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MBA PROFESSIONAL REPORT

MAINTENANCE PRODUCTION DEMAND AND CAPACITY ANALYSIS OF THIRD MAINTENANCE BATTALION

December 2017

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MAINTENANCE PRODUCTION DEMAND AND CAPACITY ANALYSIS OF THIRD MAINTENANCE BATTALION

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Submitted in partial fulfillment of the requirements for the degree of

MASTER OF BUSINESS ADMINISTRATION

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LIST OF ACRONYMS AND ABBREVIATIONS

AAV	Amphibious Assault Vehicle
AIMD	Intermediate Maintenance Detachment
Ao	Operational Availability
ARP	Armament Repair Platoon
CJLOTS	Combined Joint Logistics Over the Shore
CLR	Combat Logistics Regiment
CONUS	Continental United States
DCD	Deadline Control Date
DRRS-MC	Defense Readiness Reporting System Marine Corps
DYNO	Dynomometer
ELMACO	Electronics Maintenance Company
EMC	Engineer Maintenance Company
F/AD	Force/Activity Designator
F&E	Fuel and Electric
FY	Fiscal Year
GCSS-MC	Global Combat Support System Marine Corps
GESP	Ground Equipment Staging Program
GSM	General Support Maintenance Company
HMMWV	High Mobility Multipurpose Wheeled Vehicle
III MEF	Third Marine Expeditionary Force
IMA	Intermediate Maintenance Activity
LAV	Light Armored Reconnaissance Vehicle
LOGCOM	Marine Corps Logistics Command
LVS	Logistics Vehicle System
LVSR	Logistics Vehicle System Replacement
LSS	Lean Six Sigma
LUPO	Lubricating Unit Power Operated
MAC	Maintenance Allocation Chart
MCDP	Marine Corps Doctrine Publication
MCLB	Marine Corps Logistics Base

MCO	Marine Corps Order
MCTP	Marine Corps Tactical Publication
MDR	Master Data Repository (Marine Corps Logistics Command)
MEF	Marine Expeditionary Force
MLG	Marine Logistics Group
MMSOP	Maintenance Management Standard Operating Procedures
MOS	Military Occupational Specialty
MPF	Maritime Prepositioning Force
MRF-D	Marine Rotational Force Darwin (Australia)
MTM	Motor Transport Maintenance Company
MTVR	Medium Tactical Vehicle Replacement
NSW	Navy Standard Workweek
OCONUS	Outside Continental United States
OMC	Ordnance Maintenance Company
ORP	Ordnance Repair Platoon
PMCS	Preventive Maintenance Checks and Services
QC	Quality Control
RDD	Required Delivery Date
RIP	Repairable Issue Point
ROK	Republic of Korea
RRGE	Readiness Reportable Ground Equipment
SecRep	Secondary Repairable
SMR	Source Maintenance Recoverability
SR	Service Record
TDD	Time Definite Delivery
T/E	Table of Equipment
TFSMS	Total Force Structure Management System
TFSP	Total Force Structure Process
TM	Technical Manual
T/O	Table of Organization
TO&E	Table of Organization and Equipment
TPS	Toyota Production System

TQM	Total Quality Management
TRAM	Tractor, Rubber-tired, Articulated steering, Multipurpose
UMMIPS	Uniform Material Movement and Issue Priority System
UND	Urgency of Need Designator

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This project came about the result of a previous Naval Postgraduate School student's post-studies experience. By reaching back to the operational logistics management team at the Graduate School of Business and Public Policy, this former student provided me with an opportunity to research a topic relevant to a forward-deployed unit.

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I. INTRODUCTION

A. BACKGROUND

Third Maintenance Battalion, Combat Logistics Regiment (CLR) 35, Third Marine Logistics Group (MLG) provides general intermediate maintenance support to Third Marine Expeditionary Force (III MEF), headquartered on Okinawa Island, Japan. Third MEF's mission is to provide "a forward-deployed force in readiness" that is "capable of generating, deploying, and employing forces for crisis response, forward presence, major combat operations, and campaigns" (United States Marine Corps [USMC], n.d.) and therefore must maintain a high state of readiness for its organic vehicles and equipment. To prepare for this mission, III MEF supports dozens of joint and coalition exercises each year, both on Okinawa and throughout the Pacific theater. When equipment requires maintenance beyond the organizational-level maintenance capability of the owning units, it is evacuated to Third Maintenance Battalion for intermediate-level maintenance. To support III MEF's activities, in addition to operating maintenance facilities on Okinawa that serve III MEF units, Third Maintenance Battalion routinely deploys maintenance support teams to training and operation locations. While these teams provide on-site service to supported units, the garrison maintenance facilities are forced to take the resulting manpower shortfalls in-stride.

As the only permanently forward-deployed maintenance battalion in the Marine Corps, Third Maintenance Battalion faces a unique set of challenges when supporting its parent MEF. Unlike First Maintenance Battalion (CLR-15, First MLG, Camp Pendleton, CA) and Second Maintenance Battalion (CLR-25, Second MLG, Camp Lejeune, NC), Third Maintenance Battalion is geographically separated from its supported units (about 4,600 miles from Third Marine Regiment in Oahu, HI) and the supporting establishment (about 7,800 miles from Marine Corps Logistics Command in Albany, GA). This separation, compounded by the unit's facilities being located on a remote island in the western Pacific Ocean, contributes to the requirement that personnel and resources be allocated in a way that maximizes maintenance production throughput and minimizes turnaround time of equipment being serviced. Additionally, lead times for supplies, repair parts, and depot-level maintenance are longer, impacting operational availability (Ao). Shortening turnaround time increases mission capable time, and therefore increases Ao.

The battalion assigns personnel to its various maintenance facilities based on the battalion's mission, supported units' demand, and personnel availability. Because Third Maintenance Battalion supports so many units across a large geographical area, assigning scarce personnel resources presents a constant challenge. The unit would like to better understand its stochastic capacity for performing various maintenance tasks to improve service to its supported units and make better informed personnel assignment decisions.

