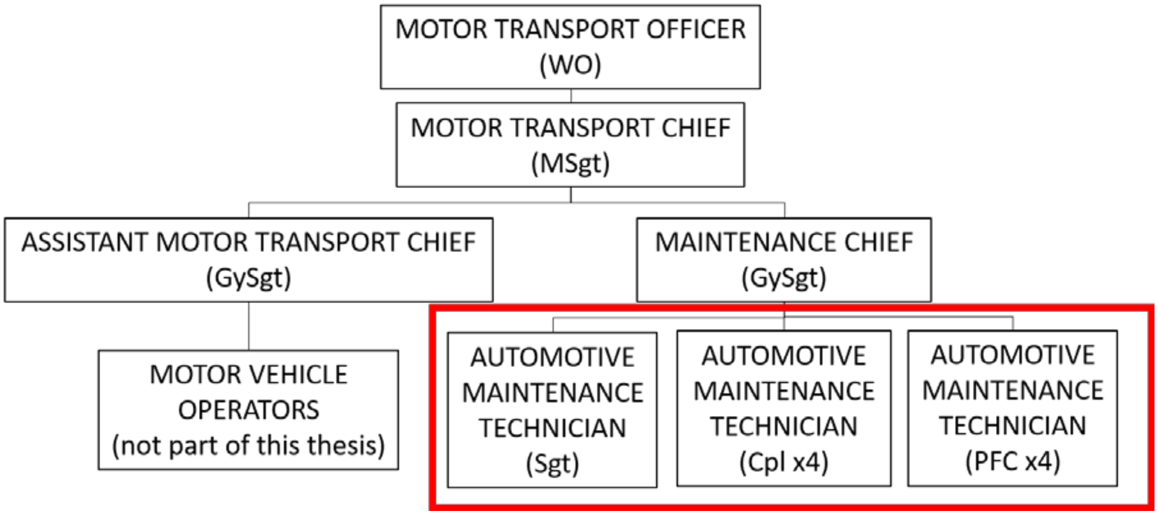


Figure 7. 5th Bn, 11th Marine Headquarters Battery Motor Transport Maintenance Section

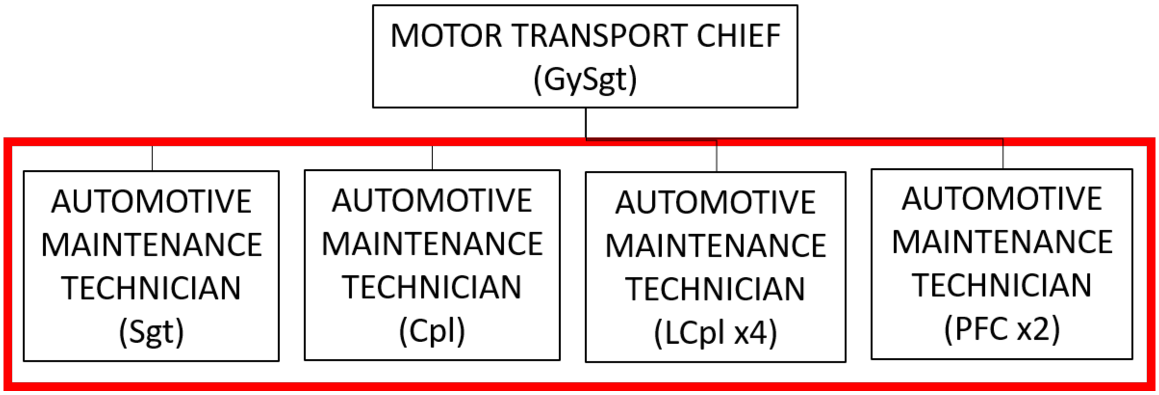


Figure 8. 5th Bn, 11th Mar Rocket Battery R Motor Transport Maintenance Section

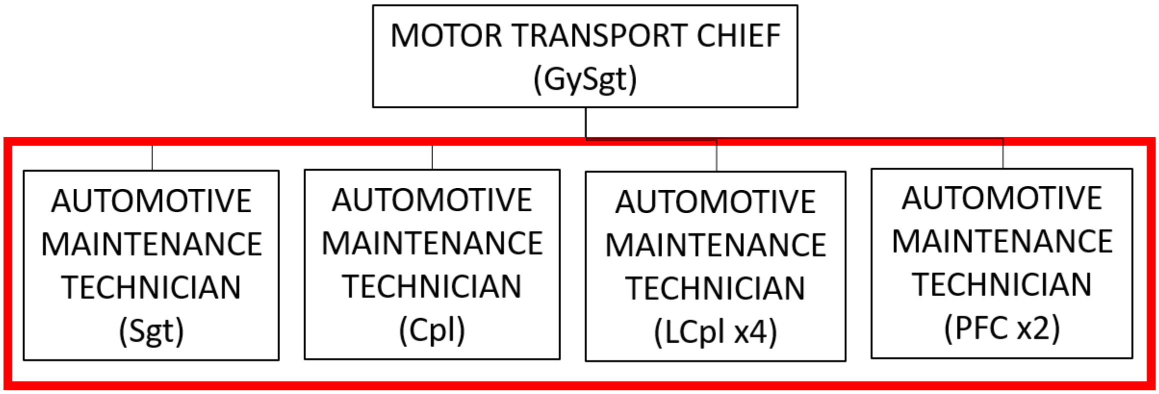


Figure 9. 5th Bn, 11th Mar Rocket Battery S Motor Transport Maintenance Section

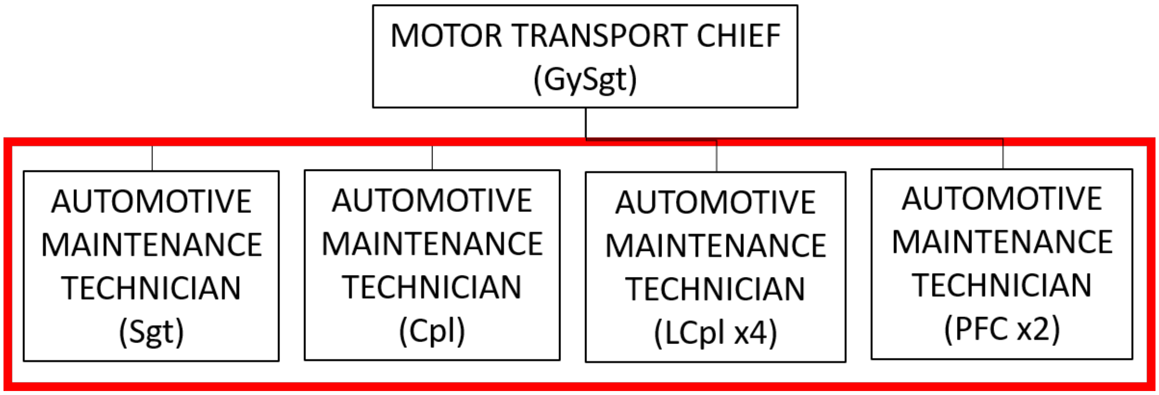


Figure 10. 5th Bn, 11th Mar Rocket Battery T Motor Transport Maintenance Section

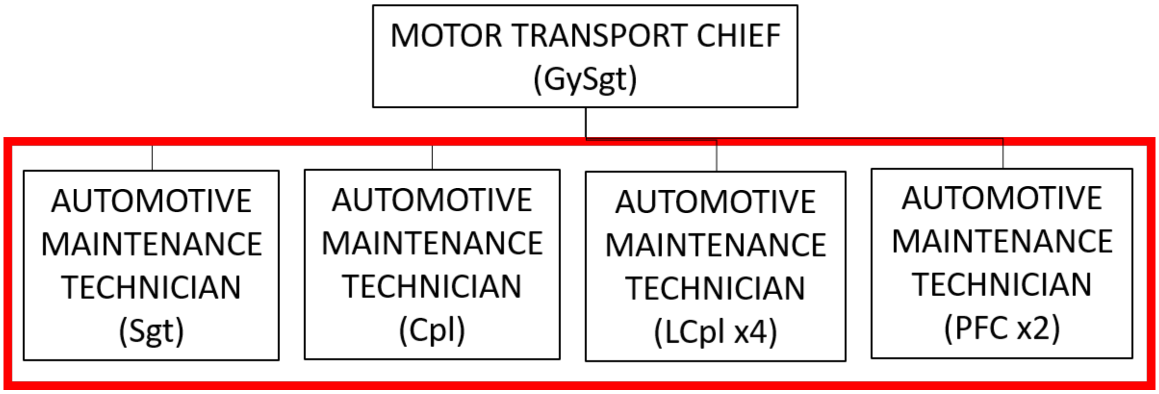


Figure 11. 5th Bn, 11th Mar Rocket Battery Q Motor Transport Maintenance Section

(3) 1st TSB

As the command's name suggests, 1st TSB supports all things transportation. This includes land, air and sea modes of transportation. This thesis focuses on its land operations and the equipment used to support them. Per unit identification code (UIC) M28410's T/O&E report, dated 30 August 2017, 1st TSB is given the mission to:

"Provide transportation and throughput support for the MEF to facilitate the distribution of personnel, equipment, and supplies by air, ground, and sea." (Headquarters Marine Corps, 2017, p.1)

This command represents the LCE of the MAGTF in this thesis. The MAGTF commander's ability to rapidly flow forces to and from combat theaters depends upon 1st TSB's ability to support with motor transport assets in a ready condition. The command possesses a little less than 40 category "D" or "Delta" TAMCN items, totaling in excess of 400 individual end items (Headquarters Marine Corps, 2018). Figures 12 and 13 provide a visual of the types and sizes of equipment employed by this command critical to providing transportation support to the MAGTF.

Figure 12. MKR16/AMKR16 Tractor. Transports Heavy Cargo when Trailer Attached. Source: POE LS Marine Corps (2016).

Figure 13. M870A2E1 Medium Heavy Equipment Transporter (MHET). Used in conjunction with MKR16. Source: POE LS Marine Corps (2016).

First Transportation Support Battalion receives the largest allocation of Motor Transport automotive mechanics among the commands analyzed in this thesis. This command also possesses multiple T/O&E reports vice one consolidated report. Motor Transport maintenance falls under the Support Company organizational structure. Headquarters Marine Corps authorizes more than 50 organizational automotive mechanics per the authorized strength report indicator on the T/O&E report (Total Force Structure Division, 2017). During an interview with 1st TSB's motor transport maintenance officer (Chief Warrant Officer Tilley, interview with author, January 17, 2018), he indicated that approximately 24 Marines on average perform maintenance actions without interruption. Figure 14 illustrates the organizational structure of 1st TSB's motor transportation maintenance section, which exists within Support Company.

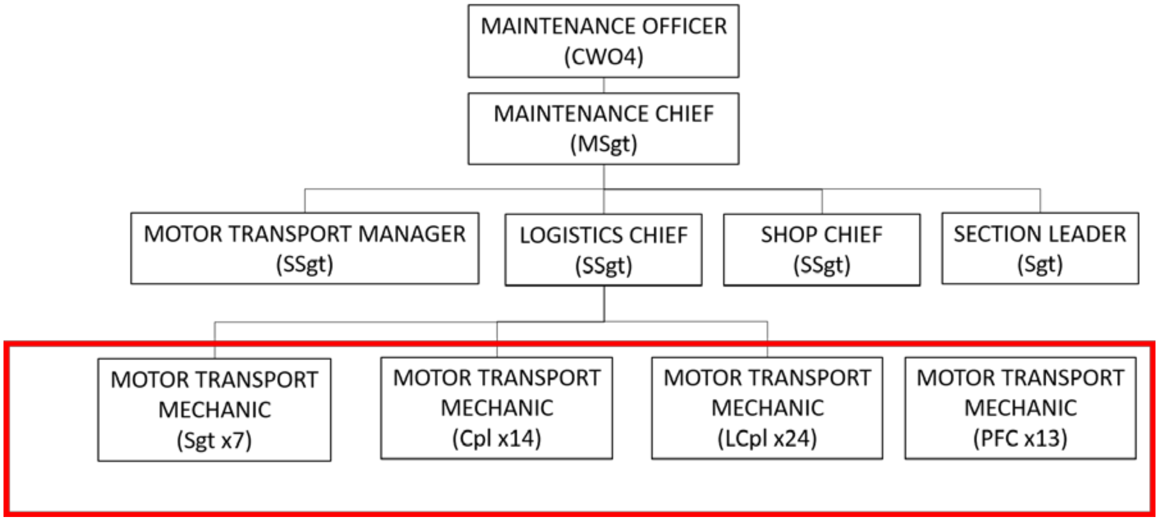


Figure 14. 1st TSB Motor Transport Maintenance Section

b. Maintenance Production Process

This section provides background information with regard to the maintenance production process as prescribed by *MCO 4790.2*. Figure 15 provides a flow chart of the maintenance production process at each of the commands analyzed in this thesis.

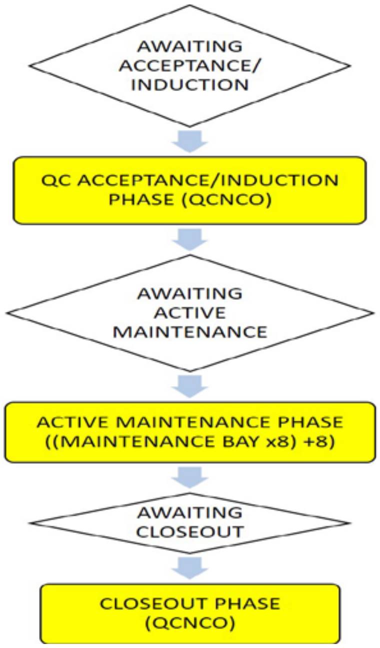


Figure 15. Maintenance Flow Chart Common to Each Command

(1) Acceptance Phase

Per *MCO 4790.2*, the acceptance phase represents the initial step of the maintenance production process. It consists of three steps, including inspection, scheduling, and assignment within the maintenance activity (Headquarters Marine Corps, 2016).

The maintenance section inspects equipment entering maintenance service to ensure the equipment is complete and prepared to receive maintenance service. Scheduling ensures, to the maximum extent possible, that equipment arrives at the maintenance activity at or after the time maintenance resources become available. Scheduling usually applies to PMCS; calibration; modification; or routine maintenance, which are planned maintenance actions conducted on full mission capable (MC) equipment. As such, scheduling also allows the customer to continue using its equipment until the maintenance activity can perform maintenance on it. Non-scheduled equipment maintenance due to a random defect does not require scheduling and is taken to the maintenance shop upon identifying that a defect exists. Non-scheduled maintenance usually occurs for degraded or deadlined equipment. Upon conclusion of the inspection and scheduling stages of the acceptance phase, equipment is assigned to a particular maintenance section/shop (Headquarters Marine Corps, 2016).

(2) Induction Phase

Induction consists of the physical delivery of equipment requiring maintenance service to the maintenance activity. Customers deliver such equipment by priority established during the acceptance phase (Headquarters Marine Corps, 2016).

Each command analyzed in this thesis performs the acceptance phase with a QCNCO. Each command assigns two Marines as QCNCOs within the shop, but only one QCNCO conducts actions in the acceptance/induction phase per vehicle. In the absence of both QCNCOs, either the Maintenance Chief performs the necessary duties in the acceptance phase or equipment is set aside on the motor transport maintenance lot until a QCNCO becomes available. On average, the acceptance phase requires one hour to thoroughly process equipment and transition it into the induction phase (Chief Warrant Officer Collum, Chief Warrant Officer Palmer, Chief Warrant Officer Tilley, interview with author, January 17, 2018). Because the customer or owning command must first open a 1st echelon maintenance service request within GCSS-MC prior to the Motor Transport maintenance section opening a 2d echelon maintenance service request, the acceptance phase may exceed the 1-hour average time to process. Delays usually occur when the 1st echelon service request contains errors or discrepancies that prevent the proper processing of the 2d echelon service request.

The induction and acceptance phases occur simultaneously within the three commands. The inspection step within the acceptance phase occurs within the Motor Transport maintenance area, as such, equipment immediately enters the induction phase of maintenance upon completion of all steps within the acceptance phase.

(3) Active Maintenance Phase

The active maintenance phase marks the beginning of the repair process. Sequential, logical steps occur during this phase to ensure the required services proceed in an efficient and effective manner. These steps include inspection, preparation, performance and quality control (Headquarters Marine Corps, 2016).

The inspection step includes verifying equipment records associated with the required service(s) are current. Preparation involves ensuring a technician possess all technical publications and information; support equipment; and test measurement and diagnostic equipment required to perform the required maintenance service. The performance step ensures only qualified personnel perform the maintenance task required per equipment type and technical publication (Headquarters Marine Corps, 2016).

Quality control involves a complete inspection and update of records (within the automated logistics information system (ALIS)) of equipment following the performance step of the active maintenance phase. If the equipment does not perform as designed, equipment remains in the maintenance cycle for further maintenance action. Fully functional equipment allows for transfer of equipment to the maintenance closeout phase (Headquarters Marine Corps, 2016).

During the active maintenance phase, each command possesses qualified automotive maintenance technicians, MOS 3521, per respective equipment technical publications. However, capacity of qualified personnel presents one obstacle to efficiently processing the volume of equipment entering the motor transport maintenance cycle. On average, the three commands perform active maintenance utilizing between 23% - 31% capacity of their available automotive mechanic technicians due to deployments and tasks other than maintenance. Capacity reduces immediately due to the assignment of QCNCOs, layette non-commissioned officer (NCO), tool room NCO, platoon sergeant, and shop chief. The reduced capacity quantity differs based upon the organizational structures seen in Figures 4, 7-11, and 14. To fill these billets, the motor transport maintenance officers/chiefs assign at least six automotive maintenance technicians (Chief Warrant Officer Collum, Chief Warrant Officer Palmer, Chief Warrant Officer Tilley, interview with author, January 17, 2018). Three of the six billets do not exist on the commands' Tables of Organization, but the requirement comes from the FSMAO. Without Marines assigned to these billets, commands risk receiving a less than favorable analysis of their maintenance support operations. However, this policy conflict alone does not represent the cause of stress and strain on the maintenance system.

Physical capital affects maintenance production during the active maintenance phase. Each command possesses a set quantity of maintenance bays to perform active maintenance on vehicles. Marine Wing Support Squadron Three Seven One and 1st TSB utilize 8 of 10 maintenance bays to perform active maintenance. For MWSS-371, two maintenance bays serve as a tire storage and repair area, and a HAZMAT area. For 1st TSB, two maintenance bays serve as active maintenance bays for engineer equipment. For 5/11, it possesses and utilizes two maintenance bays to perform vehicle maintenance. When vehicle maintenance bays reach maximum capacity, each command conducts overflow maintenance within the Motor Transport maintenance lot (less repairs requiring extensive petroleum, oils, and lubricants (POL) drainage) (Chief Warrant Officer Collum, Chief Warrant Officer Palmer, Chief Warrant Officer Tilley, interview with author, January 17, 2018). The data allows simulating a percentage of vehicles restricted from active maintenance based upon defect code, but time constraints prevent the author from including this aspect into the simulation model for this thesis.

(4) Maintenance Closeout Phase

The maintenance closeout phase marks the end of the maintenance cycle time and indicates “repairs complete”. However, three steps must be completed to finalize this phase. First, the customer must physically retrieve the equipment from the maintenance activity in order to complete the closeout phase and end the maintenance cycle. In addition to physically retrieving the equipment, the customer’s supply and maintenance personnel must update equipment maintenance and accountability records. After completing these three steps within the maintenance closeout phase, the maintenance cycle time officially ends. To ensure an efficient closeout, the maintenance activity and customer (including supply and maintenance personnel) must maintain close coordination (Headquarters Marine Corps, 2016). Without such coordination, the maintenance closeout phase experiences delays, which prolong the maintenance cycle time. The author elaborates upon this point in Chapter IV of this thesis.

The maintenance closeout phase requires approximately the same amount of time of one hour to complete as the acceptance and induction phases within the three commands. Processing times beyond one hour during this phase occur when customers or owning commands (to include supply and maintenance personnel) fail to promptly retrieve repaired equipment and complete the maintenance and accountability records' administrative actions (Chief Warrant Officer Palmer, interview with author, January 17, 2018).

B. LITERATURE REVIEW

1. Workload Evaluation Method

Nelsen (2010) published a report for DC, I&L, *Establishment of Standard Ratios of PEIs to Maintainers Study*, aimed at analyzing the equipment maintainer-staffing problem within the Marine Corps. In his report, Nelsen proposed developing the Marine Corps maintainers requirement criteria (MMRC) process, supported by the "workload evaluation" method. This process would serve as the tool to analytically determine the appropriate maintainer staffing requirements for organizational and intermediate level maintenance activities within the Marine Corps. Nelsen highlights the fact that, in 2010, no system exists to collect and archive the data necessary to adequately determine a maintainer to equipment ratio. As such, Nelsen (2010) recommends the establishment of processes and procedures that capture and analyze equipment maintenance data, generate maintainer availability data and perform command workload evaluations.

Nelsen initially planned to develop a database to support the "workload evaluation" method. However, he abandoned this approach due to the lack of empirical data required to make the database functional. During a "Kick Off" meeting to discuss the research topic, Nelsen notes that one participant recommended evaluating the validity of past T/O by comparing them against present T/Os. Data, once again, presented a major challenge to employing this analysis technique. Such a comparison requires historical equipment maintenance readiness data to determine the effectiveness of previous T/Os (Nelsen, 2010).

Before settling on the proposed MMRC process, Nelsen considered building a computer simulation model of a maintenance workshop. However, he deemed this method as not applicable nor practical due to lack of data and the requirement to meet important assumptions regarding queuing theory (Nelsen, 2010). The MMRC process uses the workload evaluation method as the analytical foundation. Inputs into this method include annual equipment maintenance burdens and maintainer availability data, along with the quantity of equipment maintained by a particular MOS (Nelsen, 2010). Such data did not exist during the conduct of Nelsen's research; however, he concluded that the annual equipment maintenance burden data could come from Marine Corps maintenance management systems while maintainer availability data could come from surveys or direct supervisor observation (Nelsen, 2010).

Fortunately, most of the data required to support the creation of the MMRC, conduct a computer simulation and compare past T/Os to current ones exists in quantity. Unfortunately, data quality represents the major obstacle to creating a reliable MMRC process today. From Nelsen's research, this thesis uses the workload evaluation method to determine an unconstrained, static motor transport automotive mechanic staffing goals for the commands analyzed.

2. Simulation Modeling

Bazargan-Lari, Gupta, and Young (2004) developed a simulation to support manpower planning for maintenance sections at Continental Airlines. The model "provides guidelines to the development of enhanced staffing models and a better understanding of resource requirements on a daily basis" (Bazargan-Lari et al., 2004, p. 1677).

Bazargan-Lari et al. (2004) describe the system they model in terms of equipment/fleet type, maintenance schedules, maintenance programs, standard maintenance timings, shift schedules, and management problems. Bazargan-Lari et al. (2004) build the model based upon several assumptions. These assumptions include the quantity of technician pools, the pool from which the model extracts a technician based upon the requirement, constraints on utilizing a technician already engaged in a maintenance job, the availability of a technician after completing a maintenance job, and the qualification of a technician to perform a maintenance job on a particular equipment/fleet type.

Carlton (2012) applied simulation modeling and regression analysis as a method to developing enlisted manpower requirements aboard Navy surface ships. He examines two divisions, fire controlman (CF) and enginemen (EA) divisions, aboard the Arleigh Burke-class destroyer. The model factors include each Sailor type in the division with distribution parameters of corrective maintenance times and the minimum, mode, and maximum corrective maintenance work times. The response variables all relate to the number of hours spent processing a type of work (Carlton, 2012). Carlton first conducted simulations to determine the simulated mean work backlog of tasks and "plots the predicted values of work backlog against increasing division sizes to provide… insight on the effects of changing manpower requirement levels" (Carlton, 2012, p. v).

This thesis employs a computer simulation of the respective motor transport maintenance shops of MWSS-371, 5/11, and 1st TSB. Each of the three commands conduct organizational level maintenance up to second echelon and limited third echelon equipment maintenance. Similar to Carlton (2012), this thesis conducts simulations to determine the mean time in maintenance for motor transport equipment entering the maintenance cycle. Unlike Carlton (2012), this thesis does not use a regression model as part of the manpower requirements process, but instead capitalizes on an optimization tool based upon a minimizing mean time in maintenance objective and an upper bound threshold on maintainer utilization rates for each command.

C. SUMMARY

In summary, the United States Marine Corps lacks a formal tool to identify maintainer requirements. As the 37th CMC equips the Marine Corps with equipment that enables the Enterprise to meet present and future military challenges while placing a heavy emphasis on readiness, manpower planners, program managers, and occupational field sponsors need a tool that allows them to identify the appropriate amount of mechanics to maintain the equipment. Without a manpower staffing tool to properly staff equipment maintainers, the potential exists for the Marine Corps to experience decreased ground equipment readiness as a result. This thesis aims to develop a method for use initially as a proof of concept to determine the appropriate amount of motor transport maintainers required to maintain motor transport equipment within an organizational level ground command. Though this thesis focuses on the motor transport community, the tool aims to support in determining maintainer staffing requirements for all ground equipment commodities.

III. METHODS

A. WORKLOAD EVALUATION METHOD

Nelsen (2010) proposed an MMRC process to determine maintainer staffing requirements. The tool uses a workload evaluation method to calculate the requirement as shown in Figure 16. The author uses this static method to calculate the number of maintainers required to maintain a certain quantity of motor transport equipment and includes the output from this method as an input into the simulation model.

$$\boldsymbol{N_m = \frac{\sum_{i=1} n_i * W_i}{A_m}}$$

Where:

n_i = number of end items of type *i* in the unit.

W_i = number of annual maintenance man-hours required for each item of type *i*.

A_m = annual man-hours availability of a maintainer of the given MOS *m*.

N_m = number of maintainers required for the evaluated unit.

Figure 16. Formal expression of the workload evaluation method for a given MOS m. Source: Nelsen (2010).

Whereas Nelsen (2010) uses the end item’s annual maintenance burden in labor hours for a particular MOS, the author uses the average annual maintenance burden across multiple years with respect to the end item and not the MOS 3521 maintainer. The author assumes that MOS 3521 performs the majority of labor on motor transport equipment is. For equipment pending fielding (O/H quantity of 0 with planned allowance greater than 0), the author calculates the average annual maintenance burden of all motor transport equipment in a particular year for each year of data available. The author then sums the averages of each year of data available to use as the best estimate of annual maintenance burden for equipment pending fielding. From the historical data, the author derives the variable W_i by summing the labor hours if of a particular TAMCN and within a particular year. The variables from the data set include military labor hours, TAMCN, and date received in shop.

For the variable n_i, the author uses the O/H quantities listed for each TAMCN and command on TLCM – OST. From. The author subtracts from a 365-day year the number of holiday liberty days, weekends not included in the holiday liberty days, and an additional 20 days to account for average annual leave days for an individual Marine in order to derive the number of days in a year available for maintenance. As a reference for the holiday liberty days, the author uses the *Fiscal Year 2018 Holiday Observations Liberty Periods* bulletin (Marine Corps Installations East–Marine Corps Base, 2017). The calculation yields a constant of 236 days in a year available to perform maintenance. To derive the variable A_m, the author multiplies the average daily available maintenance hours, provided by the maintenance officers and chiefs interviewed for this thesis, by the constant 236 days in a year available to perform maintenance. The author does not obtain a unit training, exercise, and employment plan (TEEP). With the TEEP, the author assumes a much more accurate "average daily available hours" variable could be used to calculate A_m. The next section discusses the simulation method used to determine the optimal organizational automotive mechanic staffing requirement.

B. SIMULATION MODELING METHOD

In this section, the author provides information regarding the simulation modeling method. The author explains terms and characteristics of the Simio simulation software used to develop the models in this thesis, discusses the development of the model, and illustrates the conceptual model representing the motor transport maintenance systems analyzed in this thesis.

1. Simio

Simio simulation software provides an intelligent objects based simulation framework for experienced and new modelers to use. Is also allows the use of other modeling techniques allowing for a free mix of modeling approaches within a single model. The software gives modelers options to use pre-built objects or create custom objects

(Simio, 2017). Simio's interactive mode provides immediate feedback and allows for rapid model debugging. Before moving forward to discuss model factors and responses, the author provides a few terms associated with Simio simulation model development.

a. Object

An object is an autonomous modeling construct that defines the construct's characteristics, data, behavior, user interface, and animation (Kelton et al., 2014). One example of an object could be a commercial ship.

b. Entity

An entity represents the physical "things" that move around in the system modeled (Kelton et al., 2014). If one can imagine it, one can create it as an entity regardless of field of industry or area of expertise. Entities are part of an object model and can be designed to display intelligent behavior (Kelton et al., 2014).

c. Processes

A process is a set of actions that take place over (simulation) time. A process may change the state of the system (Kelton et al., 2014). Simio software applies some model processes upon inserting input parameters such as inter-arrival time into the model. A modeler may also create add-on processes to facilitate the execution of actions unique to the system modeled.

d. Resource Object

An object used as a resource possesses a capacity constraint, a queue where tokens await available capacity, automatic statistics on allocated and scheduled capacity, and it intelligently interacts with the object attempting to seize it (Kelton et al., 2014). Three types of resource objects exist in the model used in this thesis.

e. Token

Tokens facilitate the execution of processes within the model. Kelton et al (2014) define a token as a delegate that executes the steps in a process. Tokens serve as delegates for entities usually but serve as delegates for any object executing a process (Kelton et al., 2014).

f. Add-On Process

Add-on processes allow flexibility to the modeler and enable adding supplemental processes to built-in objects that increase the validity of a model (Kelton et al., 2014). Three add-on processes exist within the model used in this thesis.

g. Referencing Data Tables and Selecting Entity Type

Simio offers a simple way to include data from data tables into the model. It provides a modeler the option of referencing a specific row within a table or randomly selecting data from a row. A modeler accomplishes data table referencing via a resources property window.

h. Resource Scheduling

Resource scheduling in Simio simulation software allows a modeler to create resource work schedules. Work schedules can include a capacity constraint based upon the nature of the system one models. One assumes that resources, whether human or system resources, take a break during the workday. The break-period represents a resource constraint if capacity equals zero.

2. Developing the Model

This section relates the terms and characteristics of Simio discussed earlier in this chapter to the development of the models within this thesis. Figures in this section highlight certain topics discussed.

a. Objects

The models in this thesis consist of several objects. The “worker” object represents the organizational automotive mechanic with MOS 3521. The “worker” object serves as a secondary resource to the “workstation” object. The “source” object represents the entry point for entities entering the maintenance cycle. The source object creates entities and the "worker" object resident within the model. Two "server" objects exist within the model. The first "server" object, called QC Acceptance, represents the first phase of the maintenance cycle. The second "server" object, called QC Closeout, represents the last phase of the maintenance cycle. Several "workstation" objects exist within each model, varying in quantity specific to each unit modeled within the system. Finally, a "sink" object included in the model facilitates the destruction of entities created by the "source" object. Destroying an entity represents returning equipment to the customer. Figure 17 provides an illustration of the objects and entities used in each model.

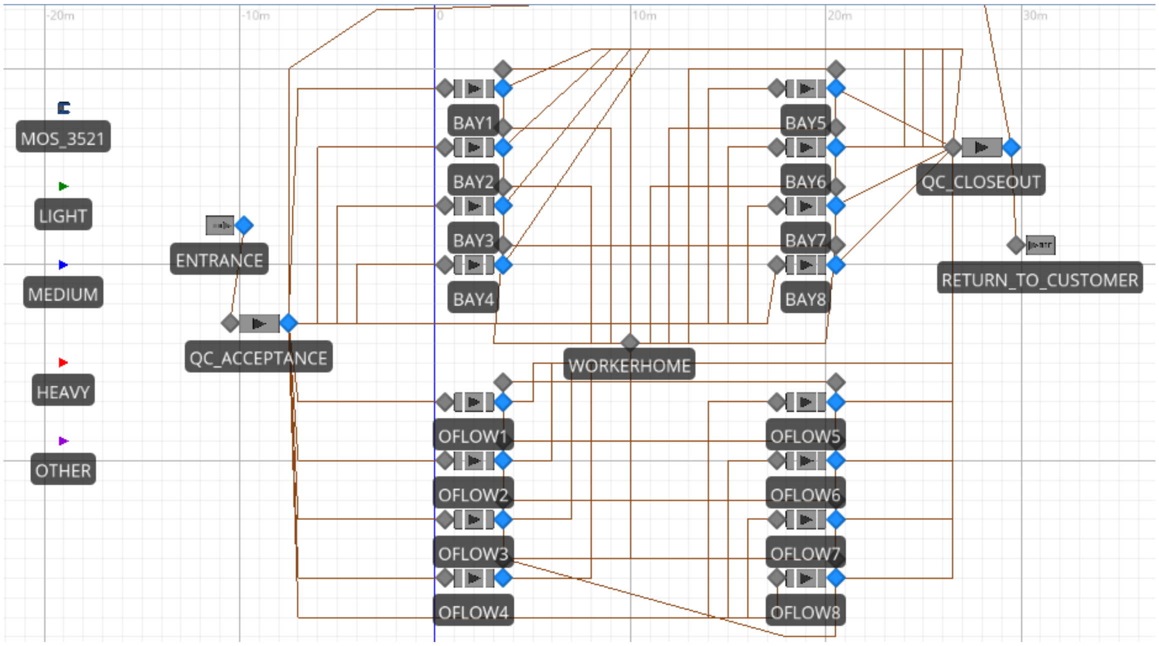
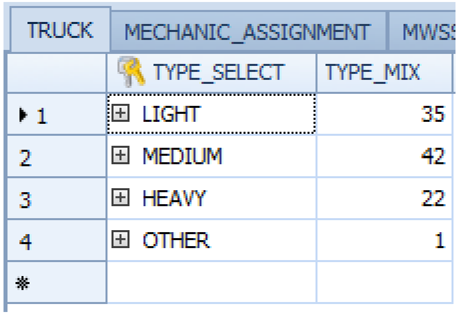


Figure 17. Illustration of Simulation Model in Interactive Mode

b. Entities

Five entity types represent motor transport equipment types based upon functional area. The MWSS-371 and 5/11 models listed in Figure 18 include "light," "medium," "heavy," and "other" entity types. The 1st TSB model includes "light," "medium," "heavy," and "engineer" entity types. The "type mix" column serves as a weight selection. Based upon the weights, this system would perform the most maintenance tasks on "medium" type equipment with "light" type equipment representing the second most serviced equipment in the maintenance cycle.



	TYPE_SELECT	TYPE_MIX
▸ 1	⊞ LIGHT	35
2	⊞ MEDIUM	42
3	⊞ HEAVY	22
4	⊞ OTHER	1
✱		

Figure 18. Entity Type Data Table

c. Processes and Add-On Processes

Specific input and distribution parameters dictate the processes and actions occurring within each model. Simulation processes occur over a simulation time of 26, 280 hours or 1095 days. The author includes three add-on processes into each model. The "minor task decision" add-on process decides probabilistically (1%) whether an entity is a short task (< half an hour) or a long task (> half an hour). If a short task, the QCNCO completes the task and returns equipment to the customer. The "input QC acceptance exited" add-on process enables the model to record the amount of time an entity remains in the maintenance system if it is a long-task entity. This mitigates skewing the "mean time in maintenance" response produced by the optimization models. The final add-on process, "return to customer entered" tallies the time an entity that went through each phase of the maintenance cycle spent in maintenance. Figure 19 provides an illustration of add-on processes used in the simulation models.

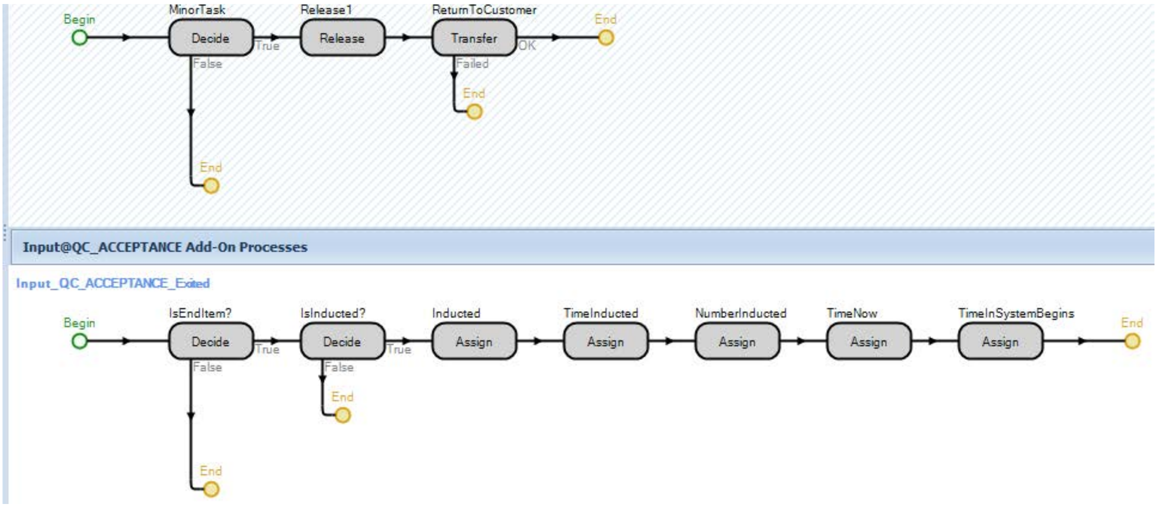
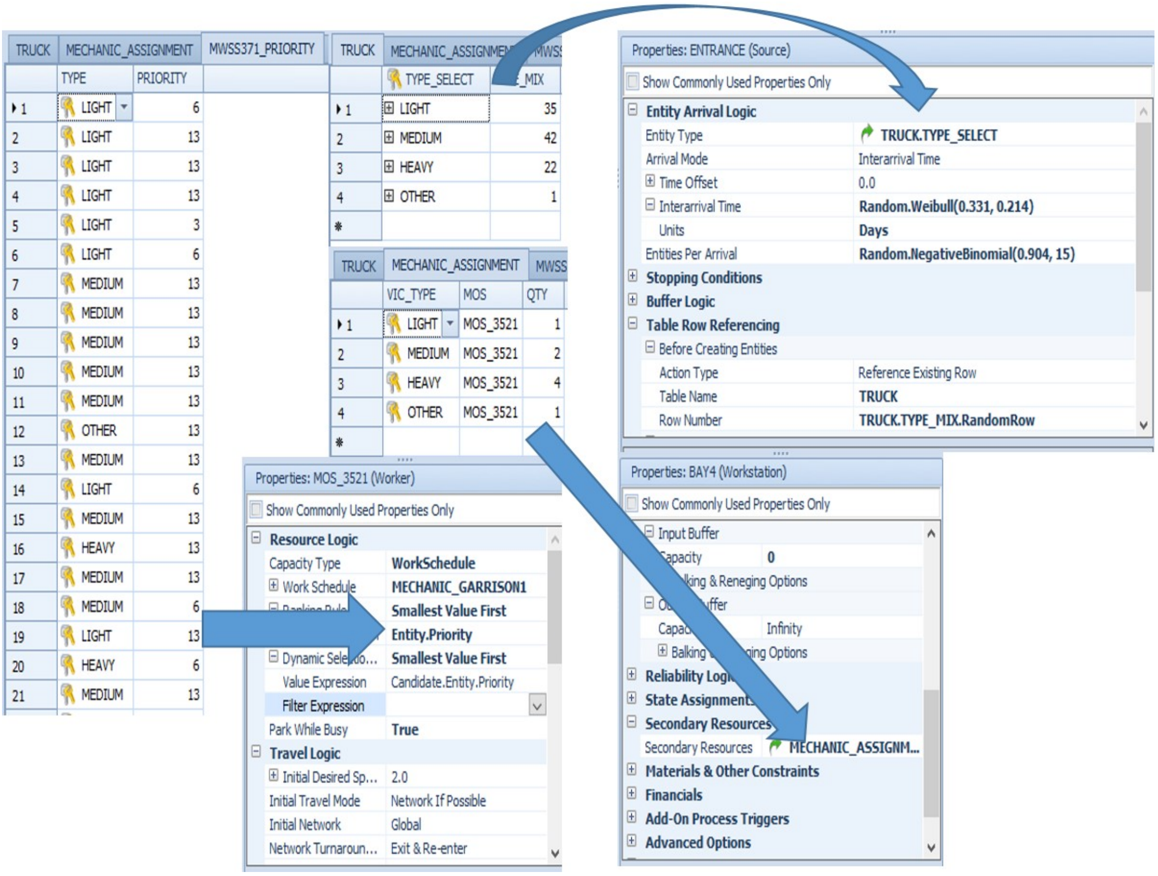


Figure 19. Simulation Model Add-On Processes

d. Referencing Data Tables and Selecting Entity Types

To create entities and model processing logic, the model references several data tables created by the author. The “truck” data table serves as the table used to create randomly different entity types within each model (see Figure 20). The “type select” column serves as the key column used to assign randomly a priority to the entity selected by the “source” object. The “source” object references the “MWSS371 priority” data table using the “state assignments” option in the object property window. The “workstation” objects reference the “mechanic assignment” data table in each model to assign a specific quantity of “worker” objects based upon entity type requesting to seize a resource.



	TYPE	PRIORITY
1	LIGHT	6
2	LIGHT	13
3	LIGHT	13
4	LIGHT	13
5	LIGHT	3
6	LIGHT	6
7	MEDIUM	13
8	MEDIUM	13
9	MEDIUM	13
10	MEDIUM	13
11	MEDIUM	13
12	OTHER	13
13	MEDIUM	13
14	LIGHT	6
15	MEDIUM	13
16	HEAVY	13
17	MEDIUM	13
18	MEDIUM	6
19	LIGHT	13
20	HEAVY	6
21	MEDIUM	13

	TYPE_SELECT	_MIX
1	⊞ LIGHT	35
2	⊞ MEDIUM	42
3	⊞ HEAVY	22
4	⊞ OTHER	1
*		

	VIC_TYPE	MOS	QTY
1	LIGHT	MOS_3521	1
2	MEDIUM	MOS_3521	2
3	HEAVY	MOS_3521	4
4	OTHER	MOS_3521	1
*			

Properties: ENTRANCE (Source)

☐ Show Commonly Used Properties Only

⊟ **Entity Arrival Logic**	
Entity Type	**TRUCK.TYPE_SELECT**
Arrival Mode	Interarrival Time
⊞ Time Offset	0.0
⊟ Interarrival Time	**Random.Weibull(0.331, 0.214)**
Units	**Days**
Entities Per Arrival	**Random.NegativeBinomial(0.904, 15)**
⊞ **Stopping Conditions**	
⊞ **Buffer Logic**	
⊟ **Table Row Referencing**	
⊟ Before Creating Entities	
Action Type	Reference Existing Row
Table Name	**TRUCK**
Row Number	**TRUCK.TYPE_MIX.RandomRow**

Properties: MOS_3521 (Worker)

☐ Show Commonly Used Properties Only

⊟ **Resource Logic**	
Capacity Type	**WorkSchedule**
⊞ Work Schedule	**MECHANIC_GARRISON1**
	Smallest Value First
	Entity.Priority
⊟ Dynamic Sele…o…	**Smallest Value First**
Value Expression	Candidate.Entity.Priority
Filter Expression	
Park While Busy	**True**
⊟ **Travel Logic**	
⊞ Initial Desired Sp…	2.0
Initial Travel Mode	Network If Possible
Initial Network	Global
Network Turnaroun…	Exit & Re-enter

Properties: BAY4 (Workstation)

☐ Show Commonly Used Properties Only

⊟ Input Buffer	
apacity	**0**
lking & Reneging Options	
⊟ O… uffer	
Capa	Infinity
⊞ Balking …ging Options	
⊞ **Reliability Logi**	
⊞ **State Assignment**	
⊟ **Secondary Resources**	
Secondary Resources	**MECHANIC_ASSIGNM…**
⊞ **Materials & Other Constraints**	
⊞ **Financials**	
⊞ **Add-On Process Triggers**	
⊞ **Advanced Options**	

“Priority,” “truck,” and “mechanic assignment” data tables with “source,” “worker,” and “workstation” resource objects referencing the data tables

Figure 20. Data Tables and Referencing Objects

3. Conceptual Model

This section provides the reader insight into the conceptual design and functionality of the simulation model. Figure 21 illustrates the design of each Motor Transportation maintenance model developed for this thesis with regard to inputs, model components, and outputs. Figure 22 provides a visual depiction of the processes and logic occurring within the models. The author possesses a general knowledge of the Marine Corps ground equipment maintenance system based upon personal experience and Marine Corps orders relative to ground equipment maintenance. However, the author gained better insight into the motor transport maintenance system through interviews with some of the principal stakeholders of this research at each of the commands analyzed in this thesis.