B. RESEARCH OBJECTIVES

The primary research objective was to develop and illustrate an analytical method by which an intermediate maintenance activity can determine how to employ its scarce personnel resources to maximize maintenance production and improve customer service. The analysis results could inform personnel staffing decisions, such as whether to deploy a maintenance support team or retain garrison capacity. For this research, maintenance demand and personnel capacity were used to develop an aggregate plan based on capacity utilization levels. Although Third Maintenance Battalion did not report capacity shortfalls or unmet demand during the period to be studied, the battalion nevertheless sought ways to improve customer service through analysis of its performance.

C. ANALYTICAL APPROACH

The analytical approach for this research was to apply aggregate capacity planning concepts to demand and capacity data in order to assess capacity utilization. First, demand was analyzed based on customer cycle time (i.e., time that equipment was in Third Maintenance Battalion custody), maintenance cycle time during which work was performed, and the actual time spent performing maintenance tasks. The analysis categorized service records by equipment type and work type, and aggregated workload by labor hours required. Second, capacity was assessed based on staffing levels and personnel availability, measured in available labor hours. Third, capacity utilization was computed to determine the unit's ability to meet demand and evaluate the amount of stress placed on the unit.

D. SCOPE

Third Maintenance Battalion is structured to reflect the different equipment types being maintained, such as ordnance, engineer, or motor transport. Recommendations to improve the maintenance turnaround time for different equipment types are impacted by resources required in the maintenance process, such as different maintenance personnel skillsets, repair facilities, and maintenance equipment. As such, this research project is limited to one company within Third Maintenance Battalion: Motor Transport Maintenance Company (MTM). Of Third Maintenance Battalion's companies, MTM is the largest, yet it comprises the fewest different military occupational specialties (primarily 3521, Automotive Maintenance Technician, and 3529, Motor Transport Maintenance Chief), making it most suitable to demonstrate the potential value of developing an aggregate capacity plan.

MTM performs maintenance mostly on motor vehicles, so the maintenance tasks performed on different equipment types tend to be similar. For example, replacing the engine of a Medium Tactical Vehicle Replacement (MTVR) involves a process similar to replacing the engine of a High Mobility Multipurpose Wheeled Vehicle (HMMWV). In contrast, the Ordnance Maintenance Company provides service for a wide range of equipment, from infantry weapons systems to ordnance vehicles, such as the Amphibious Assault Vehicle (AAV).

The time period covered in this research is restricted to two years for two main reasons. First, although the operational tempo is high, scheduled exercises tend to repeat on a regular basis. Most scheduled exercises and deployments recur on an annual basis, so cycles observed in maintenance demand and capacity are likely to continue. Therefore, a two-year period captures the majority of exercises that might cause demand to fluctuate and helps to ensure the broadest range in demand levels. Second, as new equipment is fielded and modified, maintenance requirements and time can change over time. By studying two recent years, equipment versions can be assumed to be relatively consistent across the entire period studied.

Recommendations drawn from this research are also restricted in scope: they are made within the constraint of current unit structure. Although in the long term, adjusting the unit's structure might yield greater improvement, in the short term Third Maintenance Battalion cannot adjust existing structure and budget. Therefore, any recommendations implemented by the battalion would have to be made within the limits of current personnel and fiscal resources. While in the commercial sector a company's ability to increase production capacity is largely limited by fiscal resources, military units have the ability to surge capacity without incurring additional labor expense. This surge is not without cost, however: extended hours can increase fatigue and lower morale, thereby reducing capacity over protracted surge periods.

Finally, scheduling and dispatch rules were not considered in the analysis. Most significantly, customer and maintenance cycle times recorded in GCSS-MC do not indicate reasons for delays. Addressing urgent service records first or prioritizing simpler maintenance operations could affect cycle times. For example, routine service records might experience longer cycle times when urgent service records are open, and complex repairs might be delayed until simpler repairs are completed.

E. RESEARCH OUTLINE

This report presents the research in three main sections: introduction and background, data analysis and findings, methodology for future applications, and recommendations for future research. The first section, introduction and background, includes this introductory chapter, a literature review, general background on Marine Corps maintenance of ground equipment, and specific background on MTM and Third Maintenance Battalion. The second section, data analysis and findings, presents an aggregate demand and capacity analysis based on collected data from LOGCOM and Third Maintenance Battalion. The final section lists recommendations for Third Maintenance Battalion, outlines a methodology for future analysis, and suggests areas of study for future research based on results from this project.

II. LITERATURE REVIEW

Chapter II provides background on pertinent orders and regulations for USMC maintenance operations and a literature review of capacity analysis tools and methodologies. Next, it includes a review of previous analyses of military activities, specifically maintenance activities. Finally, this chapter reviews literature pertaining to aggregate planning.

A. USMC MAINTENANCE ORDERS, DIRECTIVES, AND REGULATIONS

According to Title 10, U.S. Code, logistics is the responsibility of each military service. As such, guidance, orders, and directives for USMC ground equipment maintenance are published at various levels of the Marine Corps hierarchy. At the highest level, Marine Corps Doctrine Publication (MCDP) 4, *Logistics,* lists maintenance as one of the six core functions of USMC logistics (USMC, 2016, p. 47). Marine Corps Tactical Publication (MCTP) 3–40E, *Maintenance Operations,* provides service-level guidance on functions of maintenance, including maintenance management, maintenance-related programs, maintenance organizations, maintenance planning, and maintenance execution. Specific maintenance definitions and instructions are published in the Marine Corps Order (MCO) 4790 series. Technical publications for maintenance of USMC equipment are maintained by Marine Corps Logistics Command (LOGCOM), Distribution Management Center, Albany, GA. III MEF, CLR-35, and Third Maintenance Battalion orders and regulations that promulgate local policy are maintained at the respective headquarters.