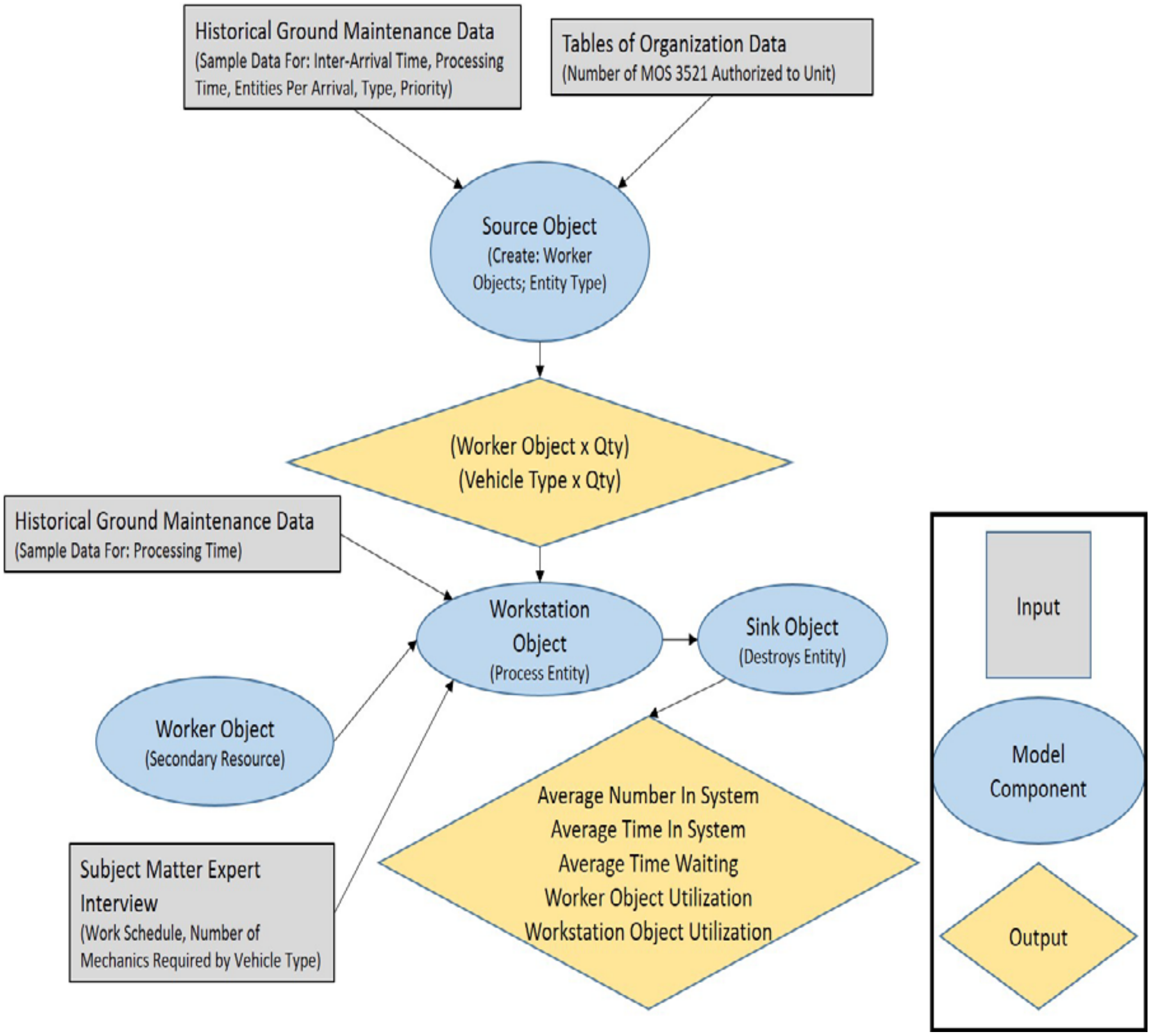


Figure 21. Flow Chart of Inputs, Model Components, and Outputs of the Motor Transportation Maintenance Model

To develop models comparable to the realities of each command’s maintenance system, the author uses real-world data. Before building the model, the author develops some assumptions about the real-world maintenance system and fits distributions to the inter-arrival time (date received in shop), processing time (military labor hours), and entity per arrival (quantity inducted) derived from the data.

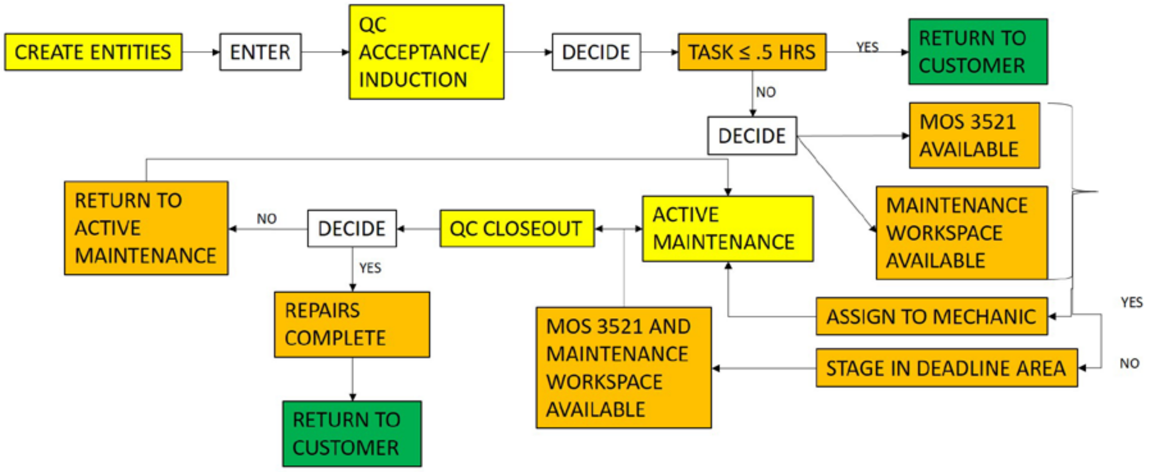


Figure 22. Conceptual Design of the Motor Transport Maintenance System Simulation Model

a. Assumptions

The author assumes the following to develop the simulation model:

- There exists only one maintainer type in the model
- A maintainer suspends work when off-shift
- A maintainer completes work on one entity type before beginning on another
- A maintainer begins work on another entity type upon completion of a previous task if on-shift
- Each work schedule varies by command
- A maintainer possesses the requisite skills to work on any entity type
- A maintainer possesses the required tools to perform any task within the command's level of maintenance (allows focus on maintenance actions only without the effects of supply support)
- A maintainer possesses the required part to repair any defect within the command's level of maintenance (allows focus on maintenance actions only without the effects of supply support)
- Vehicles arrive to maintenance during maintainer off-shift due to field operations and training and await commencement of maintenance operations
- QC acceptance and closeout personnel are always available for the duration of the established workday

- MWSS-371 and 1st TSB’s overflow maintenance spaces equal the amount of actual maintenance facilities each command possesses, giving a total of 16 spaces to perform maintenance within these two commands
- Deployed and garrison work schedules differ

The model consists of several objects and entities, including a worker object, source object, workstation objects, two server objects, a sink object, four to five entities (data driven by command) representing equipment type, worker nodes, one worker home node, and connectors linking primary objects to one another. At the “create entities” step in Figure 22, the source object first creates the specified quantity of worker objects in a successive manner. Next, the source object randomly creates entities in time steps based upon the specified inter-arrival time and distribution assigned. The worker object remains in the system to process entities at a workstation object as a secondary resource. However, the source object creates new entities that exit the system via the sink object. Once an entity enters the system, the next step decides the first destination of the entity. The first destination upon entering the system is the “QC acceptance” server object.

At the “QC acceptance server object, the model simulates action conducted at this phase of the maintenance cycle based upon the prescribed processing times and distributions entered into the model. Per the responses from the stakeholders interviewed within each command, this process takes on average approximately 45–60 minutes (Chief Warrant Officer Collum, Chief Warrant Officer Palmer, Chief Warrant Officer Tilley, interview with author, January 17, 2018). If this step requires less than half an hour to complete, the entity goes directly to the sink object and exits the system. This represents completion of tasks that do not necessarily require a maintenance facility for repair. If equipment requires extensive repairs beyond the time span of half an hour, then the QCNCO faces a decision point of assigning a mechanic to conduct maintenance and a facility in which to conduct it. If neither a maintenance facility nor mechanic is available, the QCNCO stages the equipment in the deadlined area until such time conditions favor the conduct of equipment maintenance. The model simulates this by using the dynamic selection process built within the simulation software. Mechanics prioritize maintenance using priority codes based upon whether a vehicle is deadlined, degraded, or require minor repairs. The model assigns priorities to an entity prior to departing the “QC acceptance” server object using a state assignment process. Once the QCNCO assigns equipment to a mechanic and maintenance facility, the active maintenance phase begins.

The active maintenance phase represents the main objective of motor transport mechanics, to fix and repair motor transport equipment in order to return it to a mission capable status. At this step, the model uses workstation and worker resource objects to process entities entering a workstation object. The model allows processing based upon a work schedule resembling the work schedule and time dedicated to maintenance specific to the command. The model also assigns a certain quantity of Marines to process a particular entity based upon the entity type. The model simulates this action by way of setting a column key in the “truck” table that corresponds to the entity and quantity of mechanics related to that entity in the “mechanic assignment” table. Each workstation and worker resource object simulates active maintenance labor hours/processing time based upon random input distributions. Once processing ends in this phase, an entity leaves this step and enters into the “QC closeout” phase of maintenance.

The “QC closeout” step simulates the last step in the equipment maintenance cycle. At this step, the QCNCO ensures the quality of the maintenance task(s) performed on equipment receiving maintenance. This step takes approximately 45–60 minutes as well (Chief Warrant Officer Collum, Chief Warrant Officer Palmer, Chief Warrant Officer Tilley, interview with author, January 17, 2018). As depicted in Figure 20, if the QCNCO declare the repairs unsatisfactory, equipment returns to the active maintenance phase for repairs. Once complete in the active maintenance phase again, equipment enters the “QC closeout” phase again for inspection by the QCNCO. The QCNOC either clears the equipment for return to the customer or returns it to the active maintenance phase. The model simulates approximately one percent of equipment in the system re-routing to the active maintenance phase once. Once repairs are complete, equipment is returned to its customer.

C. SUMMARY

In summary, Chapter III discusses the methods used in this thesis to address its main objective. The author first discusses the workload evaluation method developed by Nelsen (2010) and its application within this thesis. The author then focuses on the primary tool used in this thesis, which is the simulation model, while describing some assumptions of the model. Figure 21 provides an illustration of the model inputs, components and outputs. Figure 22 provides an illustration of the model logic and functionality. The next chapter provides information about the design of the experiment.

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IV. DESIGN OF THE EXPERIMENT

Chapter III covered the development of the simulation models and the workload evaluation method. This chapter briefly discusses the distribution selection process used for this thesis, the model factors and responses, and provides an illustration of the final design of the experiment.

A. DISTRIBUTIONS

The author uses a statistical software package called StatFit3 to fit distributions to the data for inter-arrival and processing times as well as entities per arrival applied to the models in this thesis. The real-world data did not conform to any particular distribution during analysis in its original form. As an alternative to the failure to find a distribution fit via a goodness-of-fit test, the author assumes distribution fits for the inter-arrival times, processing times, and entities per arrival count based upon each data set's summary statistics and probability distribution function comparison. First, the author determines whether the data are continuous or discrete. The author assumes inter-arrival and processing times to be continuous while assuming entities per arrival to be discrete for each model within this thesis. According to Maddah (2017), using empirical tools such as summary statistics, histograms, and quantile summaries assist with hypothesizing a family of distribution (Maddah, 2017, p. 8). The author uses descriptive statistics to hypothesize probability distributions for the three inputs as well as a visual comparison of the probability distribution functions. Maddah (2017) suggests determining probability distributions for continuous data based upon the coefficient of variation (CV) provided in the descriptive statistics. A CV > 1 suggests gamma or Weibull with shape parameter $\beta < 1$ a CV $\approx$ 1 suggests an exponential distribution, and a CV < 1 suggests a gamma or Weibull distribution with a shape parameter $\beta > 1$ (Maddah, 2017, p. 8). For discrete data, Maddah (2017) suggests determining the Lexis ratio to decide on applying a negative binomial or geometric fit if $\tau > 1$, Poisson if $\tau \approx 1$, or binomial if $\tau < 1$ (Maddah, 2017, p. 8). Kelton et al. (2014) suggest visually comparing the probability distributions of different distributions to that of the original data set. The probability distribution curve that best aligns with that of the original data should be considered the best distribution fit for the data.

Table 1 reveals that each command’s CV for inter-arrival time exceed one, ruling out an exponential distribution. Figure 23 shows for each unit that the Weibull distribution fits the data better than a gamma distribution. As such, the author selects a Weibull distribution to apply to inter-arrival time for each model. Cleary the Lexis ratio for each command’s entities per arrival data exceeds one. To the author’s eyes, Figure 24 suggests that each command’s entities per arrival distribution is of the negative binomial family. Finally, the CV for each command’s processing time, except 5th Bn, 11th Mar, is greater than one. If one stops with only an analysis of the descriptive statistics, one might apply an exponential distribution to the data for 5/11. However, Figure 25 provides a strong case for a gamma distribution. This distribution almost perfectly aligns with the actual data, suggesting gamma to be the best fit for the data. For MWSS-371 and 1st TSB, the author applies a Weibull distribution and a gamma distribution, respectively, to the models.

According to Table 1, 75% of arrivals occur within one day or less for each unit with two or less pieces of equipment arriving for maintenance. Processing times differ for each unit. Marine Wing Support Squadron Three Seven One complete maintenance on equipment within eight hours or less for 75% of the equipment inducted into the maintenance system. On the other hand, 5/11 and 1st TSB appear to take a bit longer to complete maintenance on equipment. This may not suggest much since the number of observations differ, leaving gaps by unobserved processing times. If the number of observations matched for each unit, the possibility exists for MWSS-371 to display longer processing times for 75% of the observations. Next, the author discusses the factors in the models.

Table 1. Inter-arrival Time, Entities per Arrival, and Processing Time Descriptive Statistics

	N	Mean	Std Dev	Variance	CV	25%	Median	75%	Min	Max
MWSS371 Inter-Arrival	602.00	1.62	3.83	14.64	236.75	0.00	0.00	1.00	0.00	55.00
5/11 Inter-Arrival	873.00	1.08	3.49	12.17	323.98	0.00	0.00	1.00	0.00	79.00
1st TSB Inter-Arrival	944.00	1.00	2.49	6.20	248.42	0.00	0.00	1.00	0.00	31.00
MWSS371 Per Arrival	602.00	1.59	1.45	2.11	91.63	1.00	1.00	2.00	1.00	16.00
5/11 Per Arrival	873.00	1.68	2.05	4.21	122.11	1.00	1.00	2.00	1.00	44.00
1st TSB Per Arrival	944.00	1.78	2.47	6.11	138.77	1.00	1.00	2.00	1.00	47.00
MWSS371 Processing	955.00	5.64	6.72	45.15	119.20	0.50	3.52	8.88	0.02	55.80
5/11 Processing	1467.00	7.55	7.47	55.76	98.95	3.00	5.82	11.00	0.02	55.30
1st TSB Processing	1682.00	8.46	13.00	168.99	153.65	2.10	5.00	10.21	0.02	198.33

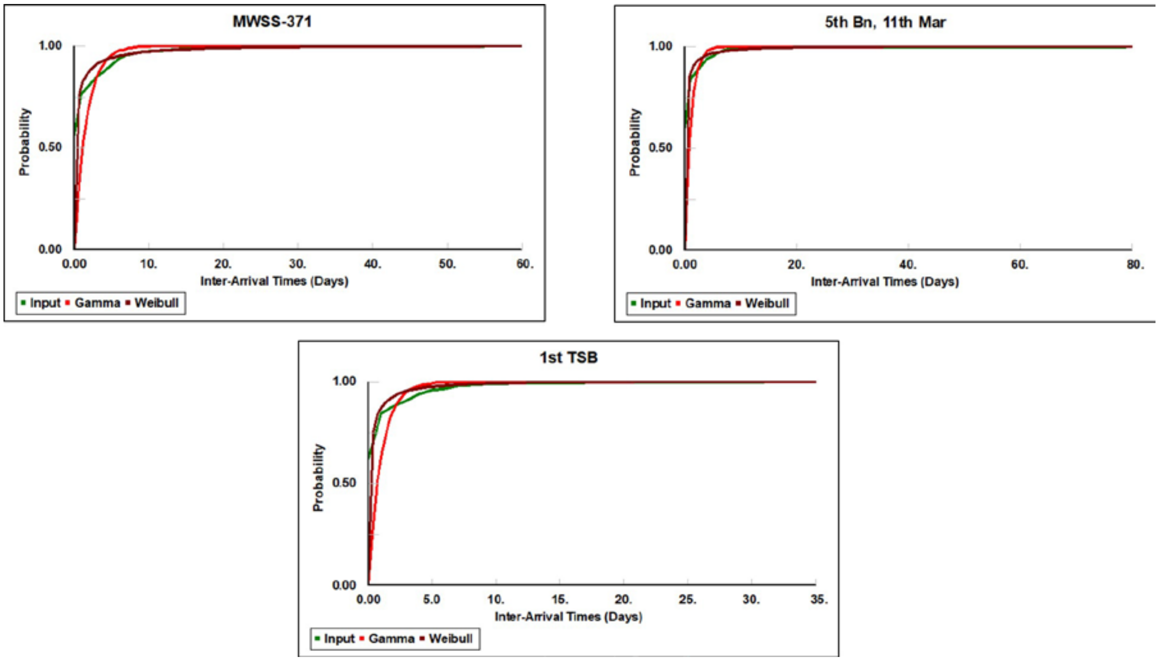


Figure 23. Inter-arrival Time Probability Distribution Graphs

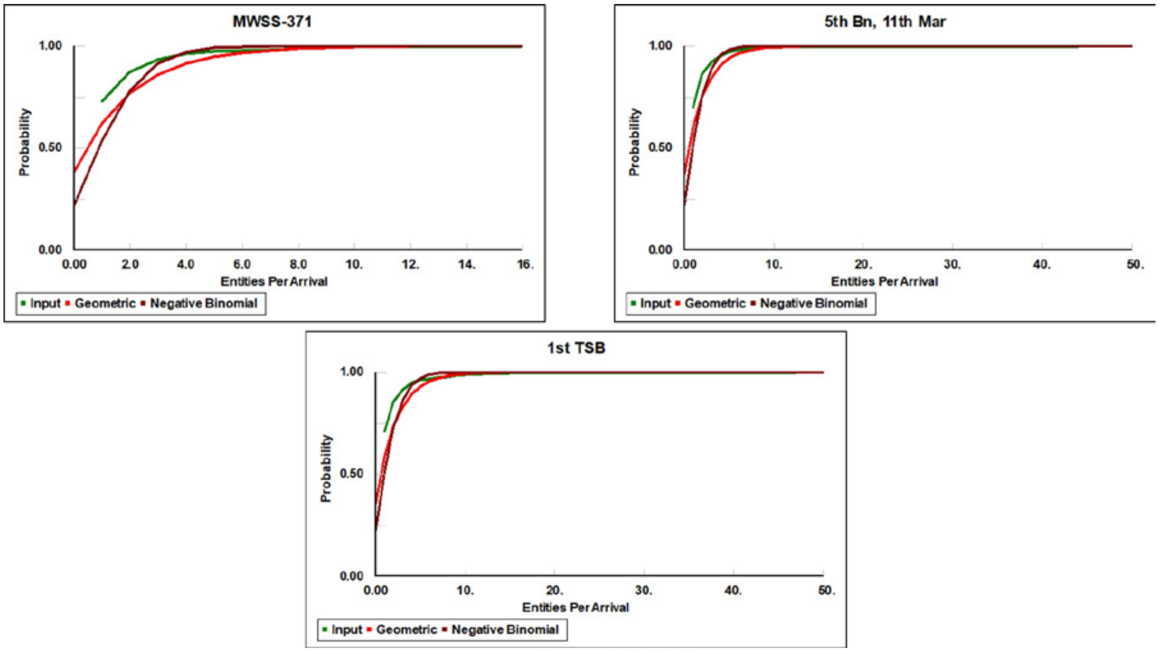


Figure 24. Entities per Arrival Probability Distribution Graphs

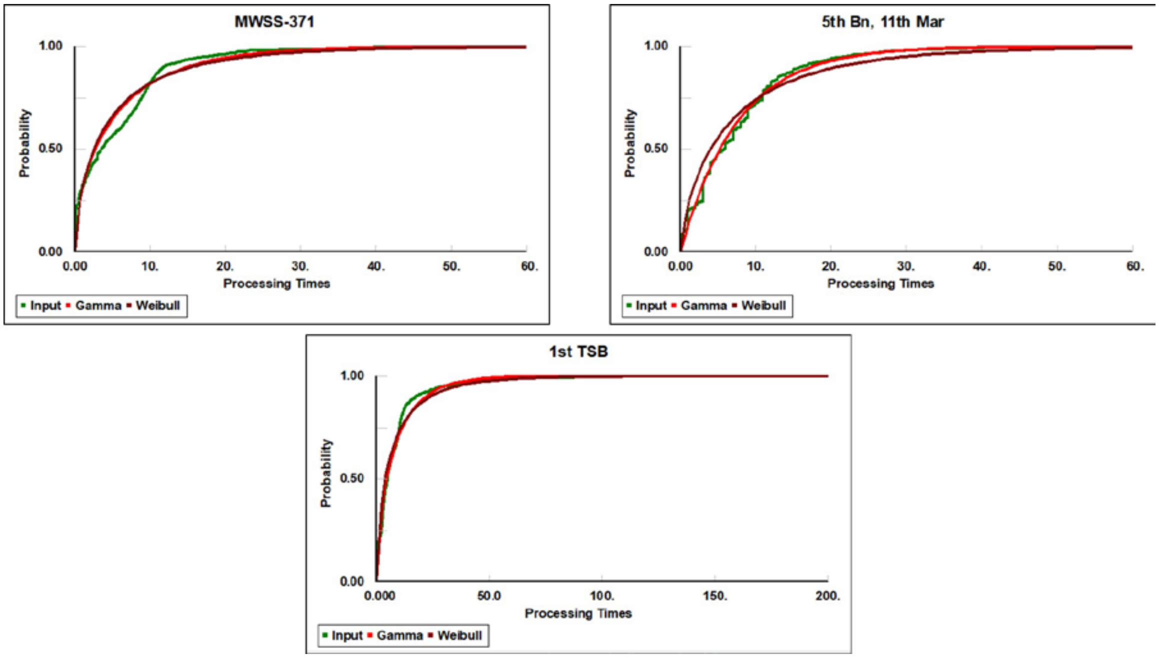


Figure 25. Processing Time Probability Distribution Graphs

B. MODEL FACTORS

For each model created in this thesis, the factors include the number of maintainers assigned; input distributions and parameters for inter-arrival and processing times as well as entities per arrival; and work schedules. Input distributions and work schedules do not vary during the run of the experiments. The author sets these factors in the “source,” “worker,” “server,” and “workstation” resource objects’ property windows. The number of maintainers assigned does vary within the experiments. The author uses the average number of maintainers available to perform maintenance—as described by the motor transport maintenance officers and chiefs from each unit—as the low level of maintainers assigned. To assign the high level, the author uses the staffing goals produced from the workload evaluation method.

C. MODEL RESPONSES

The primary objective of this thesis is to provide a proof of concept for a manpower planning method that relates changes in the number of Marines available to perform maintenance to materiel readiness of motor transport equipment at the organizational command level. To that end, the primary response variable includes the mean time in maintenance (days). The secondary responses include the number of maintainers and the mechanic utilization rate. The mechanic utilization rate does not represent a goal but informs decision makers of the stress placed upon maintainers based upon a particular staffing level. It also reveals the percentage of maintainers available to perform ancillary duties while meeting the target of less than 30 days of mean time in maintenance. Informative responses include the average number of equipment in the system and the mechanic idle rate. The mechanic idle rate coupled with the mechanic utilization rate allows planners at the organizational level to predetermine the number of mechanics to provide to support other duties, such as camp support duties, retirement ceremonies, and changes of command without experiencing decreased maintenance productivity. Figures 26 and 27 show the formulas for the primary response and the mechanic utilization rate.

$$T = \frac{}{N_i}$$

Where:

$L_i = \text{total labor hours for end item of type } i$
$N_i = \text{number of observations for end item of type } i$
$T = \text{average time in system}$

Figure 26. Mean Time in System Formula

$$P = \frac{M_{iu}}{M_{ic}} * 100$$

Where:

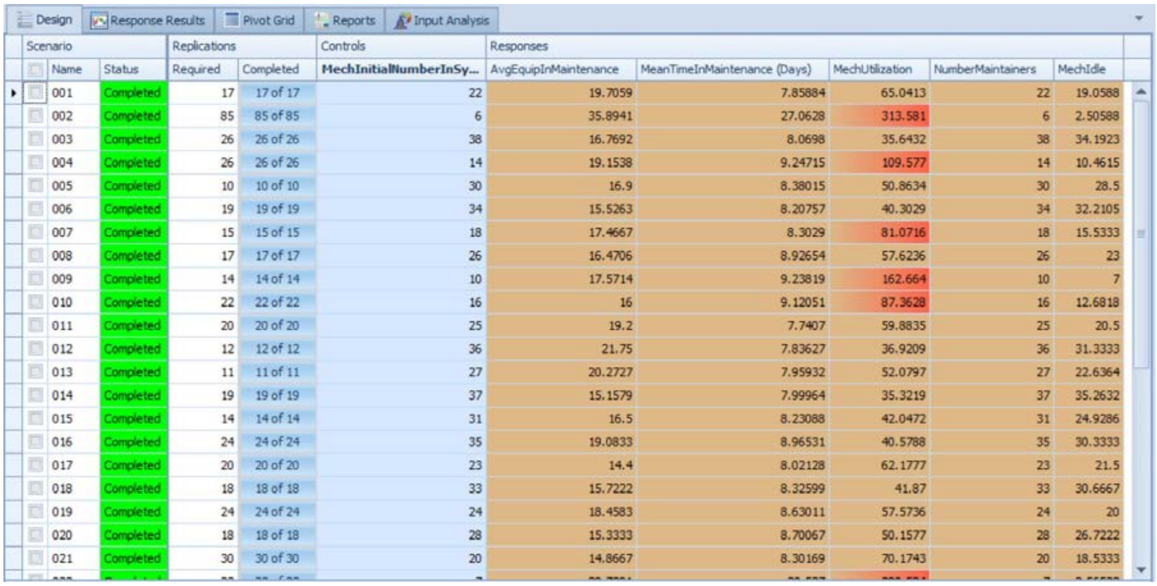
$M_{iu} = \text{average utilization of maintainer of type } i$
$M_{ic} = \text{average capacity of maintainer of type } i$
$P = \text{average utilization}$

Figure 27. Maintainer Utilization Formula

D. FINAL EXPERIMENTAL DESIGN

The optimization experiment is set to run a minimum of 10 replications, a maximum of 200 replications, and a maximum of 300 scenarios over a simulation time of 26, 280 hours or 1095 days. The objective is to minimize the mean time in maintenance (days) subject to a 30-day maximum threshold for mean time in maintenance and an 80% maximum threshold for mechanic utilization rate. To determine the number of scenarios to run, low and high levels are set along with an increment level for the factor number of maintainers assigned. For each model, the author sets the increment level to one for all models while the low and high levels are set at different levels dependent upon the command. The optimization tool, Opt Quest, determines the appropriate number of replications to run for each scenario. The experiment terminates when each scenario completes once. For the models in this thesis, scenarios vary by increasing the number of maintainers assigned, by a quantity of one, beginning at the low levels and ending at the high levels set for each model. Each model contains a garrison optimization experiment as well as a deployed optimization experiment, for six experiments across three models. Figure 28 displays the optimization experiment setup using the Simio optimization add-in tool Opt Quest.

After obtaining the optimal staffing level from the optimization experiments, the author runs one experiment using only the optimal staffing level. The experiment runs for 200 replications over a simulation time of 1095 days. Besides these changes, the experiment setup looks similar to that seen in Figure 28.



Scenario		Replications		Controls	Responses				
Name	Status	Required	Completed	MechInitialNumberInSy...	AvgEquipInMaintenance	MeanTimeInMaintenance (Days)	MechUtilization	NumberMaintainers	MechIdle
001	Completed	17	17 of 17	22	19.7059	7.85884	65.0413	22	19.0588
002	Completed	85	85 of 85	6	35.8941	27.0628	313.581	6	2.50588
003	Completed	26	26 of 26	38	16.7692	8.0698	35.6432	38	34.1923
004	Completed	26	26 of 26	14	19.1538	9.24715	109.577	14	10.4615
005	Completed	10	10 of 10	30	16.9	8.38015	50.8634	30	28.5
006	Completed	19	19 of 19	34	15.5263	8.20757	40.3029	34	32.2105
007	Completed	15	15 of 15	18	17.4667	8.3029	81.0716	18	15.5333
008	Completed	17	17 of 17	26	16.4706	8.92654	57.6236	26	23
009	Completed	14	14 of 14	10	17.5714	9.23819	162.664	10	7
010	Completed	22	22 of 22	16	16	9.12051	87.3628	16	12.6818
011	Completed	20	20 of 20	25	19.2	7.7407	59.8835	25	20.5
012	Completed	12	12 of 12	36	21.75	7.83627	36.9209	36	31.3333
013	Completed	11	11 of 11	27	20.2727	7.95932	52.0797	27	22.6364
014	Completed	19	19 of 19	37	15.1579	7.99964	35.3219	37	35.2632
015	Completed	14	14 of 14	31	16.5	8.23088	42.0472	31	24.9286
016	Completed	24	24 of 24	35	19.0833	8.96531	40.5788	35	30.3333
017	Completed	20	20 of 20	23	14.4	8.02128	62.1777	23	21.5
018	Completed	18	18 of 18	33	15.7222	8.32599	41.87	33	30.6667
019	Completed	24	24 of 24	24	18.4583	8.63011	57.5736	24	20
020	Completed	18	18 of 18	28	15.3333	8.70067	50.1577	28	26.7222
021	Completed	30	30 of 30	20	14.8667	8.30169	70.1743	20	18.5333

Figure 28. Final Experiment Design Using Simio Optimization Tool Opt Quest

E. SUMMARY

This chapter briefly described data distribution fitting, the model factors and responses, and the final experimental design. The next chapter discusses the results of the workload evaluation method and the simulation models created in this thesis.

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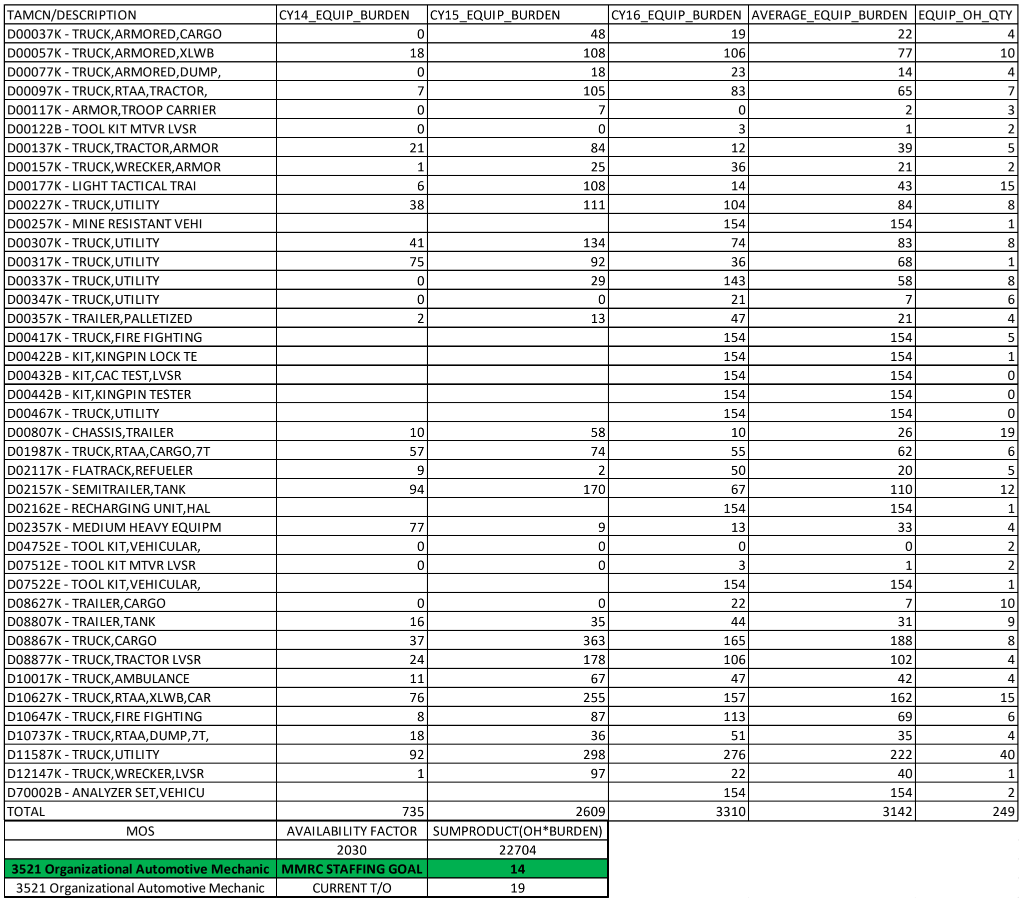
V. RESULTS

A. WORKLOAD EVALUATION METHOD

This section provides the results of the workload evaluation method for each command. Figure 29 presents an MMRC staffing goal of 14 for MWSS-371. This method produced a maintainer requirement that equals five less than the current T/O. The command's total average equipment burden across three years equals 3142 hours based upon the data. Calculating the sum product of the total average equipment burden and O/H quantities of each TAMCN, the total annual equipment burden for motor transport equipment equals 22,704 hours. Based upon a 7-hour workday available for maintenance multiplied by 236 days, the availability factor for one maintainer at this command equals 1652 hours.

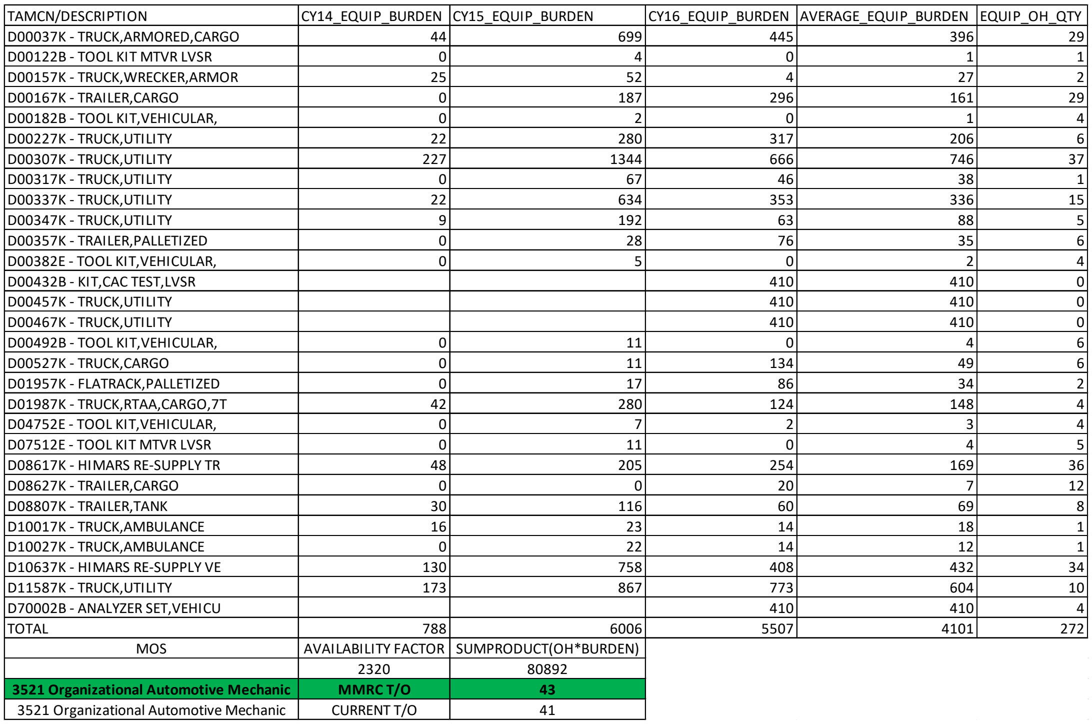


TAMCN/DESCRIPTION	CY14_EQUIP_BURDEN	CY15_EQUIP_BURDEN	CY16_EQUIP_BURDEN	AVERAGE_EQUIP_BURDEN	EQUIP_OH_QTY
D00037K - TRUCK,ARMORED,CARGO	0	48	19	22	4
D00057K - TRUCK,ARMORED,XLWB	18	108	106	77	10
D00077K - TRUCK,ARMORED,DUMP,	0	18	23	14	4
D00097K - TRUCK,RTAA,TRACTOR,	7	105	83	65	7
D00117K - ARMOR,TROOP CARRIER	0	7	0	2	3
D00122B - TOOL KIT MTVR LVSR	0	0	3	1	2
D00137K - TRUCK,TRACTOR,ARMOR	21	84	12	39	5
D00157K - TRUCK,WRECKER,ARMOR	1	25	36	21	2
D00177K - LIGHT TACTICAL TRAI	6	108	14	43	15
D00227K - TRUCK,UTILITY	38	111	104	84	8
D00257K - MINE RESISTANT VEHI			154	154	1
D00307K - TRUCK,UTILITY	41	134	74	83	8
D00317K - TRUCK,UTILITY	75	92	36	68	1
D00337K - TRUCK,UTILITY	0	29	143	58	8
D00347K - TRUCK,UTILITY	0	0	21	7	6
D00357K - TRAILER,PALLETIZED	2	13	47	21	4
D00417K - TRUCK,FIRE FIGHTING			154	154	5
D00422B - KIT,KINGPIN LOCK TE			154	154	1
D00432B - KIT,CAC TEST,LVSR			154	154	0
D00442B - KIT,KINGPIN TESTER			154	154	0
D00467K - TRUCK,UTILITY			154	154	0
D00807K - CHASSIS,TRAILER	10	58	10	26	19
D01987K - TRUCK,RTAA,CARGO,7T	57	74	55	62	6
D02117K - FLATRACK,REFUELER	9	2	50	20	5
D02157K - SEMITRAILER,TANK	94	170	67	110	12
D02162E - RECHARGING UNIT,HAL			154	154	1
D02357K - MEDIUM HEAVY EQUIPM	77	9	13	33	4
D04752E - TOOL KIT,VEHICULAR,	0	0	0	0	2
D07512E - TOOL KIT MTVR LVSR	0	0	3	1	2
D07522E - TOOL KIT,VEHICULAR,			154	154	1
D08627K - TRAILER,CARGO	0	0	22	7	10
D08807K - TRAILER,TANK	16	35	44	31	9
D08867K - TRUCK,CARGO	37	363	165	188	8
D08877K - TRUCK,TRACTOR LVSR	24	178	106	102	4
D10017K - TRUCK,AMBULANCE	11	67	47	42	4
D10627K - TRUCK,RTAA,XLWB,CAR	76	255	157	162	15
D10647K - TRUCK,FIRE FIGHTING	8	87	113	69	6
D10737K - TRUCK,RTAA,DUMP,7T,	18	36	51	35	4
D11587K - TRUCK,UTILITY	92	298	276	222	40
D12147K - TRUCK,WRECKER,LVSR	1	97	22	40	1
D70002B - ANALYZER SET,VEHICU			154	154	2
TOTAL	735	2609	3310	3142	249

MOS	AVAILABILITY FACTOR	SUMPRODUCT(OH*BURDEN)
	2030	22704
3521 Organizational Automotive Mechanic	**MMRC STAFFING GOAL**	**14**
3521 Organizational Automotive Mechanic	CURRENT T/O	19

Figure 29. MWSS-371 Workload Evaluation Output

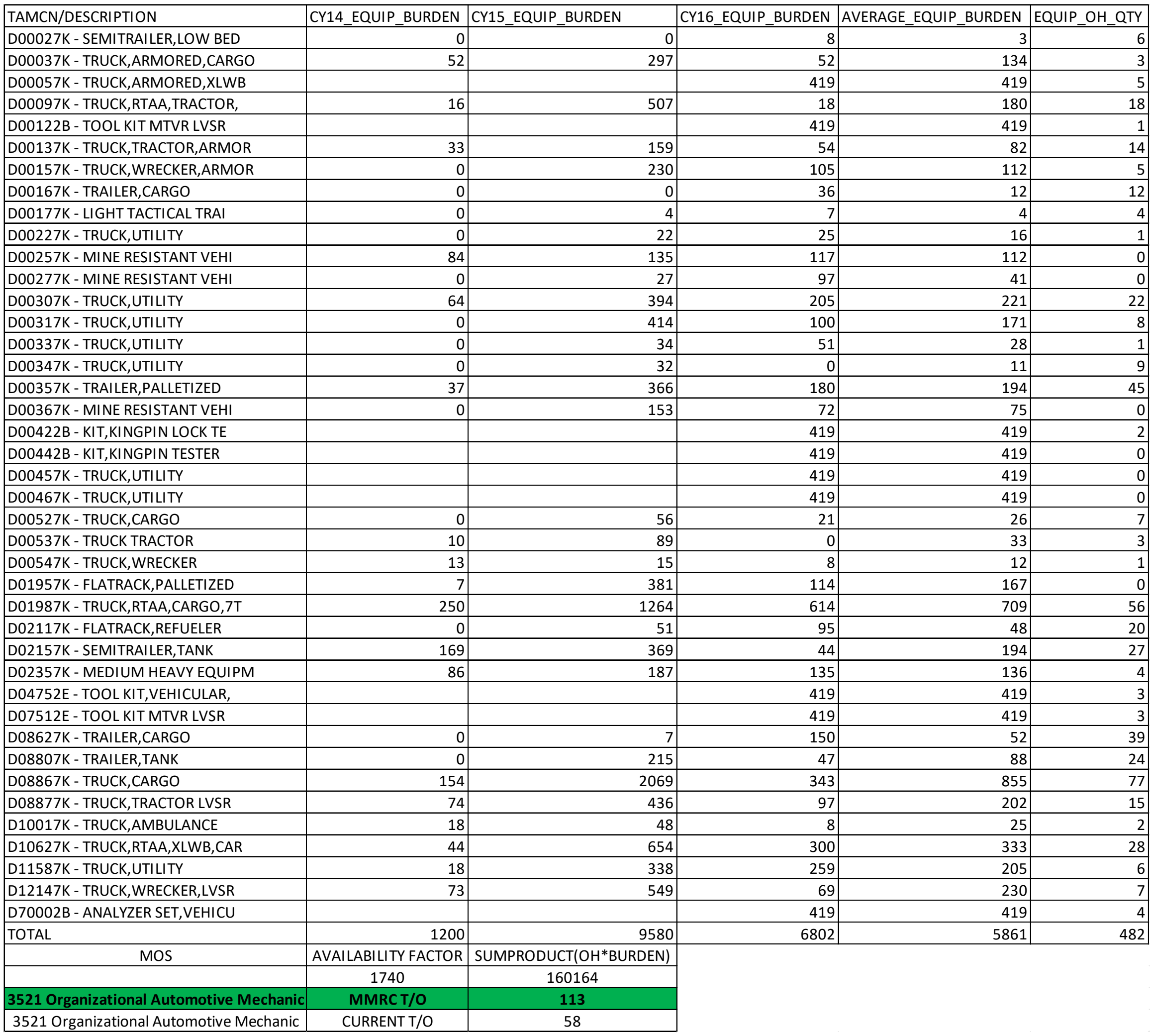
Figure 30 presents an MMRC staffing goal of 43 for 5/11. This method produced a maintainer requirement that equals two more than the current T/O. The command's total average equipment burden across three years equals 4101 hours based upon the data. Calculating the sum product of the total average equipment burden and O/H quantities of each TAMCN, the total annual equipment burden for motor transport equipment equals 80,892 hours. Based upon an 8-hour workday on average available for maintenance multiplied by 236 days, the availability factor for one maintainer at this command equals 1888 hours.