B. CAPACITY PLANNING

To determine whether a unit has sufficient capacity to meet demand, available capacity must first be calculated. MCO 5311.1E, *Total Force Structure Process* (TFSP), defines the standard mission/operation duty weeks that are used to build Marine Corps units' tables of organization. The Marine Corps standards are based on projected wartime operational requirements because units in the operating forces constitute a "force in readiness" and are thus structured for deployment. As an operational forces unit, Third

Maintenance Battalion's structure is designed to support two 12-hour work shifts in continual rotation. Of the 12 hours, 11.04 hours are assumed to be productive, for a total of 77.28 hours per week. These standards, while useful for structuring units for wartime operations, are less applicable for lower operational tempo scenarios such as day-to-day operations at Third Maintenance Battalion.

The U.S. Navy utilizes the Navy Standard Workweek (NSW) to make this calculation in the aviation community, as discussed in Allen (2005). The NSW derives manpower requirements from aircraft maintenance standards and use levels, prescribing different theoretical capacities for garrison and at-sea/deployed environments. This research indicates that although the NSW planning factors are imperfect, they are nevertheless useful in "determining wartime [personnel] requirements based on projected aircraft utilization" (Allen, 2005, p. 33).

To determine maintenance production capacity at Third Maintenance Battalion, this research uses the capacity planning factors provided by the Maintenance Operations Section. These factors represent capacity made available for maintenance production at Third Maintenance Battalion: 27.85 hours per week, or 5.57 hours per day of a five-day workweek (C. Galbraith, personal communication, October 17, 2017).

C. USMC GROUND EQUIPMENT MAINTENANCE

Technical manuals (TMs) for each item of Marine Corps Ground Equipment list time estimates to perform maintenance tasks in the Maintenance Allocation Chart (MAC). Estimates are listed by component/assembly (e.g., engine mount), maintenance function (e.g., inspect, test, service, adjust, replace, repair), and maintenance level (e.g., operator/crew, unit, direct/general support, depot). These estimates do not always reflect actual maintenance time, nor can they be used in isolation to determine customer or maintenance cycle time and equipment readiness. Srinivasan, Jones, and Miller (2004) applied critical chain methodology to the maintenance production process for D02097K MK48 Logistics Vehicle System (LVS) maintenance. Although the unit appeared to have sufficient capacity to meet demand, maintenance readiness levels were lower than expected. After implementing process improvements, maintenance readiness levels improved dramatically.

D. AGGREGATE PLANNING

This analysis will employ aggregate planning techniques to generate a staffing (aggregate) plan based on the demand placed on Motor Transport Maintenance Company. According to Krajewski and Ritzman (2005), grouping workload by “similar services, products, units of labor, or units of time” allows an organization to develop an overarching staffing plan. Although Motor Transport Maintenance Company performs maintenance on several different types of vehicles, the basic skillset of the maintainers is approximately the same. Therefore, workload can be aggregated by unit of labor (i.e., labor hour).

Aggregate planning can be used in both make-to-stock and make-to-order settings. Although commonly applied to make-to-stock systems, Gansterer (2015) shows how aggregate planning can also be used for scheduling make-to-order systems. Because decision-makers in make-to-stock settings use forecasts to make planning decisions, make-to-order aggregate planning models might incorporate actual customer orders, bills of material, and personnel resource availability (Gansterer, 2015). Although maintenance production is largely a make-to-order system (i.e., maintenance to be performed varies on each inducted vehicle), USMC ground equipment maintenance exhibits some characteristics of a make-to-stock system. For example, maintenance units might forecast preventive maintenance checks and services (PMCS) requirements based on operating hours, prescribed modifications to the entire fleet of a particular vehicle, or scheduled exercises and deployment rotations.

Once the aggregate plan has been developed, it needs to be disaggregated so unit leadership can assign personnel to maintenance production tasks. In their research, Yalcin and Bucher (2004) explain that disaggregation is a necessary process to minimize costs associated with transitioning between different production tasks while adhering to the aggregate plan (p. 1024). From the aggregate plan developed for Motor Transport Maintenance Company, disaggregation will assist in assigning maintenance personnel to different types of vehicles and equipment. In other maintenance units where additional skillsets and occupational specialties are assigned, disaggregation would be used to break overall labor hours down across different occupational specialties and work sections.

E. THEORY OF CONSTRAINTS AND LEAN SIX SIGMA

Originally written in 1984, *The Goal: A Process of Ongoing Improvement* presented Goldratt's (2014) "Theory of Constraints" as a novel. It describes a methodology to identify and mitigate the bottleneck effects of constraints within a system.

Lean Six Sigma (LSS) is the juxtaposition of two process improvement methodologies: Lean production, originally the Toyota Production System (TPS) developed by Taiichi Ohno (Ohno, 1978), and Six Sigma, a successor to the Total Quality Management (TQM) methodology that was developed by Motorola in 1986 (McCarty, Daniels, Bremer, & Gupta, 2005). Together known as Lean Six Sigma, they have become the basis for process improvement in the 20th century. Many public and private organizations have incorporated LSS methodologies into operations to reduce costs, the goal of process improvement (Ohno, 1978).[1]

Although the LSS model for process improvement is designed for teams and chartered problems, certain tools are applicable to the analysis of any process. Bottleneck analysis identifies and addresses the step in a process that constrains the process throughput. Once mitigated, the next constraining step is identified and mitigated. Two additional tools, process mapping and value stream maps, are used to describe a process and the process steps that add "value" to the process. Value-added processes are the steps of a process significant to the customer (Goldratt, 2014; George, Rowlands, Price, & Maxey, 2005).

[1] Costs in the maintenance production process include actual cost of repair parts, labor cost of personnel involved in the maintenance process, and opportunity cost of lost equipment usage while undergoing repair. Although this project does not focus specifically on these costs, reducing maintenance cycle time will decrease opportunity cost for the customer. Although cost reduction is not the stated goal of this project, decreasing the cycle time of maintenance, by definition, is a reduction in opportunity cost for the customer.

F. PROCESS IMPROVEMENT IN MILITARY LOGISTICS

The U.S. Navy's AIRspeed system is an implementation of TOC and LSS methodologies to military logistics, specifically naval aviation. Several studies have assessed the impact of AIRspeed and other process improvement techniques on military maintenance activities and demonstrated their effectiveness. While extensive research exists on aviation logistics, fewer studies have examined ground equipment maintenance production processes.

Goh and Tay (1995) applied another methodology for process improvement, Total Quality Management (TQM), to Singapore's military. Their research analyzed 12 months of data and referred to the U.S. Department of Defense's implementation of TQM in their report. Although their study covered on-going improvement efforts, they found that low maintenance readiness levels could be improved by applying TQM techniques in maintenance units.

Jafar, Yang, and Mejos (2006) researched implementation of process improvement techniques to the Intermediate Maintenance Detachment (AIMD) in their master's thesis. Their research specifically applied to aviation and included an evaluation of AIRspeed, the U.S. Navy's process improvement standards. U.S. Navy and USMC aviation and aviation maintenance both incorporate AIRspeed and are funded by the U.S. Navy, whereas USMC ground equipment is a separate maintenance function contained entirely within Marine Corps logistics organizations.

In their 2006 technical report for the Acquisition Research Program at NPS, Apte and Kang discussed how the U.S. Department of Defense could apply Lean Six Sigma (LSS) methodologies to maintenance production (among other logistics activities) in order to reduce life cycle cost of weapons systems. Elements of the report were incorporated into their 2007 presentation at the Acquisition Research Symposium. There Kang and Apte (2007) again applied the Lean Six Sigma (LSS) methodologies to acquiring military weapons systems and discussed specific applications in the Army, Navy, and Air Force. They argued that the bulk of the large cost of weapons systems falls into the category of operations and maintenance. Applying LSS techniques to streamline operations and maintenance policies increases the efficiency and capacity of the processes, thereby reducing total acquisition cost.

Goodwin (2006) developed a tool for assigning maintenance personnel using a linear programming model. Allen (2005) also looked at maintenance manpower, specifically the balance of personnel to workload in the F/A-18C community.

III. THIRD MAINTENANCE BATTALION

A. INTRODUCTION

This chapter outlines the mission and background of Third Maintenance Battalion and how the unit organizes and operates to accomplish its assigned tasks. The first section includes a discussion of Third Maintenance Battalion's role as an intermediate maintenance activity, including background on intermediate ground equipment maintenance in the Marines Corps. The next section is a comparison between Third Maintenance Battalion and other Marine Corps intermediate maintenance units due to Third Maintenance Battalion's unique role as a forward-deployed unit serving a widely distributed supported unit. Third, factors affecting task organization, such as operational tempo and staffing shortfalls, are identified, and Motor Transport Maintenance Company's maintenance production process is described. Finally, after a brief description of the battalion's subordinate maintenance companies, Motor Transport Maintenance Company's maintenance production process is presented in detail.

B. USMC AND THIRD MARINE LOGISTICS GROUP MAINTENANCE

This section includes general background on maintenance and readiness reporting for USMC ground equipment and a discussion of maintenance phases.

1. General Maintenance and Readiness Reporting

Ground equipment maintenance in the Marine Corps is divided into two broad levels: field level and depot level. Field level maintenance is further divided into organizational and intermediate levels, corresponding to Marine Corps units' organic maintenance capabilities. In contrast, depot level maintenance is performed at Marine Corps logistics bases such as Marine Corps Logistics Base (MCLB) Albany, GA. Third MLG units are not authorized to perform depot level maintenance (3DMLG, 2014).

By definition, maintenance beyond a unit's organic capability will be evacuated to the intermediate level. The intermediate maintenance activity will further evacuate equipment to the depot level as required and communicated through the equipment's source maintenance recoverability (SMR) code (USMC, 2016c). In its assigned mission to provide field level maintenance for III MEF, Third Maintenance Battalion has the responsibility to perform intermediate maintenance on USMC ground equipment for III MEF and all its subordinate units.

Global Combat Support System Marine Corps (GCSS-MC) is the single source for all data pertaining to maintenance of USMC ground equipment. Records are entered and updated throughout the maintenance process and header information populates Marine Corps Logistics Command's Master Data Repository (MDR) regularly for archival and research purposes. Information maintained in GCSS-MC provides input for readiness reporting on other Marine Corps systems, including Defense Readiness Reporting System Marine Corps (DRRS-MC).

2. Maintenance Phases

Maintenance phases are standard across the Marine Corps for USMC ground equipment. Maintenance Management Standard Operating Procedures (MMSOP) are consistent across the Marine Corps, as well. The Third MLG MMSOP defines phases consistently with USMC policy (3DMLG, 2014):

1. **Acceptance Phase.** This phase includes a thorough inspection of the equipment to be maintained for completeness, cleanliness, and documentation; scheduling of a shop or section to perform maintenance; and assignment of personnel and resources to perform the required maintenance. This phase is executed in conjunction with the owning unit to maximize the time equipment is available for use and ensure the proper recording of the equipment condition. It is also the phase in which required parts for service are determined to be available at the time of service.

2. **Equipment Induction Phase.** This phase consists of the service request and equipment being committed (i.e., service record, responsibility, and equipment transferred) to the assigned section or resource that will perform the maintenance.

3. **Active Maintenance Phase.** In this phase, all of the physical work and actions to maintain the equipment are performed by the assigned section. It includes an inspection to locate and inventory the equipment and its components, verification of equipment records, preparation to perform maintenance (i.e., gathering technical manuals and support equipment), maintenance performance, maintenance verification, quality control actions, and cleanup of the maintenance area.

4. **Maintenance Closeout Phase.** This phase occurs after equipment has been returned to the owning unit or a decision has been made to either evacuate the equipment to a higher echelon for repair or dispose of the equipment. Also during this phase, maintenance chiefs will ensure that equipment and service records have been properly updated and closed out prior to returning equipment to its owner.