TAMCN/DESCRIPTION	CY14_EQUIP_BURDEN	CY15_EQUIP_BURDEN	CY16_EQUIP_BURDEN	AVERAGE_EQUIP_BURDEN	EQUIP_OH_QTY
D00037K - TRUCK,ARMORED,CARGO	44	699	445	396	29
D00122B - TOOL KIT MTVR LVSR	0	4	0	1	1
D00157K - TRUCK,WRECKER,ARMOR	25	52	4	27	2
D00167K - TRAILER,CARGO	0	187	296	161	29
D00182B - TOOL KIT,VEHICULAR,	0	2	0	1	4
D00227K - TRUCK,UTILITY	22	280	317	206	6
D00307K - TRUCK,UTILITY	227	1344	666	746	37
D00317K - TRUCK,UTILITY	0	67	46	38	1
D00337K - TRUCK,UTILITY	22	634	353	336	15
D00347K - TRUCK,UTILITY	9	192	63	88	5
D00357K - TRAILER,PALLETIZED	0	28	76	35	6
D00382E - TOOL KIT,VEHICULAR,	0	5	0	2	4
D00432B - KIT,CAC TEST,LVSR			410	410	0
D00457K - TRUCK,UTILITY			410	410	0
D00467K - TRUCK,UTILITY			410	410	0
D00492B - TOOL KIT,VEHICULAR,	0	11	0	4	6
D00527K - TRUCK,CARGO	0	11	134	49	6
D01957K - FLATRACK,PALLETIZED	0	17	86	34	2
D01987K - TRUCK,RTAA,CARGO,7T	42	280	124	148	4
D04752E - TOOL KIT,VEHICULAR,	0	7	2	3	4
D07512E - TOOL KIT MTVR LVSR	0	11	0	4	5
D08617K - HIMARS RE-SUPPLY TR	48	205	254	169	36
D08627K - TRAILER,CARGO	0	0	20	7	12
D08807K - TRAILER,TANK	30	116	60	69	8
D10017K - TRUCK,AMBULANCE	16	23	14	18	1
D10027K - TRUCK,AMBULANCE	0	22	14	12	1
D10637K - HIMARS RE-SUPPLY VE	130	758	408	432	34
D11587K - TRUCK,UTILITY	173	867	773	604	10
D70002B - ANALYZER SET,VEHICU			410	410	4
TOTAL	788	6006	5507	4101	272
MOS	AVAILABILITY FACTOR	SUMPRODUCT(OH*BURDEN)			
	2320	80892			
3521 Organizational Automotive Mechanic	**MMRC T/O**	**43**			
3521 Organizational Automotive Mechanic	CURRENT T/O	41			

Figure 30. 5/11 Workload Evaluation Output

Figure 31 presents an MMRC staffing goal of 113 for 1st TSB. This method produced a maintainer requirement that equals 55 more than the current T/O. The command's total average equipment burden across three years equals 5861 hours based upon the data. Calculating the sum product of the total average equipment burden and O/H quantities of each TAMCN, the total annual equipment burden for motor transport equipment equals 160,164 hours. Based upon a 6-hour workday on average available for maintenance multiplied by 236 days, the availability factor for one maintainer at this command equals 1416 hours.



TAMCN/DESCRIPTION	CY14_EQUIP_BURDEN	CY15_EQUIP_BURDEN	CY16_EQUIP_BURDEN	AVERAGE_EQUIP_BURDEN	EQUIP_OH_QTY
D00027K - SEMITRAILER,LOW BED	0	0	8	3	6
D00037K - TRUCK,ARMORED,CARGO	52	297	52	134	3
D00057K - TRUCK,ARMORED,XLWB			419	419	5
D00097K - TRUCK,RTAA,TRACTOR,	16	507	18	180	18
D00122B - TOOL KIT MTVR LVSR			419	419	1
D00137K - TRUCK,TRACTOR,ARMOR	33	159	54	82	14
D00157K - TRUCK,WRECKER,ARMOR	0	230	105	112	5
D00167K - TRAILER,CARGO	0	0	36	12	12
D00177K - LIGHT TACTICAL TRAI	0	4	7	4	4
D00227K - TRUCK,UTILITY	0	22	25	16	1
D00257K - MINE RESISTANT VEHI	84	135	117	112	0
D00277K - MINE RESISTANT VEHI	0	27	97	41	0
D00307K - TRUCK,UTILITY	64	394	205	221	22
D00317K - TRUCK,UTILITY	0	414	100	171	8
D00337K - TRUCK,UTILITY	0	34	51	28	1
D00347K - TRUCK,UTILITY	0	32	0	11	9
D00357K - TRAILER,PALLETIZED	37	366	180	194	45
D00367K - MINE RESISTANT VEHI	0	153	72	75	0
D00422B - KIT,KINGPIN LOCK TE			419	419	2
D00442B - KIT,KINGPIN TESTER			419	419	0
D00457K - TRUCK,UTILITY			419	419	0
D00467K - TRUCK,UTILITY			419	419	0
D00527K - TRUCK,CARGO	0	56	21	26	7
D00537K - TRUCK TRACTOR	10	89	0	33	3
D00547K - TRUCK,WRECKER	13	15	8	12	1
D01957K - FLATRACK,PALLETIZED	7	381	114	167	0
D01987K - TRUCK,RTAA,CARGO,7T	250	1264	614	709	56
D02117K - FLATRACK,REFUELER	0	51	95	48	20
D02157K - SEMITRAILER,TANK	169	369	44	194	27
D02357K - MEDIUM HEAVY EQUIPM	86	187	135	136	4
D04752E - TOOL KIT,VEHICULAR,			419	419	3
D07512E - TOOL KIT MTVR LVSR			419	419	3
D08627K - TRAILER,CARGO	0	7	150	52	39
D08807K - TRAILER,TANK	0	215	47	88	24
D08867K - TRUCK,CARGO	154	2069	343	855	77
D08877K - TRUCK,TRACTOR LVSR	74	436	97	202	15
D10017K - TRUCK,AMBULANCE	18	48	8	25	2
D10627K - TRUCK,RTAA,XLWB,CAR	44	654	300	333	28
D11587K - TRUCK,UTILITY	18	338	259	205	6
D12147K - TRUCK,WRECKER,LVSR	73	549	69	230	7
D70002B - ANALYZER SET,VEHICU			419	419	4
TOTAL	1200	9580	6802	5861	482
MOS	AVAILABILITY FACTOR	SUMPRODUCT(OH*BURDEN)			
	1740	160164			
3521 Organizational Automotive Mechanic	**MMRC T/O**	**113**			
3521 Organizational Automotive Mechanic	CURRENT T/O	58			

Figure 31. 1st TSB Workload Evaluation Output

B. SIMULATION MODEL

This section provides the results of the simulation modeling method for each command. The author uses JMP Pro 13 to analyze each model's results. The author presents summary data, output distributions, and line graphs (highlights optimal staffing level) for mean time in maintenance (days), mean maintainer utilization rate, and mean maintainer idle rate. Garrison scenario results are discussed first followed by deployed scenario results.

1. Garrison Scenario Results

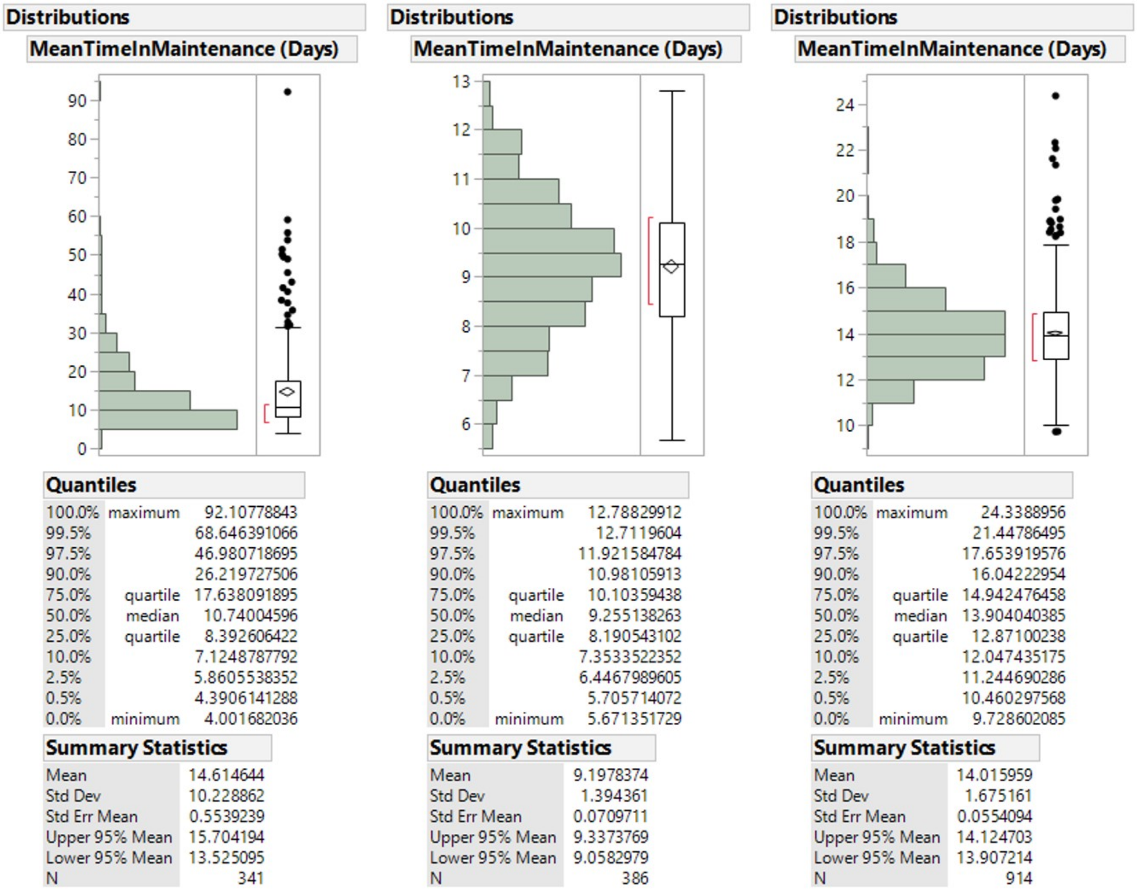
Table 2 provides summary statistics for each unit analyzed in this thesis. Beginning with the primary response variable, 75% of motor transport equipment enters and exits the maintenance system within approximately 20 days or less across the range of staffing levels applied to this scenario. Looking at the maintainer utilization rate, the data suggests that MWSS-371 and 1st TSB's mechanics possess no flexibility within their systems to perform other tasks. However, the maintainer idle rate for these commands suggest that some slack exists within their respective maintenance systems.

Table 2. Garrison Optimization Summary Data for MWSS-371,5/11, and 1st TSB

MWSS-371						
Response	Min	25%	Median	Mean	75%	Max
MeanTimeInMaintenance (Days)	4.00	8.39	10.74	14.61	17.64	92.11
MaintainerUtilization	50.13	94.89	145.81	180.13	266.34	474.16
NumberMaintainers	6.00	6.50	11.00	11.32	15.00	19.00
MaintainerIdle	0.00	0.00	2.12	2.52	4.26	9.56
EquipInMaintenance	4.00	13.00	18.00	24.58	27.00	146.00
5th Bn, 11th Mar						
Response	Min	25%	Median	Mean	75%	Max
MeanTimeInMaintenance (Days)	5.67	8.19	9.26	9.20	10.10	12.79
MaintainerUtilization	27.14	47.49	64.23	71.43	87.03	175.00
NumberMaintainers	12.00	19.00	27.50	27.46	35.00	43.00
MaintainerIdle	0.00	3.75	5.59	5.75	7.74	15.17
EquipInMaintenance	9.00	22.75	29.00	32.45	38.00	94.00
1st TSB						
Response	Min	25%	Median	Mean	75%	Max
MeanTimeInMaintenance (Days)	9.73	12.87	13.90	14.02	14.94	24.34
MaintainerUtilization	67.80	101.29	135.57	162.95	202.54	456.18
NumberMaintainers	24.00	45.00	68.00	68.23	91.00	113.00
MaintainerIdle	0.00	1.75	3.12	3.18	4.57	7.99
EquipInMaintenance	13.00	39.00	52.00	57.12	69.00	261.00

a. *Optimization and Staffing Level Experiments*

This section provides results of the optimization and staffing level experiments for each command analyzed in this thesis. The author begins with providing and discussing the mean time in maintenance quantile and summary statistics from each command's optimization experiment. Then the author discusses the process of selecting the optimal staffing level. Finally, the author discusses the results of the selected staffing level experiments. Figure 32 provides opportunity for deeper analysis of the primary response for each command. The author uses JMP Pro 13 to develop this figure.



Quantiles

100.0%	maximum	92.10778843
99.5%		68.646391066
97.5%		46.980718695
90.0%		26.219727506
75.0%	quartile	17.638091895
50.0%	median	10.74004596
25.0%	quartile	8.392606422
10.0%		7.1248787792
2.5%		5.8605538352
0.5%		4.3906141288
0.0%	minimum	4.001682036

Summary Statistics

Mean	14.614644
Std Dev	10.228862
Std Err Mean	0.5539239
Upper 95% Mean	15.704194
Lower 95% Mean	13.525095
N	341

Quantiles

100.0%	maximum	12.78829912
99.5%		12.7119604
97.5%		11.921584784
90.0%		10.98105913
75.0%	quartile	10.10359438
50.0%	median	9.255138263
25.0%	quartile	8.190543102
10.0%		7.3533522352
2.5%		6.4467989605
0.5%		5.705714072
0.0%	minimum	5.671351729

Summary Statistics

Mean	9.1978374
Std Dev	1.394361
Std Err Mean	0.0709711
Upper 95% Mean	9.3373769
Lower 95% Mean	9.0582979
N	386

Quantiles

100.0%	maximum	24.3388956
99.5%		21.44786495
97.5%		17.653919576
90.0%		16.04222954
75.0%	quartile	14.942476458
50.0%	median	13.904040385
25.0%	quartile	12.87100238
10.0%		12.047435175
2.5%		11.244690286
0.5%		10.460297568
0.0%	minimum	9.728602085

Summary Statistics

Mean	14.015959
Std Dev	1.675161
Std Err Mean	0.0554094
Upper 95% Mean	14.124703
Lower 95% Mean	13.907214
N	914

From left to right, MWSS-371, 5/11, and 1st TSB

Figure 32. Garrison Optimization Mean Time In Maintenance Distributions

At first glance, the summary statistics reveal an average time in maintenance of less than 30 days for each command. Because the optimization experiment contains varying maintainer staffing levels, this statistic implies that each staffing level can achieve the goal for mean time in maintenance of less than or equal to 30 days. Even better is the fact that 90% of all equipment entering maintenance should return to the customer in 30 days or less across all commands at all staffing levels. Marine Wing Support Squadron Three Seven One experiences the highest turn-around time of 26 days or less across all staffing levels for 90% of all equipment entering the maintenance cycle. Neither Table 2 nor Figure 32 provide the answer to the main question regarding the optimal number of mechanics to assign to a command that minimizes the number of days equipment inducted into maintenance remains in the maintenance cycle. We cover this aspect of the research next.

Figure 33 reveals two potential optimal staffing levels of 17 and 19 maintainers that yield a mean time in maintenance of approximately eight and nine days respectively. At 17 maintainers, the mean maintainer scheduled utilization rate equals approximately 85% with a mean maintainer idle rate of approximately 4%. At 19 maintainers, the mean maintainer scheduled utilization rate equals 74% with an idle rate of nearly 6%. Referring back to Figure 29 in this chapter, the simulation method produced potential optimal staffing levels for MWSS-371 equaling three to five more maintainers than that produced by the workload evaluation method. The close proximity of the results for both 17 and 19 maintainer presents a decision point in the manpower planning process. Do planners decide to decrease the staffing level to 17 in order to gain only one day of shortened mean time in maintenance or maintain the status quo? The author feels the more prudent choice is to maintain the status quo.

With the optimal staffing level selected, the author runs an experiment with 19 maintainers in the system. This allows for analysis of maintenance effectiveness at the optimal staffing level. In particular, the author reviews quantile and summary statistics produced by JMP Pro 13 to determine the percentage of equipment processed within the 30-day threshold. If between 75% and 90% results reveal that the command meets the threshold with the staffing level applied with a small confidence interval around the mean, this signals to the author adequate assignment of staffing level to the command.

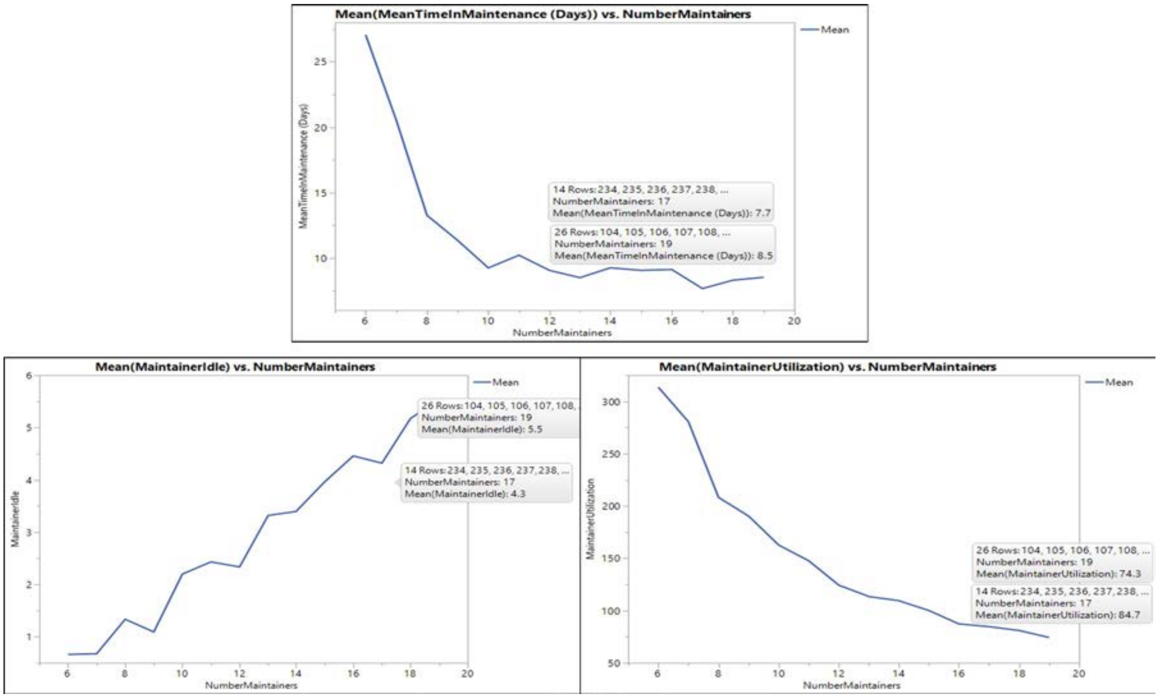
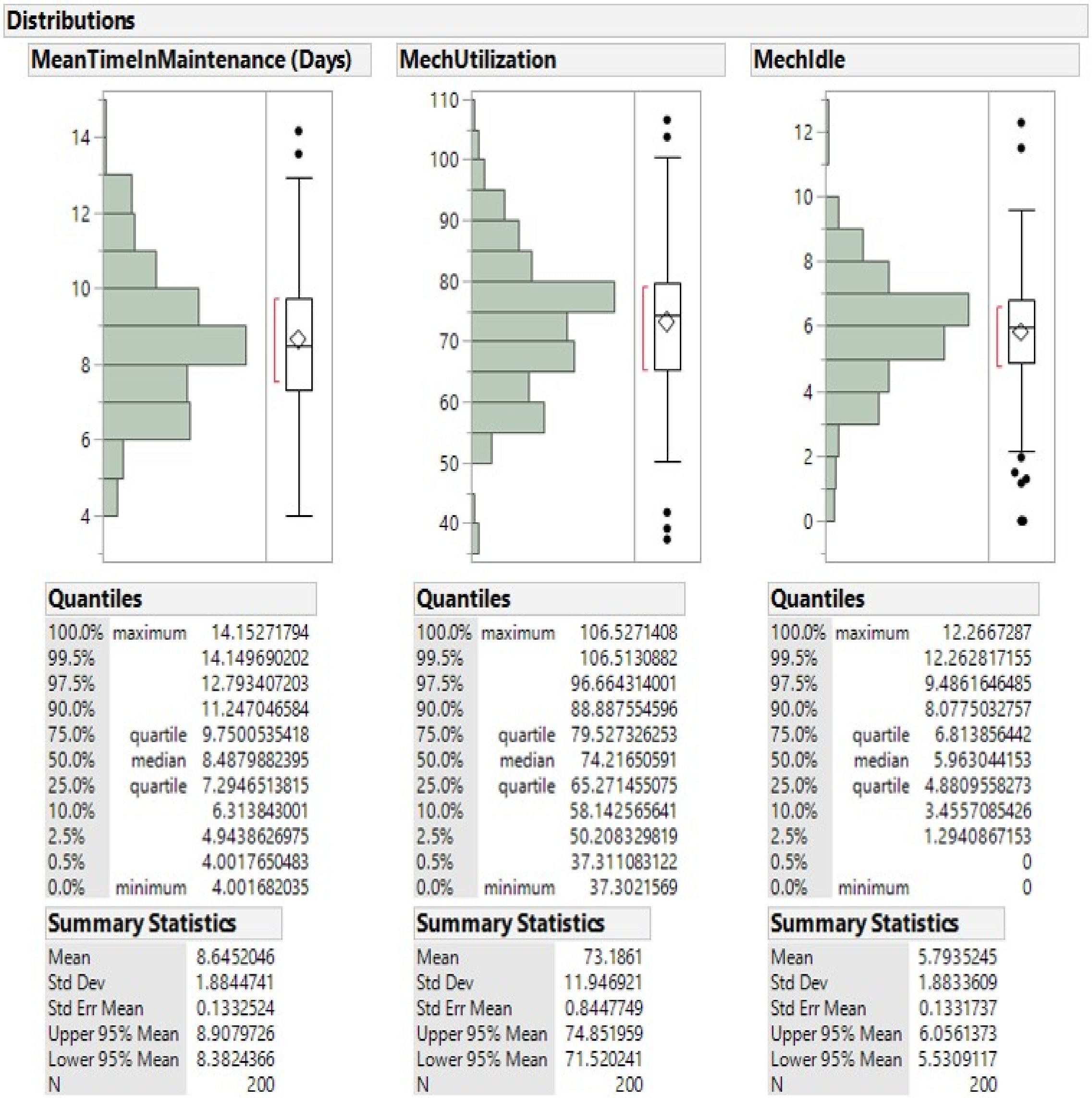