C. THIRD MAINTENANCE BATTALION

This section includes background information on Third Maintenance Battalion including its assigned mission and position within the command hierarchy. It also discusses the battalion's support relationship to III MEF and compares it to maintenance battalions with similar missions across the Marine Corps. Finally, this section describes the battalion maintenance procedures and subordinate companies.

1. Mission and Background

The mission of Third Maintenance Battalion is to "provide field-level maintenance support for Marine Corps-furnished tactical ordnance, engineer, motor transport, communications-electronics, and general support equipment of the Marine expeditionary force (MEF)" (USMC, 2016k). The battalion is one of three within Combat Logistics Regiment 35 (CLR-35), the general support logistics regiment for III Marine Expeditionary Force (III MEF), as depicted in Figure 1.

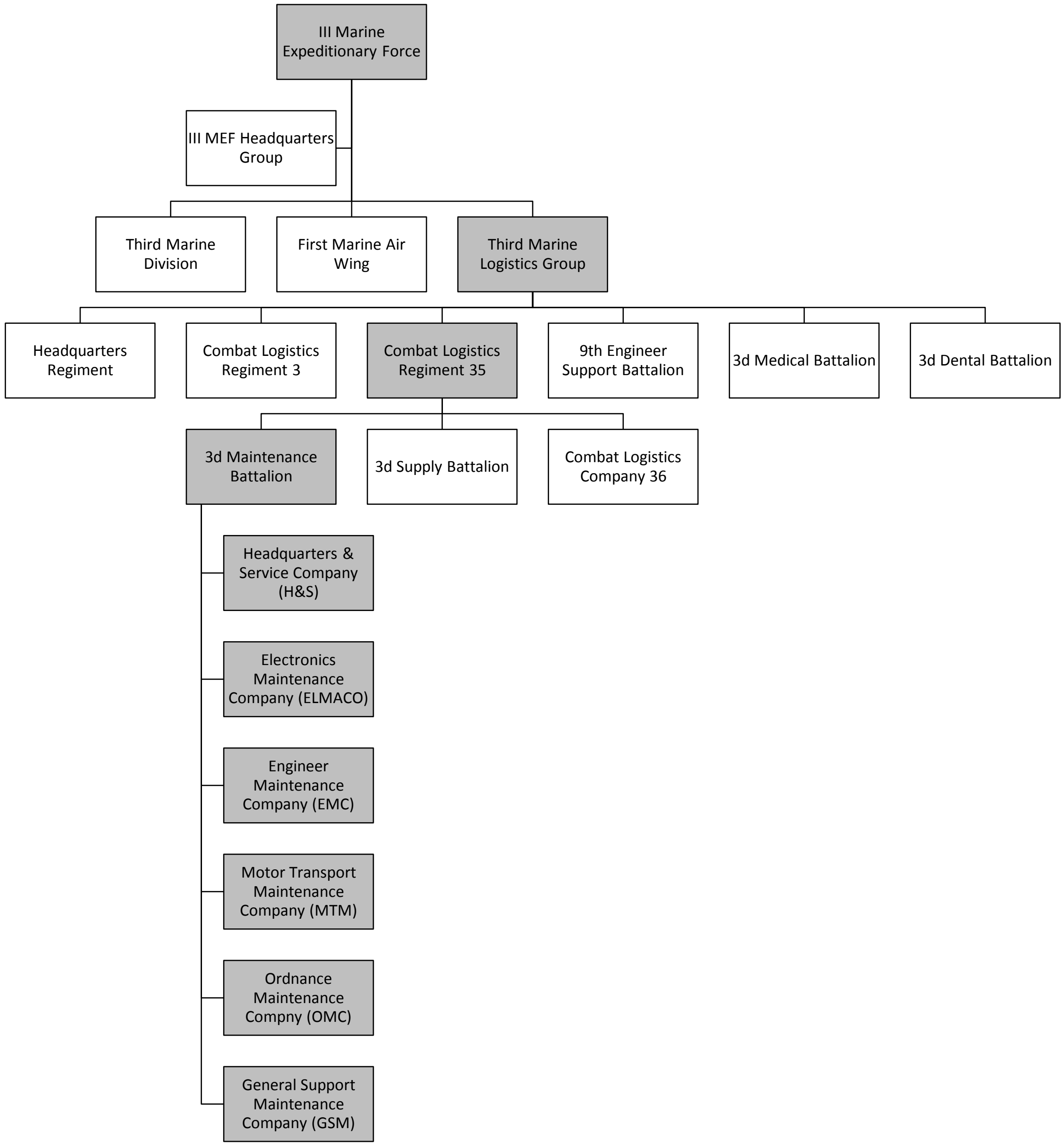

Figure 1. Command Hierarchy

Along with its mission, the battalion also has the following specified tasks:

- Provide command and control as well as command support functions
- Provide intermediate maintenance tasks on end items

- Provide field-level maintenance in support of the SecRep [secondary repairable] program
- Provide a tracked and wheeled vehicle recovery capability
- Provide calibration services for Marine Corps TMDE [test, measure, and diagnostic equipment]
- Provide technical assistance and perform overflow organizational maintenance
- Provide field-level maintenance technical inspection services
- Provide management of MEF SecReps (USMC, 2016k)

The battalion is based in Okinawa, Japan, at various locations within the Marine Corps Base Camp Butler complex. The battalion headquarters is located aboard Camp Kinser. Electronics Maintenance Company (ELMACO), Motor Transport Maintenance Company (MTM), General Support Maintenance Company (GSM), and the Repairable Issue Point (RIP) are co-located with the battalion headquarters aboard Camp Kinser. Engineer Maintenance Company (EMC) is located aboard Camp Foster. Ordnance Maintenance Company (OMC), MTM North, and RIP North are located aboard Camp Hansen.

To accomplish its mission and tasks, Third Maintenance Battalion is organized into a headquarters and service company and five maintenance companies of between 92 and 211 personnel, as shown in Table 1.

Table 1. Third Maintenance Battalion Table of Organization Summary.

UIC	Company	M/O	M/E	N/O	N/E	Civ	Total
M29022	Headquarters & Service Co (H&S)	12	96	1	1	-	110
M29023	Ordnance Maintenance Company (OMC)	5	88	-	-	-	93
M29024	Engineer Maintenance Company (EMC)	4	117	-	-	-	121
M29025	Electronics Maintenance Company (ELMACO)	5	124	-	-	13	142
M29026	Motor Transport Maintenance Company (MTM)	2	209	-	-	-	211
M29027	General Support Maintenance Company (GSM)	4	141	-	-	17	162
M29021	**Third Maintenance Battalion**	**32**	**775**	**1**	**1**	**30**	**839**

M/O = Marine Officer, M/E = Marine Enlisted, N/O = Navy Officer, N/E = Navy Enlisted
Adapted from USMC (2016a, 2016b, 2016d, 2016e, 2016h, 2016i, and 2016k).

Each company is task-organized to provide "field-level maintenance support for Marine Corps-furnished … equipment of the Marine expeditionary force (MEF)" (USMC, 2016k). The data in Table 1 reflects the Total Force Structure Management System (TFSMS) data; however, the actual staffing levels tend to be lower on average (approximately 70%) based on staffing goals,[2] personnel rotation, and other tasking requirements (Salm, 2017a).

2. Deployments and Detachments in Support of III MEF Operations

Third Maintenance Battalion maintains a high operational tempo as a forward-deployed intermediate maintenance activity (IMA). In addition to maintenance activities

[2] Because the table of organization is based on wartime manning, a unit in garrison will not be staffed to 100%, but to a staffing goal determined by Headquarters Marine Corps.

at its permanent facilities on Okinawa, the battalion regularly deploys maintenance support teams (MSTs) and maintenance support teams (MSTs) in support of Third Marine Expeditionary Force (III MEF) operations and exercises.

Third Maintenance Battalion supports several annual exercises with personnel detachments, including Marine Rotational Force Darwin (MRF-D) and MRF-D Ground Equipment Staging Program (GESP) in Darwin, Australia, and Coalition/Joint Logistics Over the Shore (CJLOTS) in Republic of Korea (ROK). Ordnance MSTs are detached in support of Military Sealift Command’s Maritime Prepositioning Force (MPF) operations, including aboard the USNS LUMMUS and USNS WILLIAMS in Guam, and USNS SISLER in Diego Garcia. The battalion also provides motor transport, utility, and heavy engineer equipment MSTs of up to 30 personnel in support of III MEF units.

3. Comparison to Other USMC Maintenance Battalions

Each of the three active component Marine Logistics Groups (MLGs) are organized similarly to Third MLG, with the general support maintenance battalion assigned as the subordinate unit to the general support regiment (USMC, 2016j). The other USMC general maintenance battalions are located at Camp Pendleton, CA (First Maintenance Battalion, CLR-15) and Camp Lejeune, NC (Second Maintenance Battalion, CLR-25).

Third Maintenance Battalion receives supply support from its adjacent general supply battalion, Third Supply Battalion, also located at Camp Kinser. Although the relationship between these battalions is functionally the same as other maintenance battalions and their adjacent supply battalions, lead times for repair parts and equipment at Third Maintenance Battalion are typically longer than lead times for battalions in the continental U.S. (CONUS). These extended lead times are mitigated to some extent by placing higher priority on materiel shipped to Okinawa, as designated by the Uniform Material Movement and Issue Priority System (UMMIPS) standards. UMMIPS Time Definite Delivery (TDD) standards are determined by unit location and mission priority. Force/Activity Designator (F/AD) and Urgency of Need Designator (UND) are set by UMMIPS standards. As a forward-deployed maintenance unit, Third Maintenance

Battalion is assigned F/AD II, corresponding to UND priority codes 02 (used when the owning unit will be unable to perform assigned missions within 20 days), 06 (used when the operational capability of the owning unit is impaired), and 12 (used for routine service requests).

As a forward-deployed force, III MEF sustains a high operational tempo that places a high demand on ground equipment. Additionally, some III MEF equipment is stationed in locations other than Okinawa (Republic of the Philippines, Republic of Korea, and Australia), requiring field maintenance and deployed maintenance support teams to repair equipment away from garrison facilities. This places increased demand on maintenance personnel and degrades capacity at garrison facilities during deployed periods and exercises.

4. Maintenance Cycle Time and Maximum Deadline Time

Readiness Reportable Ground Equipment (RRGE) that cannot perform its assigned combat mission due to a lack of critical repairs is considered "deadlined." The date on which equipment is declared non-mission capable is considered the deadline control date (DCD), triggering a countdown to the maximum deadline time. For Third MLG and other OCONUS units, the maximum amount of time an end item can be in a deadlined status is 180 days (compared to 120 days for CONUS units). For secondary repairable components, the maximum deadline time is 90 days (compared to 60 days for CONUS units). These maximum allowable times provide forward-deployed units with a longer opportunity to repair equipment before submitting for recovery to CONUS.

Once the end item timeline is exceeded, overflow (surge) maintenance procedures may be initiated with the approval of Third MLG. Overflow maintenance can also be requested by Third Maintenance Battalion when the unit is unable to meet its maintenance mission requirements. These circumstances typically occur during pre- or post-deployment operations or for urgent modifications for large quantity end items.

Although units can submit equipment with required delivery dates (RDDs), most do not, with the exception of the 31st Marine Expeditionary Unit, which regularly embarks on Navy ships more frequently than the maximum cycle times allow.