Figure 33. MWSS-371 Garrison Optimization Graphs

The estimated mean time in maintenance, maintainer utilization, and maintainer idle response at 19 maintainers are 8.5 days, 74.3%, and 5.5%, respectively, per Figure 33. Figure 34 reveals a mean time in maintenance of 8.6 days with a 95% confidence interval of [8.4, 8.9], an average maintainer utilization rate of 73.2% with a 95% confidence interval of [71.5%, 74.9%], and an average maintainer idle rate of 5.8% with a 95% confidence interval of [5.5%, 6.1%]. The small difference in outputs between the results of the optimization experiment and those of the staffing level experiment highlights the validity in selecting a staffing level based upon this process. Of note, a staffing level of 19 maintainers for this command supports a 14-day or less average time in maintenance. However, beyond the 75th percentile, MWSS-371 begins to experience a utilization rate higher than the threshold of 80%. Annual preventative maintenance may explain this ten percent occurrence of high utilization rate. This could inform the commanding officer of the need to assign more incidental drivers to preventative maintenance missions if this tool were used at the organizational level.



Distributions

MeanTimeInMaintenance (Days)

Quantiles

100.0%	maximum	14.15271794
99.5%		14.149690202
97.5%		12.793407203
90.0%		11.247046584
75.0%	quartile	9.7500535418
50.0%	median	8.4879882395
25.0%	quartile	7.2946513815
10.0%		6.313843001
2.5%		4.9438626975
0.5%		4.0017650483
0.0%	minimum	4.001682035

Summary Statistics

Mean	8.6452046
Std Dev	1.8844741
Std Err Mean	0.1332524
Upper 95% Mean	8.9079726
Lower 95% Mean	8.3824366
N	200

MechUtilization

Quantiles

100.0%	maximum	106.5271408
99.5%		106.5130882
97.5%		96.664314001
90.0%		88.887554596
75.0%	quartile	79.527326253
50.0%	median	74.21650591
25.0%	quartile	65.271455075
10.0%		58.142565641
2.5%		50.208329819
0.5%		37.311083122
0.0%	minimum	37.3021569

Summary Statistics

Mean	73.1861
Std Dev	11.946921
Std Err Mean	0.8447749
Upper 95% Mean	74.851959
Lower 95% Mean	71.520241
N	200

MechIdle

Quantiles

100.0%	maximum	12.2667287
99.5%		12.262817155
97.5%		9.4861646485
90.0%		8.0775032757
75.0%	quartile	6.813856442
50.0%	median	5.963044153
25.0%	quartile	4.8809558273
10.0%		3.4557085426
2.5%		1.2940867153
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	5.7935245
Std Dev	1.8833609
Std Err Mean	0.1331737
Upper 95% Mean	6.0561373
Lower 95% Mean	5.5309117
N	200

Figure 34. MWSS-371 Garrison Optimal Staffing Level Primary and Secondary Outputs Distributions at 19 Maintainers

Figure 35 reveals two potential optimal staffing levels of 20 and 37 maintainers that yield a mean time in maintenance of approximately eight days. At 20 maintainers, the mean maintainer scheduled utilization rate equals approximately 80% with a mean maintainer idle rate of approximately 3%. At 37 maintainers, the mean maintainer scheduled utilization rate equals 42% with an idle rate of 9%. Referring back to Figure 30 in this chapter, the simulation method produced an optimal staffing level for 5/11 that is 6 to 23 maintainers less than that produced by the workload evaluation method. With a mean maintainer utilization rate of 42%, the author eliminates a staffing level of 37 from a possible garrison staffing level and instead selects a staffing level of 20 for 5/11.

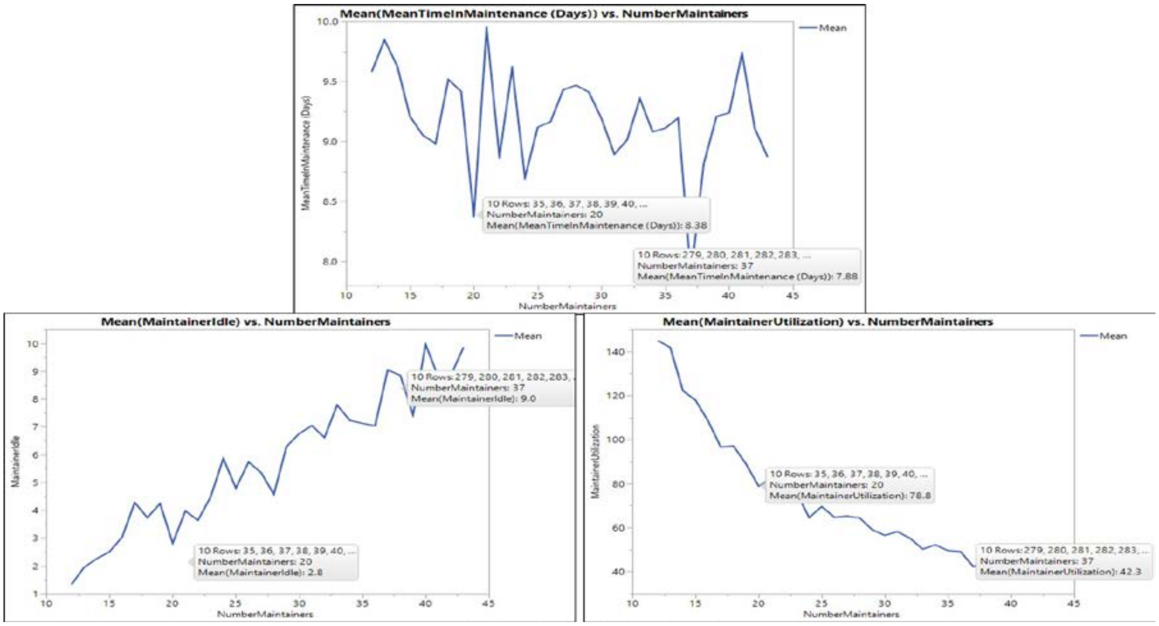
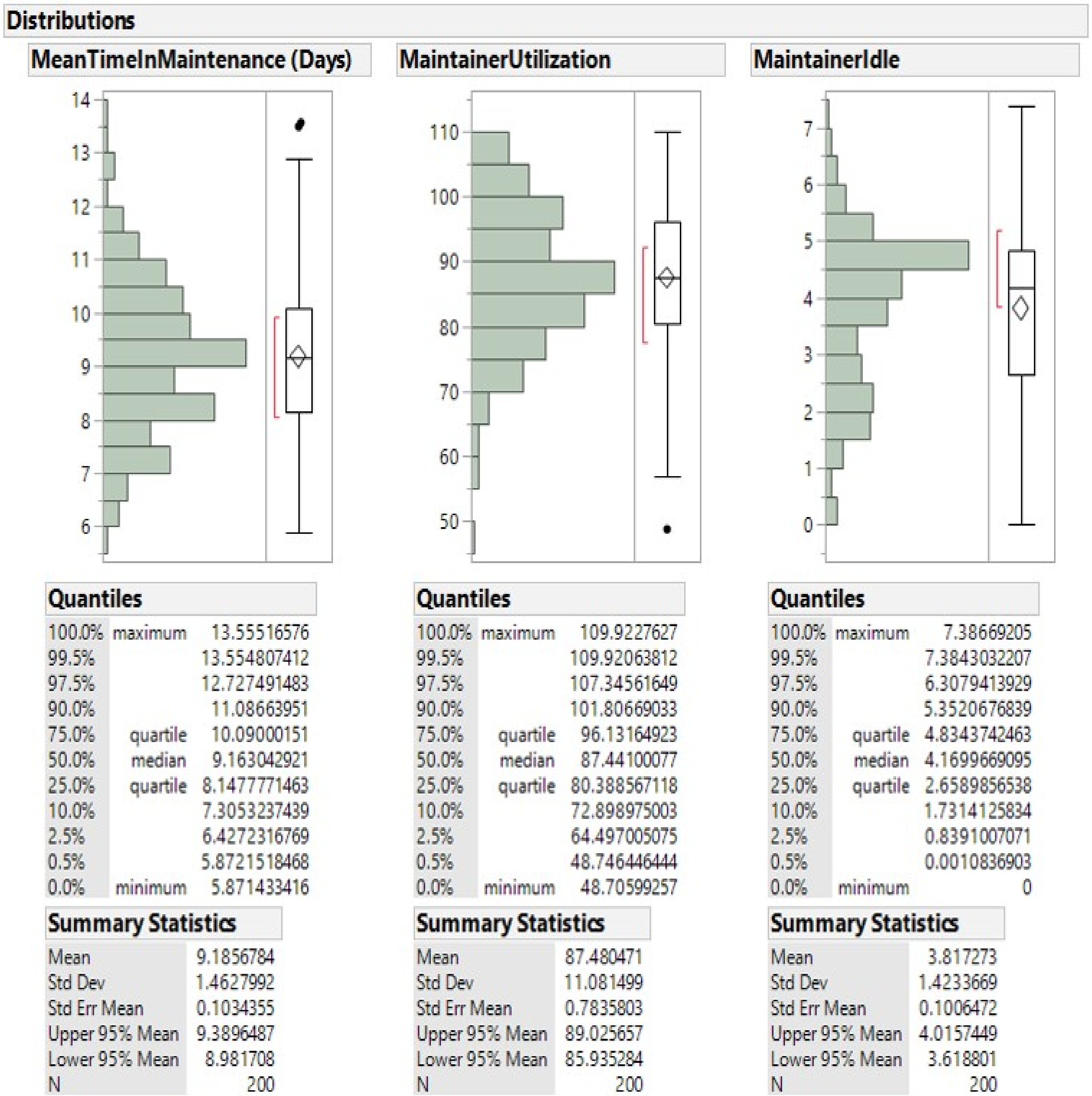


Figure 35. 5th Bn, 11th Mar Garrison Optimization Graphs

Figure 36 reveals a mean time in maintenance of 9 days with a 95% confidence interval of [8.9, 9.4]. The average scheduled utilization rate equals 87% with a 95% confidence interval of [85.9%, 89%]. The average idle rate equals 4% with a 95% confidence interval of [3.6%, 4%]. From a planning perspective, the 75th percentile statistic for maintainer utilization rate causes me some concern. This indicates that 75% of equipment entering maintenance leads to a maintainer utilization rate of 96% or less. This manning level could potentially inject undesirable consequences, such as a decrease in re-enlistments within the motor transport community due to operations tempo and ground maintenance demand



MeanTimeInMaintenance (Days)

Quantiles

100.0%	maximum	13.55516576
99.5%		13.554807412
97.5%		12.727491483
90.0%		11.08663951
75.0%	quartile	10.09000151
50.0%	median	9.163042921
25.0%	quartile	8.1477771463
10.0%		7.3053237439
2.5%		6.4272316769
0.5%		5.8721518468
0.0%	minimum	5.871433416

Summary Statistics

Mean	9.1856784
Std Dev	1.4627992
Std Err Mean	0.1034355
Upper 95% Mean	9.3896487
Lower 95% Mean	8.981708
N	200

MaintainerUtilization

Quantiles

100.0%	maximum	109.9227627
99.5%		109.92063812
97.5%		107.34561649
90.0%		101.80669033
75.0%	quartile	96.13164923
50.0%	median	87.44100077
25.0%	quartile	80.388567118
10.0%		72.898975003
2.5%		64.497005075
0.5%		48.746446444
0.0%	minimum	48.70599257

Summary Statistics

Mean	87.480471
Std Dev	11.081499
Std Err Mean	0.7835803
Upper 95% Mean	89.025657
Lower 95% Mean	85.935284
N	200

MaintainerIdle

Quantiles

100.0%	maximum	7.38669205
99.5%		7.3843032207
97.5%		6.3079413929
90.0%		5.3520676839
75.0%	quartile	4.8343742463
50.0%	median	4.1699669095
25.0%	quartile	2.6589856538
10.0%		1.7314125834
2.5%		0.8391007071
0.5%		0.0010836903
0.0%	minimum	0

Summary Statistics

Mean	3.817273
Std Dev	1.4233669
Std Err Mean	0.1006472
Upper 95% Mean	4.0157449
Lower 95% Mean	3.618801
N	200

Figure 36. 5th Bn, 11th Mar Garrison Optimal Staffing Level Primary and Secondary Outputs Distributions at 20 Maintainers

Figure 37 reveals an optimal staffing level of 95 maintainers that yield a mean time in maintenance of approximately 13 days. At this staffing level, the mean maintainer scheduled utilization rate equals approximately 93% with a mean maintainer idle rate of approximately 5%. Of note, any staffing level below 90 creates an inflexible system in which maintainer utilization exceeds 100%. Referring back to Figure 31 in this chapter, the simulation method produced an optimal staffing level for 1st TSB that is 18 less than that produced by the workload evaluation method.

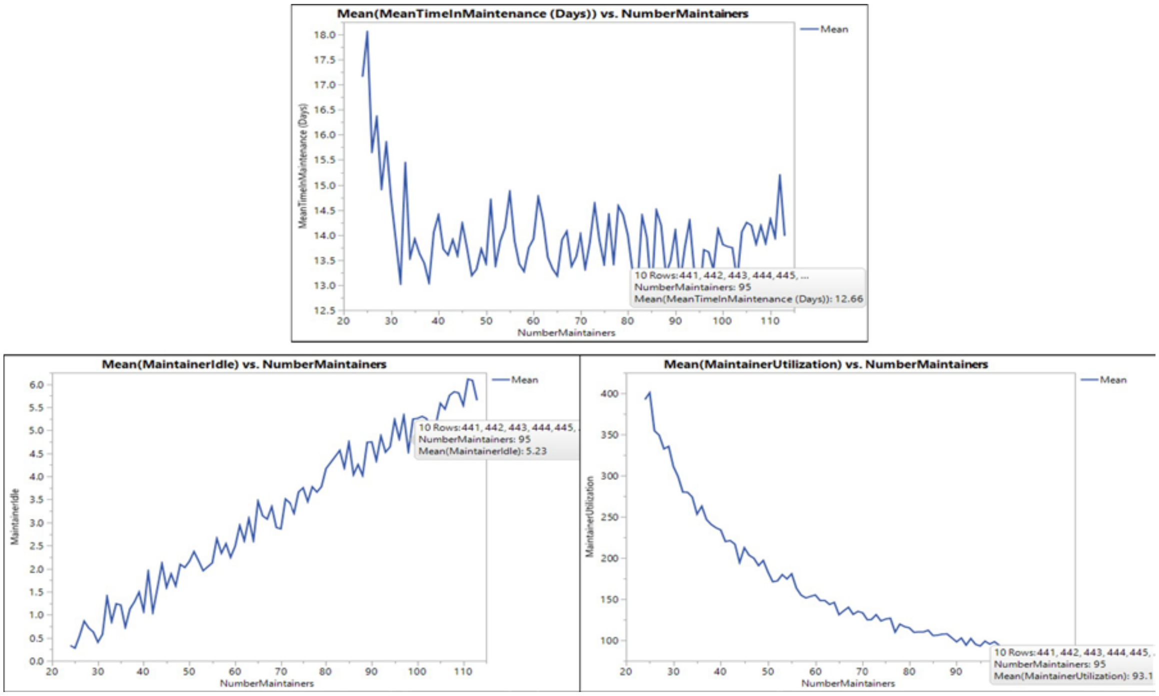
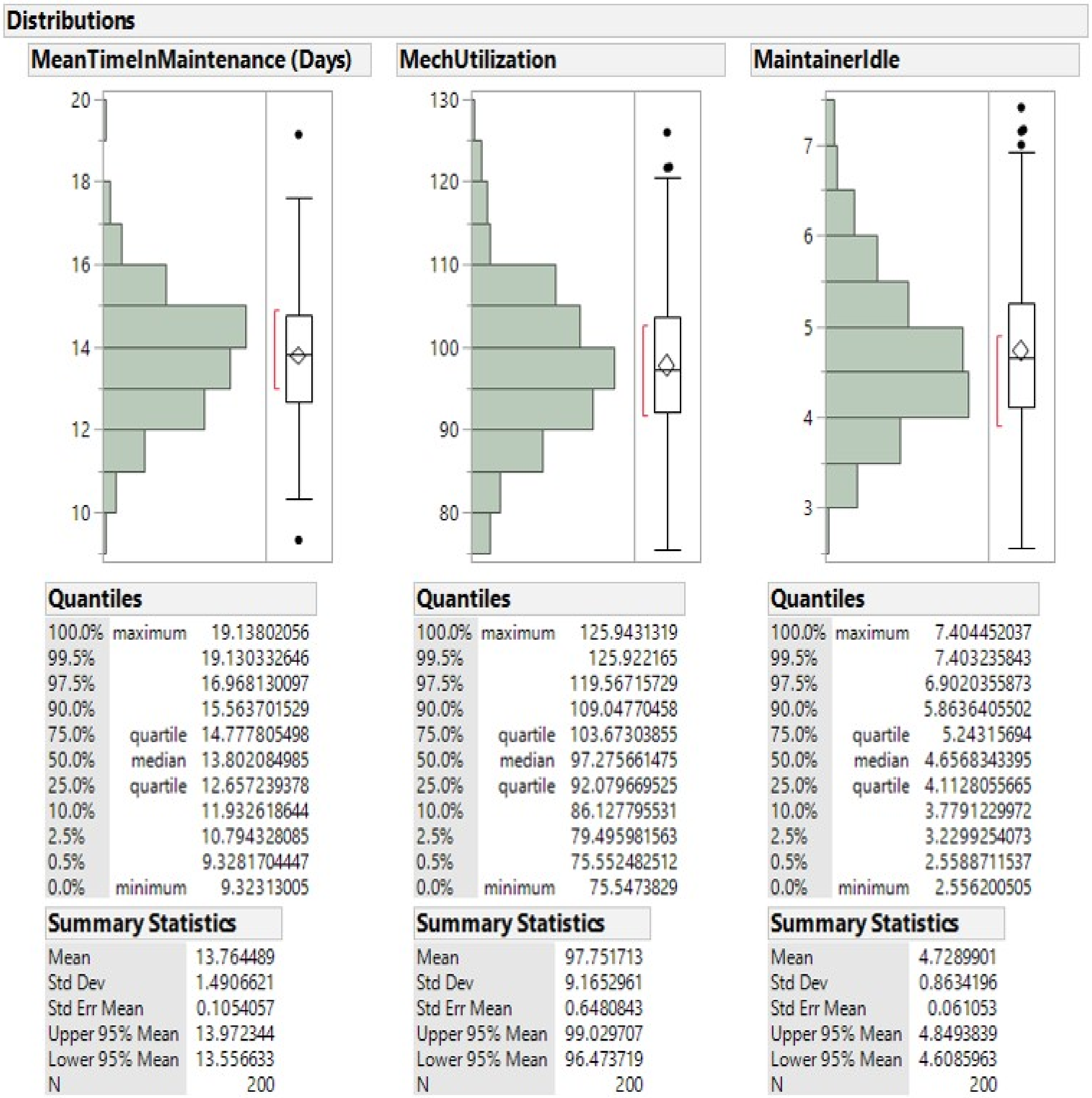


Figure 37. 1st TSB Garrison Optimization Graphs

The statistic of interest from Figure 38 is the average maintainer utilization rate. With an average rate of 97%, this maintenance system could become stressed and lack flexibility to support other tasks. In fact, at the 75th percentile, the utilization rate exceeds 100%. Even the optimal staffing level determination process yielded an average utilization rate above 90%, indicating that the staffing level may require increasing.