5. Company Missions and Overview

Each of the companies of Third Maintenance Battalion assume missions specific to categories of equipment. Headquarters and Service Company (H&S) provides command, control, and command support functions to the battalion (USMC, 2016e).

a. Electronics Maintenance Company

Electronics Maintenance Company's (ELMACO's) mission is to "provide field-level maintenance support for Marine Corps-furnished ground communications-electronics equipment of the Marine expeditionary force (MEF)" (USMC, 2016a, p. 1) According to the company's table of organization and equipment (TO&E) report, the company includes a headquarters section, maintenance support section, radio repair platoon, telephone/data systems repair platoon, and calibration/test, measure, and diagnostic equipment repair platoon (USMC, 2016a, pp. 1–7). The Third Maintenance Battalion Capabilities Brief depicts their current task organization as: headquarters section, organics platoon, calibrations (includes TMDE) platoon, and intermediate maintenance activity (IMA) platoon. Critical military occupational specialties (MOSs) are 2874 (Meteorology Technician), and 2862 (Communications Electronics Technician). Critical equipment and resources that comprise ELMACO's capabilities are the A7470 (Maintenance Facility), A00472B (Expandable Shelter), and A23372B (Non-Expandable Shelter) used to conduct field support of calibration and TMDE maintenance. The garrison calibration and intermediate maintenance activity (IMA) facilities are located aboard Camp Kinser.

b. Engineer Maintenance Company

Engineer Maintenance Company's (EMC's) mission is to "provide field-level maintenance for Marine Corps-furnished engineer equipment of a Marine expeditionary force (MEF)" (USMC, 2016b, p. 1). EMC is task-organized as follows: headquarters section, heavy equipment platoon, utilities platoon, and support platoon. Critical MOSs are 1349 (Engineer Maintenance Chief) and 0411 (Maintenance Management Specialist). Critical equipment and resources that facilitate EMC's capabilities are the C7909 (Common #32 Toolkit), Lightweight Maintenance Enclosure, C7033 (Maintenance

Contact Truck), and B0063 (Tractor, Rubber-tired, Articulated steering, Multipurpose). The heavy equipment and utilities maintenance platoons' garrison IMA facilities are located aboard Camp Foster, and the support platoon is located aboard Camp Kinser (Salm, 2017a, slide 22).

c. Ordnance Maintenance Company

Ordnance Maintenance Company's (OMC's) mission is to "provide field-level maintenance support, and tracked vehicle recovery for Marine Corps-furnished ground ordnance equipment of a Marine expeditionary force (MEF)" (USMC, 2016i, p. 1). OMC is task-organized as follows: headquarters section, armament repair platoon (ARP), and ordnance repair platoon (ORP). Critical MOSs are 2181 (Ordnance Maintenance Chief), 2149 (Amphibious Assault Vehicle Maintenance Chief), 2141 (Amphibious Assault Vehicle Mechanic), and 2147 (Light Armored Reconnaissance Vehicle Mechanic). Critical equipment and resources that comprise OMC's capabilities include the E1712 (Artillery Maintenance Shelter), E0067 (Electro-Optical Maintenance Shelter Complex), and E1714 (Small Arms Maintenance Shelter). The ARP and ORP garrison IMA and SecRep facilities are located aboard Camp Hansen (Salm, 2017a, slide 13).

d. General Support Maintenance Company

General Support Maintenance Company's (GSM's) mission is to "provide field-level maintenance support, to include component repair, for Marine Corps-furnished ground equipment of the Marine expeditionary force (MEF), less communications electronics equipment" (USMC, 2016d, p. 1). GSM is task-organized as follows: headquarters section, organics section, component repair section, and fuel and electric (F&E)/dynomometer (DYNO) section. Critical MOSs are 0411 (Maintenance Management Specialist), 3529 (Motor Transport Maintenance Chief), 2141 (Amphibious Assault Vehicle Mechanic), 2147 (Light Armored Reconnaissance Vehicle Mechanic), 2146 (Tank Mechanic), and 1349 (Engineer Maintenance Chief). Critical equipment and resources that facilitate GSM's capabilities include the portable dynomometer, B2685 (Marine Corps Tactical Welding Shop), Lightweight Maintenance Enclosure, and C7033

(Maintenance Contact Truck). GSM's garrison IMA and SecRep facilities are located aboard Camp Kinser (Salm, 2017a, slide 8).

e. Motor Transport Maintenance Company

Motor Transport Maintenance Company's (MTM's) mission is to "provide field-level maintenance support for the motor transport equipment of the Marine expeditionary force (MEF)" (USMC, 2016h, p. 1). MTM is task-organized as follows: headquarters section, organics section, general support section, MTM North, and MTM South. Critical MOSs are 3529 (Motor Transport Maintenance Chief), 0411 (Maintenance Management Specialist Chief), and 3043 (Supply Administration Specialist). Critical equipment and resources that facilitate MTM's capabilities include the C7909 (Common #32 Toolkit), Lightweight Maintenance Enclosure, C7907 (Lubricating Unit Power Operated), C7033 (Maintenance Contact Truck), D1214 (Logistics Vehicle System Replacement MKR15 Wrecker), and D1317 (Motor Transport Vehicle Replacement MK36 Wrecker). The MTM garrison IMA facility is located aboard Camp Kinser (Salm, 2017a, slide 2).

6. Motor Transport Maintenance Company's Maintenance Production Process

The MTM maintenance production process mirrors the maintenance phases described previously. MTM's procedure details are outlined subsequently, reflecting the company's two locations and the specific resources and capabilities each provide. Once equipment has been accepted by Third Maintenance Battalion and assigned to MTM North or MTM South, the maintenance process continues in one of these two locations.

According to Master Sergeant Jennifer Sanchez, Maintenance Operations Section (MOS) Chief of Third Maintenance Battalion, MTM supports 70 different units on Okinawa and 25 III MEF units off Okinawa (personal communication, October 18, 2017). The organization maintains over 65 different types of equipment, designated by different Table of Authorized Materials Control Numbers (TAMCNs; Sanchez, personal communication, October 18, 2017). Over the two years of service records studied, MTM supported 34 units and maintained 31 different TAMCNs, listed in Table 2

Table 2. List of TAMCNs Serviced by MTM. Adapted from USMC (2010).