Distributions

MeanTimeInMaintenance (Days)

Quantiles

100.0%	maximum	19.13802056
99.5%		19.130332646
97.5%		16.968130097
90.0%		15.563701529
75.0%	quartile	14.777805498
50.0%	median	13.802084985
25.0%	quartile	12.657239378
10.0%		11.932618644
2.5%		10.794328085
0.5%		9.3281704447
0.0%	minimum	9.32313005

Summary Statistics

Mean	13.764489
Std Dev	1.4906621
Std Err Mean	0.1054057
Upper 95% Mean	13.972344
Lower 95% Mean	13.556633
N	200

MechUtilization

Quantiles

100.0%	maximum	125.9431319
99.5%		125.922165
97.5%		119.56715729
90.0%		109.04770458
75.0%	quartile	103.67303855
50.0%	median	97.275661475
25.0%	quartile	92.079669525
10.0%		86.127795531
2.5%		79.495981563
0.5%		75.552482512
0.0%	minimum	75.5473829

Summary Statistics

Mean	97.751713
Std Dev	9.1652961
Std Err Mean	0.6480843
Upper 95% Mean	99.029707
Lower 95% Mean	96.473719
N	200

MaintainerIdle

Quantiles

100.0%	maximum	7.404452037
99.5%		7.403235843
97.5%		6.9020355873
90.0%		5.8636405502
75.0%	quartile	5.24315694
50.0%	median	4.6568343395
25.0%	quartile	4.1128055665
10.0%		3.7791229972
2.5%		3.2299254073
0.5%		2.5588711537
0.0%	minimum	2.556200505

Summary Statistics

Mean	4.7289901
Std Dev	0.8634196
Std Err Mean	0.061053
Upper 95% Mean	4.8493839
Lower 95% Mean	4.6085963
N	200

Figure 38. 1st TSB Garrison Optimal Staffing Level Primary and Secondary Outputs Distributions at 95 Maintainers

2. Deployed Scenario Results

The author uses the same experimental design for deployed scenarios as used in the garrison scenarios. The work schedule factor distinguishes the two scenario types from one another. Given additional time, the author would increase the arrival rate and entities per arrival count. Some experiments lasted several hours due to the amount of memory required to run the Simio simulation software. If adopted, the modeler should change arrival factors to values that would simulate the increased maintenance demand signal experienced in a deployed environment. Since the purpose of this thesis is to introduce a new manpower planning method, changing only the work schedule factor sufficiently demonstrates the different considerations of planning for a garrison staffing level versus that in a deployed environment. Table 3 displays summary statistics for each response from each command's optimization experiment.

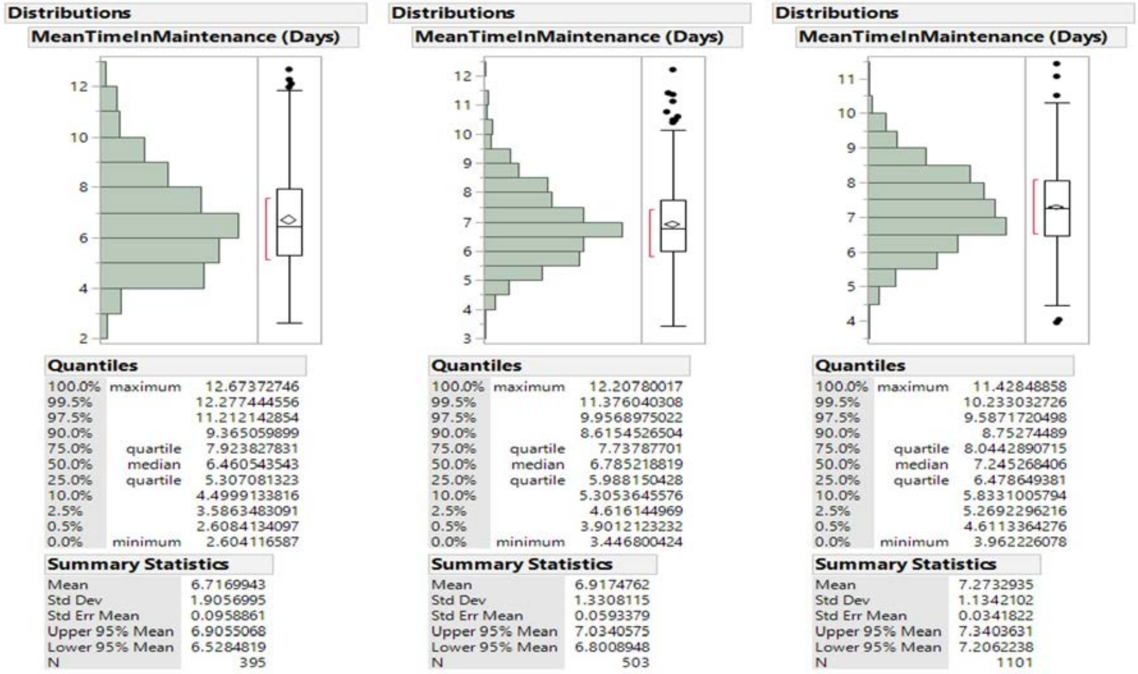
Table 3. Deployed Optimization Summary Data for MWSS-371, 5/11, and 1st TSB

MWSS-371						
Response	Min	25%	Median	Mean	75%	Max
MeanTimeInMaintenance (Days)	2.60	5.31	6.46	6.72	7.92	12.67
MaintainerUtilization	7.89	15.56	19.61	23.68	28.86	69.70
NumberMaintainers	6.00	10.00	13.00	12.94	16.00	19.00
MaintainerIdle	0.00	6.43	9.39	9.24	12.49	23.44
EquipInMaintenance	3.00	11.00	14.00	14.94	17.00	60.00
5th Bn, 11th Mar						
Response	Min	25%	Median	Mean	75%	Max
MeanTimeInMaintenance (Days)	3.45	5.99	6.79	6.92	7.74	12.21
MaintainerUtilization	6.42	11.11	14.72	16.62	20.95	38.32
NumberMaintainers	12.00	19.00	27.00	27.22	35.00	43.00
MaintainerIdle	1.81	8.64	12.75	13.14	17.27	27.93
EquipInMaintenance	7.00	22.00	26.00	26.80	31.00	58.00
1st TSB						
Response	Min	25%	Median	Mean	75%	Max
MeanTimeInMaintenance (Days)	3.96	6.48	7.25	7.27	8.04	11.43
MaintainerUtilization	8.31	12.81	16.86	20.47	25.40	57.69
NumberMaintainers	24.00	46.00	69.00	68.09	89.50	113.00
MaintainerIdle	0.00	7.00	10.83	10.86	14.70	24.05
EquipInMaintenance	15.00	31.00	36.00	37.58	43.00	85.00

As expected, the mean time in maintenance for the deployed scenarios fall below 10 days. With more hours available and no increase in maintenance demand, the system sees an abundance of flexibility to task maintainers to other duties required in a deployed environment, such as mess man, camp police, and camp security.

a. Optimization and Staffing Level Experiments

This section provides results of the deployed optimization and staffing level experiments for each command analyzed in this thesis. The author discusses statistics similar to those discussed in the Garrison Scenario Results section. The first topic of discussion centers on Figure 39.



Quantiles (MWSS-371)

100.0%	maximum	12.67372746
99.5%		12.277444556
97.5%		11.212142854
90.0%		9.365059899
75.0%	quartile	7.923827831
50.0%	median	6.460543543
25.0%	quartile	5.307081323
10.0%		4.4999133816
2.5%		3.5863483091
0.5%		2.6084134097
0.0%	minimum	2.604116587

Summary Statistics

Mean	6.7169943
Std Dev	1.9056995
Std Err Mean	0.0958861
Upper 95% Mean	6.9055068
Lower 95% Mean	6.5284819
N	395

Quantiles

100.0%	maximum	12.20780017
99.5%		11.376040308
97.5%		9.9568975022
90.0%		8.6154526504
75.0%	quartile	7.73787701
50.0%	median	6.785218819
25.0%	quartile	5.988150428
10.0%		5.3053645576
2.5%		4.616144969
0.5%		3.9012123232
0.0%	minimum	3.446800424

Summary Statistics

Mean	6.9174762
Std Dev	1.3308115
Std Err Mean	0.0593379
Upper 95% Mean	7.0340575
Lower 95% Mean	6.8008948
N	503

Quantiles

100.0%	maximum	11.42848858
99.5%		10.233032726
97.5%		9.5871720498
90.0%		8.75274489
75.0%	quartile	8.0442890715
50.0%	median	7.245268406
25.0%	quartile	6.478649381
10.0%		5.8331005794
2.5%		5.2692296216
0.5%		4.6113364276
0.0%	minimum	3.962226078

Summary Statistics

Mean	7.2732935
Std Dev	1.1342102
Std Err Mean	0.0341822
Upper 95% Mean	7.3403631
Lower 95% Mean	7.2062238
N	1101

From left to right MWSS-371, 5/11, and 1st TSB

Figure 39. Deployed Optimization Mean Time in Maintenance Distributions

The first noticeable difference between Figure 32 and Figure 39 exists within the shape of the distributions. In particular, the distribution in Figure 32 for MWSS-371 displays more of an exponential distribution whereas in Figure 39, the distribution appears more normal for the same command. Of note, at no point does either command exceed the 30-day mean time in maintenance threshold. The main takeaway from the significant differences of statistical outputs between the two figures is that increased hours available to perform maintenance correlates with increased maintenance productivity.

The deployed optimization results in Figure 40 present three options to select as the optimal manning level for MWSS-371. Because the average utilization rate does not come close to the maximum threshold of 80%, the author approached this scenario from a perspective of the acceptable minimum utilization rate. The fact that the number corresponding to the best utilization rate, in this case greater than or equal to 50%, lies in the single digit range should not deter a planner from assigning a staffing level of six maintainers to a command. However, the modeler should ensure that the parameter and distribution inputs represent reality. As mentioned earlier, the deployed models in this thesis lack the increased maintenance demand one expects to experience in a deployed environment. Based upon the selection criteria for mean time in maintenance and scheduled utilization in this situation, the author selects a staffing level of six to assign to MWSS-371 for the next notional deployment or exercise.

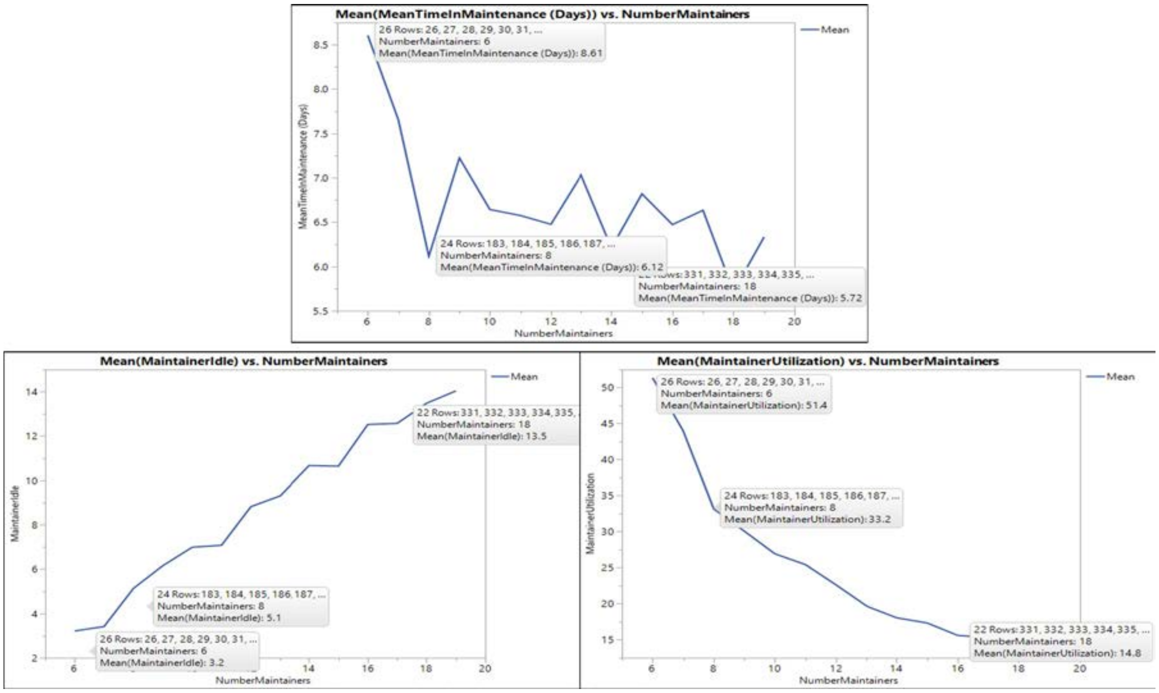
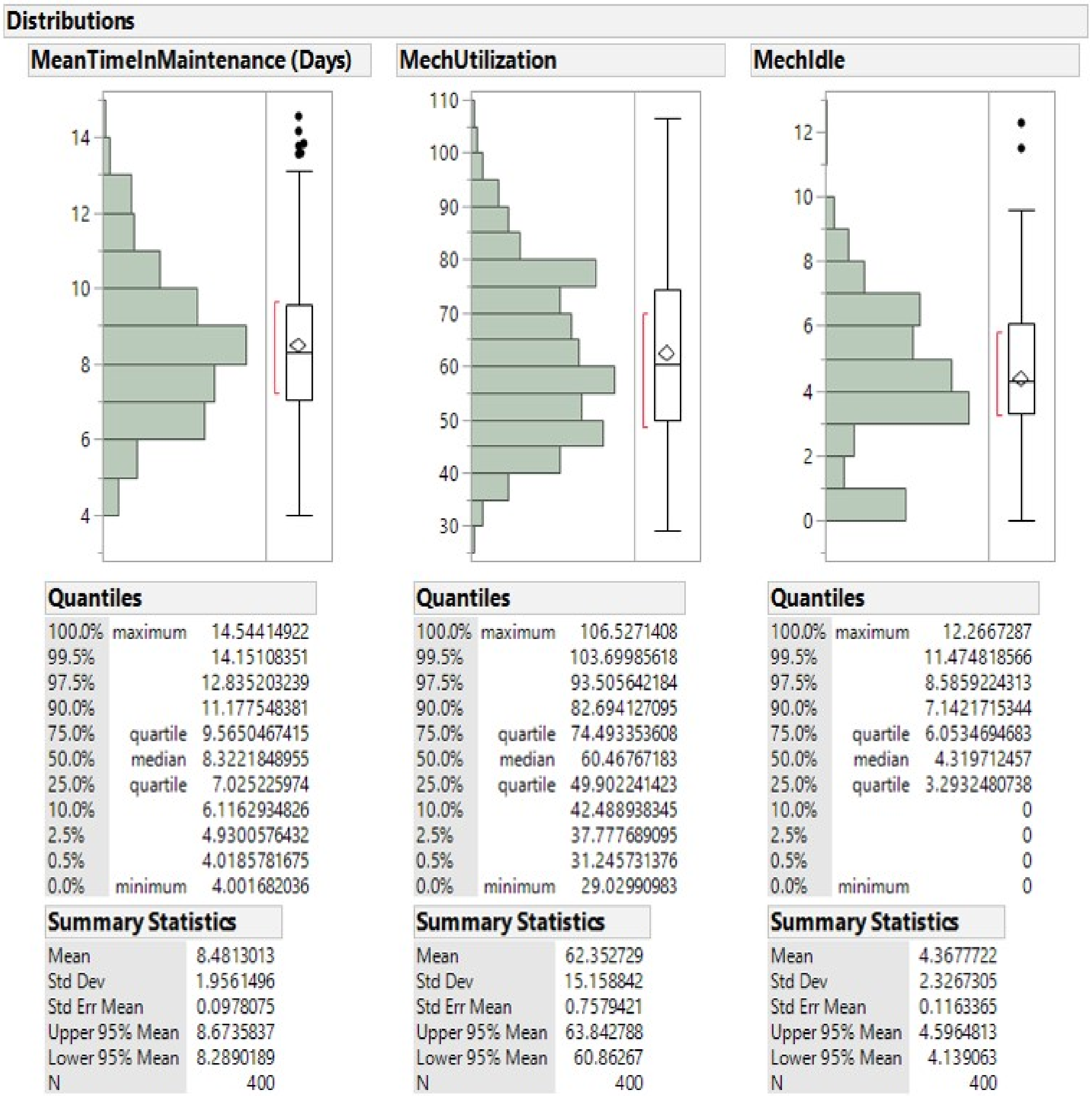


Figure 40. MWSS-371 Deployed Optimization Graphs

Figure 41 displays a slightly better mean time in maintenance result than that seen in Figure 40 for a staffing level of six maintainers. The garrison staffing level experiment yields an average time in maintenance of 8.5 days with a 95% confidence interval of [8.3, 8.7]. The garrison staffing level experiment produced a higher scheduled utilization rate of 62.4% with a 95% confidence interval of [60.9, 63.8]. The experiment produced a relatively low average maintainer idle rate of 4.4% with a 95% confidence interval of [4.1, 4.6]. The results represent a stable and very flexible situation for motor transport maintainers within this command.



MeanTimeInMaintenance (Days)

Quantiles

100.0%	maximum	14.54414922
99.5%		14.15108351
97.5%		12.835203239
90.0%		11.177548381
75.0%	quartile	9.5650467415
50.0%	median	8.3221848955
25.0%	quartile	7.025225974
10.0%		6.1162934826
2.5%		4.9300576432
0.5%		4.0185781675
0.0%	minimum	4.001682036

Summary Statistics

Mean	8.4813013
Std Dev	1.9561496
Std Err Mean	0.0978075
Upper 95% Mean	8.6735837
Lower 95% Mean	8.2890189
N	400

MechUtilization

Quantiles

100.0%	maximum	106.5271408
99.5%		103.69985618
97.5%		93.505642184
90.0%		82.694127095
75.0%	quartile	74.493353608
50.0%	median	60.46767183
25.0%	quartile	49.902241423
10.0%		42.488938345
2.5%		37.77689095
0.5%		31.245731376
0.0%	minimum	29.02990983

Summary Statistics

Mean	62.352729
Std Dev	15.158842
Std Err Mean	0.7579421
Upper 95% Mean	63.842788
Lower 95% Mean	60.86267
N	400

MechIdle

Quantiles

100.0%	maximum	12.2667287
99.5%		11.474818566
97.5%		8.5859224313
90.0%		7.1421715344
75.0%	quartile	6.0534694683
50.0%	median	4.319712457
25.0%	quartile	3.2932480738
10.0%		0
2.5%		0
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	4.3677722
Std Dev	2.3267305
Std Err Mean	0.1163365
Upper 95% Mean	4.5964813
Lower 95% Mean	4.139063
N	400

Figure 41. MWSS-371 Deployed Optimal Staffing Level Primary and Secondary Outputs Distributions at Six Maintainers

This command possesses a stable and flexible motor transport maintenance system based upon the summary statistics. Furthermore, 75% of all observations across the outputs, reveal a well-balanced system. The utilization rate from this experiment is twice as much as the rate produced by the optimization experiment, as depicted by Figures 42 and 43.

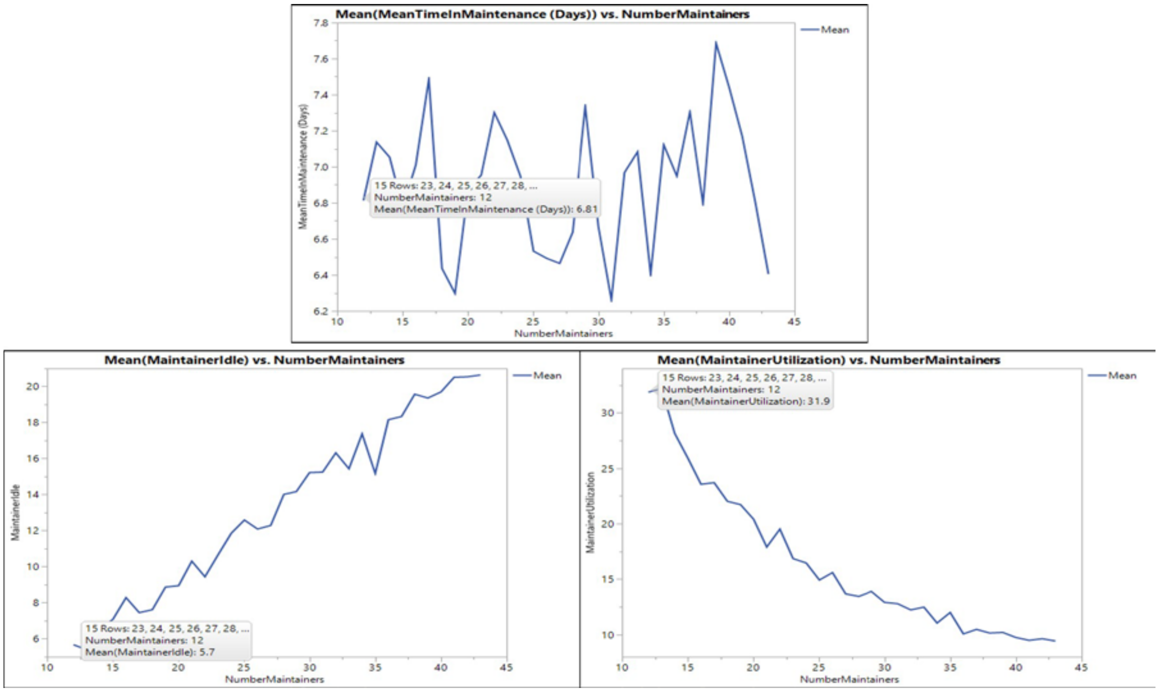
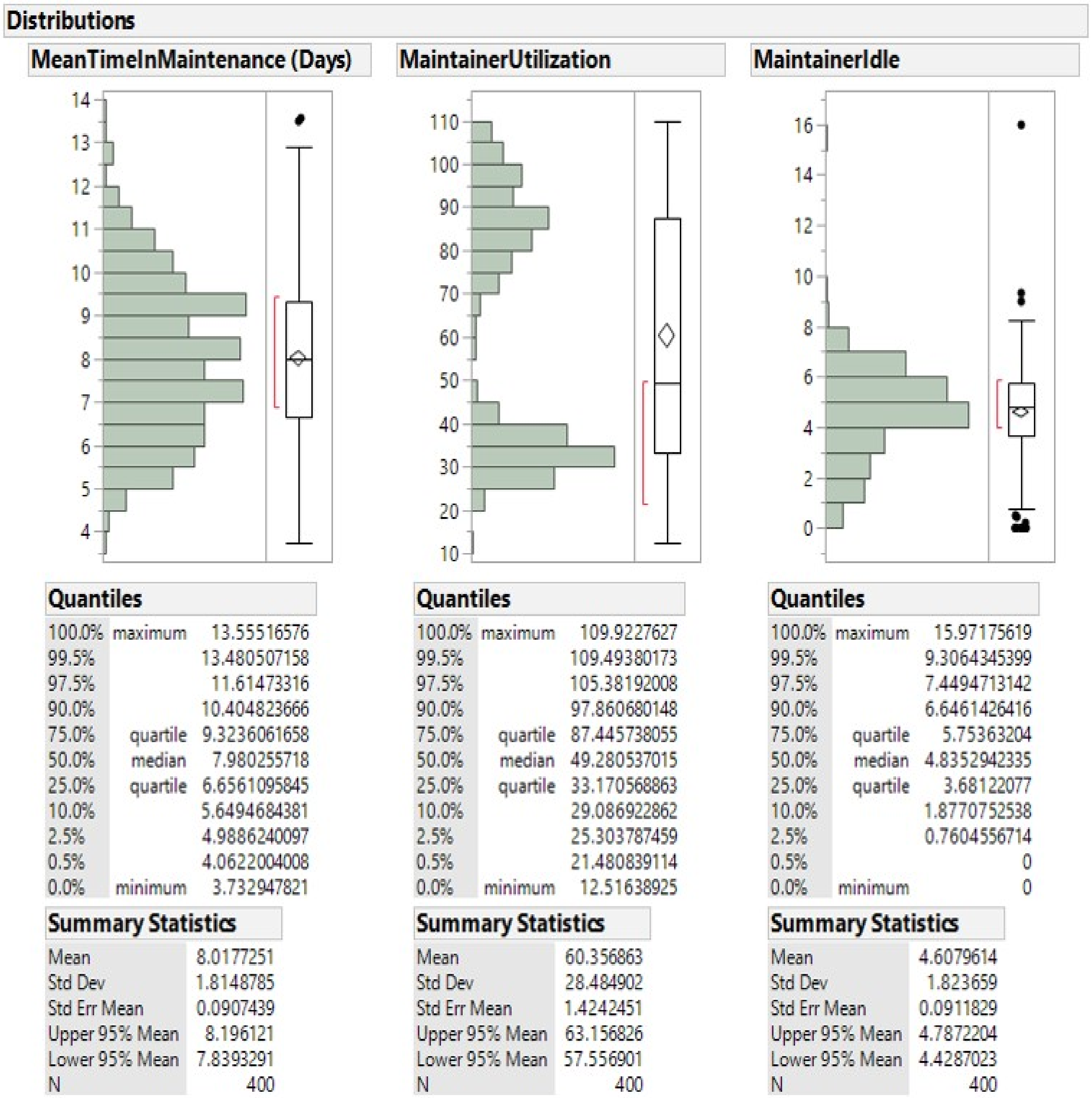


Figure 42. 5th Bn, 11th Mar Deployed Optimization Graphs

This command presents the same dilemma as MWSS-371 with regard to not nearing the maximum scheduled utilization rate threshold of 80%. Having already demonstrated the decision-making process in such a situation, the author simply reports the optimal maintainer staffing level selected (quantity of 12) for 5/11.



Quantiles (MeanTimeInMaintenance (Days))

100.0%	maximum	13.55516576
99.5%		13.480507158
97.5%		11.61473316
90.0%		10.404823666
75.0%	quartile	9.3236061658
50.0%	median	7.980255718
25.0%	quartile	6.6561095845
10.0%		5.6494684381
2.5%		4.9886240097
0.5%		4.0622004008
0.0%	minimum	3.732947821

Summary Statistics

Mean	8.0177251
Std Dev	1.8148785
Std Err Mean	0.0907439
Upper 95% Mean	8.196121
Lower 95% Mean	7.8393291
N	400

Quantiles (MaintainerUtilization)

100.0%	maximum	109.9227627
99.5%		109.49380173
97.5%		105.38192008
90.0%		97.860680148
75.0%	quartile	87.445738055
50.0%	median	49.280537015
25.0%	quartile	33.170568863
10.0%		29.086922862
2.5%		25.303787459
0.5%		21.480839114
0.0%	minimum	12.51638925

Summary Statistics

Mean	60.356863
Std Dev	28.484902
Std Err Mean	1.4242451
Upper 95% Mean	63.156826
Lower 95% Mean	57.556901
N	400

Quantiles (MaintainerIdle)

100.0%	maximum	15.97175619
99.5%		9.3064345399
97.5%		7.4494713142
90.0%		6.6461426416
75.0%	quartile	5.75363204
50.0%	median	4.8352942335
25.0%	quartile	3.68122077
10.0%		1.8770752538
2.5%		0.7604556714
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	4.6079614
Std Dev	1.823659
Std Err Mean	0.0911829
Upper 95% Mean	4.7872204
Lower 95% Mean	4.4287023
N	400

Figure 43. 5th Bn, 11th Mar Deployed Optimal Staffing Level Primary and Secondary Outputs Distributions at 12 Maintainers

At a staffing level of 24, 1st TSB is expected to achieve an equipment repair time of approximately seven days on average (Figure 44). With a scheduled utilization rate of nearly 50% and an idle rate of approximately three percent, potential exists for this staffing level to suffice even in a deployed environment with a higher maintenance demand signal. Next, we analyze the results of the experiment with a staffing level of 24 maintainers.

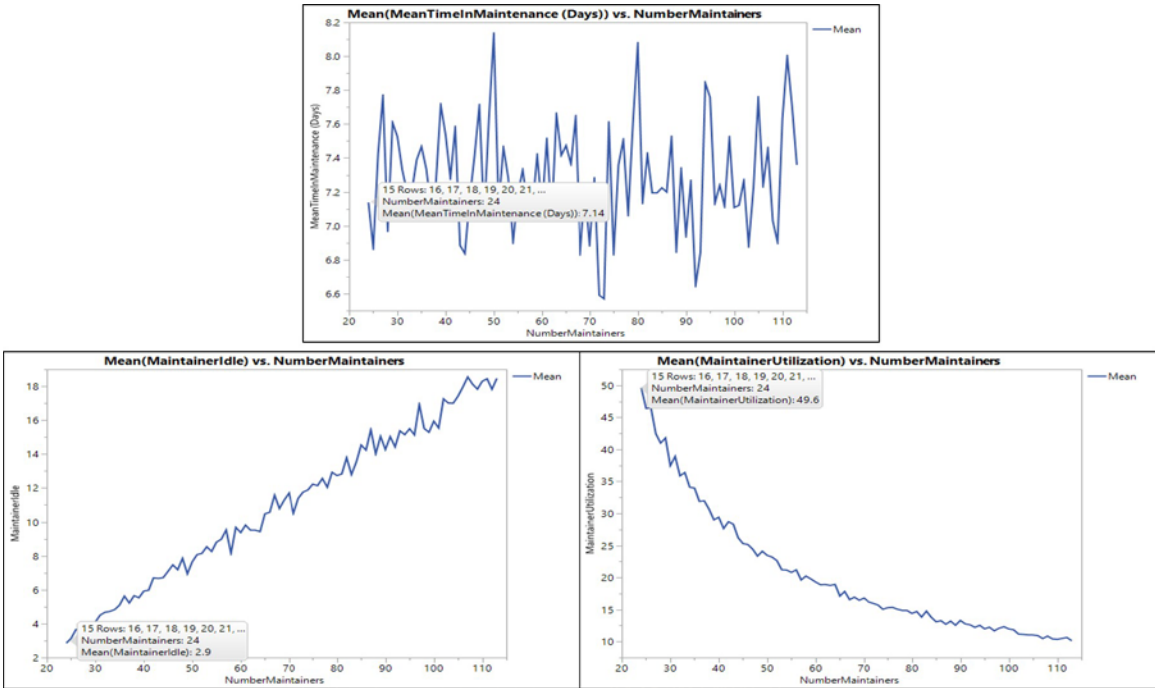
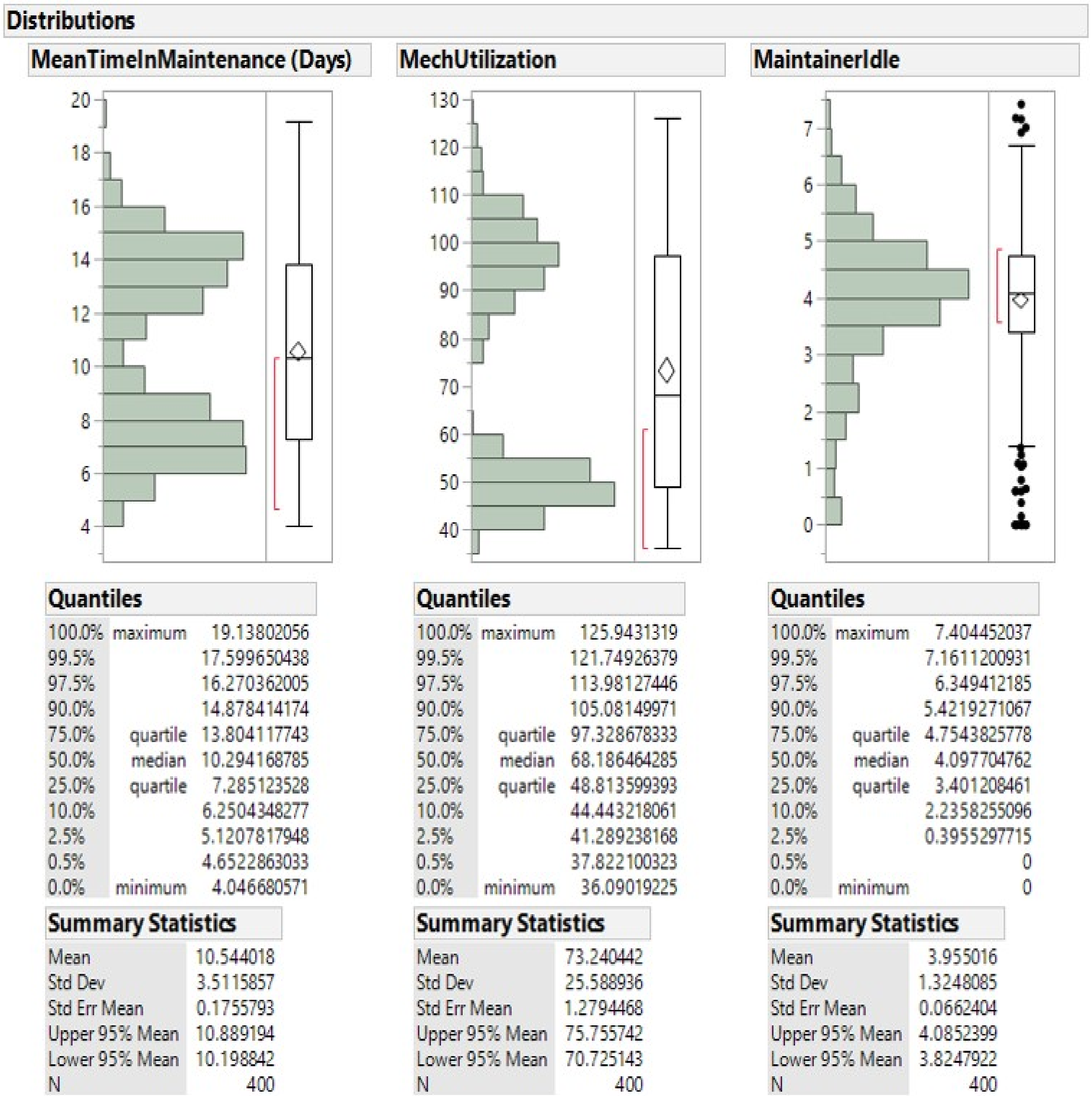


Figure 44. 1st TSB Deployed Optimization Graphs

Figure 45 reveals a stable system for 1st TSB in a deployed environment with a staffing level of 24 motor transport equipment maintainers. On average, this command returns equipment from the maintenance cycle within 11 days. At most, a customer receives equipment back from motor transport maintenance in less than 20 days. The maintainers accomplish this at an average 73.2% maintainer utilization rate and an average idle rate of 4%.



MeanTimeInMaintenance (Days)

Quantiles

100.0%	maximum	19.13802056
99.5%		17.599650438
97.5%		16.270362005
90.0%		14.878414174
75.0%	quartile	13.804117743
50.0%	median	10.294168785
25.0%	quartile	7.285123528
10.0%		6.2504348277
2.5%		5.1207817948
0.5%		4.6522863033
0.0%	minimum	4.046680571

Summary Statistics

Mean	10.544018
Std Dev	3.5115857
Std Err Mean	0.1755793
Upper 95% Mean	10.889194
Lower 95% Mean	10.198842
N	400

MechUtilization

Quantiles

100.0%	maximum	125.9431319
99.5%		121.74926379
97.5%		113.98127446
90.0%		105.08149971
75.0%	quartile	97.328678333
50.0%	median	68.186464285
25.0%	quartile	48.813599393
10.0%		44.443218061
2.5%		41.289238168
0.5%		37.822100323
0.0%	minimum	36.09019225

Summary Statistics

Mean	73.240442
Std Dev	25.588936
Std Err Mean	1.2794468
Upper 95% Mean	75.755742
Lower 95% Mean	70.725143
N	400

MaintainerIdle

Quantiles

100.0%	maximum	7.404452037
99.5%		7.1611200931
97.5%		6.349412185
90.0%		5.4219271067
75.0%	quartile	4.7543825778
50.0%	median	4.097704762
25.0%	quartile	3.401208461
10.0%		2.2358255096
2.5%		0.3955297715
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	3.955016
Std Dev	1.3248085
Std Err Mean	0.0662404
Upper 95% Mean	4.0852399
Lower 95% Mean	3.8247922
N	400

Figure 45. 1st TSB Deployed Optimal Staffing Level Primary and Secondary Outputs Distributions at 24 Maintainers

C. SUMMARY

This chapter discussed the staffing level results produced using the workload evaluation method as well as the simulation optimization and experiment method. The author uses the former to complement the latter, creating a maintainer manpower planning process. Each staffing level experiment yields slightly different results from the optimization experiments. Once cause of the discrepancy is the fact that a particular staffing level within the optimization experiment may not run as many replications as are run in the staffing level experiment for the same staffing level, in which only one quantity of maintainers exists vice the variety that exists within the optimization experiment. All commands met the 30-day mean time in maintenance objective. However, meeting the objective sometimes came at the price of overworking the maintainers and creating an unstable and inflexible system. The author provides further conclusions with respect to the results in Chapter VI.

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VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

In this final chapter of the thesis, the author summarizes the previous five chapters, offers conclusions about the results of the simulation models, and provides recommendations to several organizations within the Marine Corps for follow-on actions and other research.

A. SUMMARY

This thesis focuses on developing a manpower planning method that relates changes to United States Marine Corps (USMC) motor transport mechanics staffing levels to the time motor transport equipment spends in the maintenance system. The author only includes aspects of maintenance controlled by the maintenance personnel within the system. The author excludes supply support to prevent biasing the results. It is no secret that supply support significantly delays maintenance production. Accordingly, the author assumes the requisite repair parts and tools are O/H when equipment arrives to the maintenance section for repairs.

The MDR provides an abundance of ground equipment maintenance and supply data to support manpower planning using simulation modeling. Inconsistency in data collection across data tables present obstacles to developing the tables necessary to conduct simulation modeling. Data manipulation consumed a huge portion of research time as the data tables do not easily lend themselves to analysis using simulation-modeling techniques. The major shortcoming of this thesis exists in the form of measurement error bias. The data introduce measurement error bias by way of missing or invalid observations of processing times. This required the deletion of thousands of observations, which reduces a modeler’s ability to gain a true sense of processing times experienced in the actual maintenance system. The capturing of equipment arrivals in terms of days and not hours also introduces some measurement error bias. With that said it is quite possible that a better historical maintenance data table exists for use but was not found for this thesis. The remainder of this chapter provides conclusions about the results from Chapter V of this thesis and provides recommendations for follow-on research and the application of simulation modeling towards other research within the Marine Corps.

B. CONCLUSION

To achieve the purpose of this thesis, the author employed two methods in determining the number of maintainers required to decrease the number of days motor transport equipment remains in maintenance. The first method, the workload evaluation method, developed by Nelsen (2010) included factors time (annual equipment burden and annual maintainer available hours) and force (number of individual end items by type possesses by a command). In a perfect world where all goes according to plan, this method works perfectly. However, in reality, all seems to go disastrously out of sync with the best-laid plans. As such, the author only uses this method to assist in developing a range of staffing level options to include into the optimization model. As is the case with the simulation model, the workload evaluation method is subject to measurement error bias due to invalid or missing data within the maintenance data sets, but it does provide a baseline from which to vary staffing levels outside of the table of organization and equipment report.

The simulation modeling method serves as the primary method used in this thesis to determine staffing levels for Marine Corps motor transport sections at the organizational command level. The optimization models presented optimal staffing levels that differ from the staffing level produced by the workload evaluation method, although not by much. Introducing variation, such as varying work schedule hours, injects a dynamic that yields different results from a baseline scenario. The ability to simulate reality and the randomness that accompany it allows manpower planners to better estimate staffing level requirements for any maintenance section. Simulation provides planners immediate feedback on the validity of the optimization results through analysis of the outputs' summary statistics and quantiles. Other risk analysis tools may also benefit planners in confirming the optimal staffing level produced by the simulation model, though none were used during this research.

Building simulation models requires lots of time from the stakeholders as well as the modeler. Without stakeholder input and involvement, a modeler can waist countless hours building a model that has nothing in common with the actual system that requires analysis. With that said, the time consumed building an adequate model to address such issues as determining appropriate staffing levels or identifying choke points within the ground supply system pays dividends in the end. Whether planning for an exercise or deployment, standing up a detachment, or determining the staffing goal for a command in garrison, the simulation modeling method used in this thesis possesses the flexibility necessary to determine the staffing levels in each scenario.

C. RECOMMENDATIONS

This section offers recommendations for other research topics significant to the Marine Corps that could benefit from using simulation modeling as an analysis tool. Additionally this section recommends follow-on action relative to this thesis for DC, I&L, Deputy Commandant for Manpower and Reserve Affairs (DC, M&RA), Marine Corps Systems Command, and Marine Corps Logistics Command.

1. Recommendations for Other Research

Using simulation modeling as an analysis tool required discipline to remain on topic. The temptation to add elements to the model that do not necessarily answer the objective of the research topic arose frequently during the course of this research. For instance, the author added the effects of supply support to the model at one point, which consumed several hours of model building time. It is understood that supply support affects maintenance productivity, and adding this effect takes away from achieving the objective of determining the impact of maintainer staffing level (and maintainer's actions alone) on the length of time equipment remains in the maintenance cycle. This leads into my first recommendation for other research.

The author recommends using simulation modeling to determine opportunities for improvement within the Marine Corps ground supply system. This research would probably require at least one year of gaining an understanding of the supply system components, both internal Marine Corps components as well as external Department of

Defense and commercial components. After gaining an understanding of the system, creating the model should proceed relatively quickly, but validating the model may add to the length of time required to complete the model and run experiments.

Another opportunity to apply simulation modeling as an analysis and process improvement tool exists within the contracting community. The objective of this research could be to determine the point at which the contracting system experiences the most congestion. A secondary objective could be to determine whether the congestion is process based or policy based.

2. Recommendations for Follow-on Action

The major concern the author has with this research is the quality of the data used as input parameters and distributions for the simulation models. Based upon personal experience, a common topic of a field supply and maintenance analysis office (FSMAO) post-inspection brief includes the failure to update service requests within GCSS-MC.

To resolve the data quality failure, the author recommends that DC, I&L explores the use of automated time tracking software system within ground equipment maintenance. With the ultimate goal of integrating such technology into current automated logistics systems of record, the author recommends first to conduct a proof of concept using commercially procured systems that operate outside the GCSS-MC network infrastructure. To facilitate a mechanism for data comparison, maintainers would continue to adhere to current policy with regard to updating service requests within GCSS-MC accordingly. Upon completion of the proof of concept, an analyst would determine if data quality improved with the use of the automated time tracking software system. One simple way to measure this is to check for missing data on maintenance related data reports contained within the MDR. If the proportion of available data retrieved from the MDR is significantly less than that recorded by the automated time tracking software system, then it may benefit the Marine Corps to invest in such a software system.

Within the MDR, several maintenance related data tables exist. Each is inconsistent with respect to the data elements and observations contained within them. For instance, one data table contained a column entitled military labor hours; however, the data is missing for a large quantity of observations. On another report containing the same data element, data is present for a large majority of the observations. Marine Corps Logistics Command manages the MDR. As such, the author recommends that Marine Corps Logistics Command removes any stale data sets from the MDR and create a single data table that supports archiving supply and maintenance productivity. Additionally, the author recommends capturing supply and maintenance actions on this single data set in date-time format. This would facilitate ease of data retrieval for research purposes.

After completing the first two recommendations, the author finally recommends that Marine Corps Systems Command, DC, I&L, DC, and DC, M&RA conduct a proof of concept, employing the method described in this thesis during the procurement and manpower planning processes for new programs of record.

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