TAMCN	Nomenclature
C79052B	Common #22, Shop Equipment Common Tool Set
C79092B	Shop Equipment, GP, Common No. 32
D00037K	Truck, Cargo, 7 Ton, Armored, w/o Winch, AMK23/AMK23A1
D00057K	Truck, Cargo, 7 Ton, Armored, w/o Winch, AMK27/AMK27A1
D00077K	Truck, Dump, 7 Ton, Armored, w/o Winch, AMK29/AMK29A1
D00097K	Truck, Tractor, 7 Ton, MK31/MK31A1
D00137K	Truck, Tractor, 7 Ton, Armored, AMK31/AMK31A1
D00157K	Truck, Wrecker, 7 Ton, Armored, AMK36
D00227K	Truck, Utility, Expanded Capacity, Vehicle, M1152, M1152A1 (IAP w/o B2 and FRAG Kits)
D00307K	Truck, Utility, Expanded Capacity Vehicle, Armament Carrier, M1151A1, M1114 w/B1 Armor Kit
D00317K	Truck, Utility, Expanded Capacity Vehicle, Command and Control/General Purpose Vehicle, M1165, M1165A1 (IAP w/o B3 and FRAG Kits)
D00327K	Truck, Utility, Expanded Capacity Vehicle, TOW Carrier, Armored, M1167 w/B1 Kit
D00337K	Truck, Utility, Expanded Capacity Vehicle, IAP/Armor Ready, M1152A1 w/B2 Armor Kit
D00347K	Truck, Utility, Expanded Capacity Vehicle, Command and Control/General Purpose Vehicle, IAP/ Armor Ready, M1165A1 w/B3 Armor Kit
D00527K	Truck, Cargo, Armored, 10x10, Logistics Vehicle System Replacement (LSVR), AMKR18
D00537K	Truck, Tractor, Armored, 10x10, Logistics Vehicle System Replacement (LVSR), AMKR16
D00547K	Truck, Wrecker, Armored, 10X10, Logistics Vehicle System Replacement (LVSR), AMKR15
D01877K	Truck, Utility, Heavy Variant, M1097A2
D01987K	Truck, Cargo, 7 Ton, MK23/MK25, MK23A1/MK25A1
D08807K	Trailer, Tank, Water, 400 Gallon, M149/M149A1/M149A2
D08867K	Truck, Cargo, 10x10, Logistics Vehicle System Replacement (LSVR), MKR18
D08877K	Truck, Tractor, 10x10, Logistics Vehicle System Replacement (LVSR), MKR16
D10017K	Truck, Ambulance, 4-Litter, M997A2
D10027K	Truck, Ambulance, 2-Litter, Soft Top, M1035A2
D10627K	Truck, Cargo, 7 Ton, Extended Bed (XL), MK27/28, MK27A1/MK28A1
D10647K	Truck, Fire Fighting, Aircraft Crash and Structure Fire, A/S32P-19A
D10737K	Truck, Dump, 7 Ton, MK29/MK30, MK29A1/MK30A1
D11587K	Truck, Utility, Heavy Variant/Cargo/Troop Carrier, M1123
D11617K	Truck, Utility, Light Strike Variant (ITV-LSV), M1161
D11627K	Truck, Utility, Prime Mover (ITV-PM), M1163
D12147K	Truck, Wrecker, 10X10, Logistics Vehicle System Replacement (LVSR), MKR15

a. MTM South

Normal operating hours at MTM South's Camp Kinser location are 0730 to 1630 (eight hours per day with one hour for lunch), Monday through Friday. In extreme cases, extended hours and resources are assigned to meet required deadlines.

The equipment induction phase is performed by the quality control (QC) section. As the primary maintenance facility for MTM, the MTM South QC section consists of three noncommissioned officers (1x E-5 and 2x E-4) who conduct inspections and induct equipment. Induction includes verification that preventive maintenance checks and services (PMCS) have been performed as required and reported. If PMCS are not completed or the service record (SR) prepared by the owning unit is incorrect or incomplete, the equipment is returned to the unit for completion. The QC section inspects the vehicle to verify the reported defect and confirm that any repair parts required for organizational level repairs are on order with the owning unit. If the defect is determined to be an organizational level repair or parts are not on order, the equipment is returned to the owning unit. To complete the equipment induction phase, the MTM South QC Section assigns equipment to either the IMA 1 or IMA 2 resource group for repair.

Repairs and associated activities conducted during the active maintenance phase are recorded in GCSS-MC. Labor and hours are reported by mechanics performing maintenance to the Floor Chief to be entered into GCSS-MC and briefed to unit leadership. Once work is complete, the equipment is assigned again to the QC section for inspection. If the QC section notes defects or discrepancies in the performed maintenance, equipment is reassigned to the IMA North resource group for mitigation and correction. If no discrepancies are noted, the QC section notifies the equipment owner to pick up the vehicle, usually occurring within a week of notification.

b. MTM North

Normal operating hours at the MTM North (Camp Hansen) location are the same as MTM South (40 hours per week under normal operating conditions). The MTM North QC section consists of two noncommissioned officers (E-4) and performs the same functions during the equipment induction phase as MTM South, ensuring that PMCS and organizational maintenance records are current and accurate. Once inducted, the MTM North QC section assigns the maintenance to the IMA North resource group for repair, ending the equipment induction phase. The active maintenance phase and maintenance closeout phase consist of the same activities as MTM South.

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IV. DATA ANALYSIS AND FINDINGS

A. INTRODUCTION

This chapter summarizes the data collected and lays out the analytical approach. First, Motor Transport Maintenance Company's (MTM's) maintenance production process is mapped. Next, service record data obtained from the Marine Corps Logistics Command (LOGCOM) Master Data Repository (MDR) is used to determine demand placed on MTM. Third, information provided by Third Maintenance Battalion is used to determine MTM's capacity. Finally, the relationship between demand and capacity is analyzed to determine capacity utilization.

B. DATA COLLECTION AND SOURCES

Data for this project came from two primary sources: Third Maintenance Battalion and LOGCOM. Third Maintenance Battalion provided data on actual (versus authorized) staffing levels and operational data concerning personnel availability. The battalion also provided information from which the maintenance process could be mapped (see Figure 2).

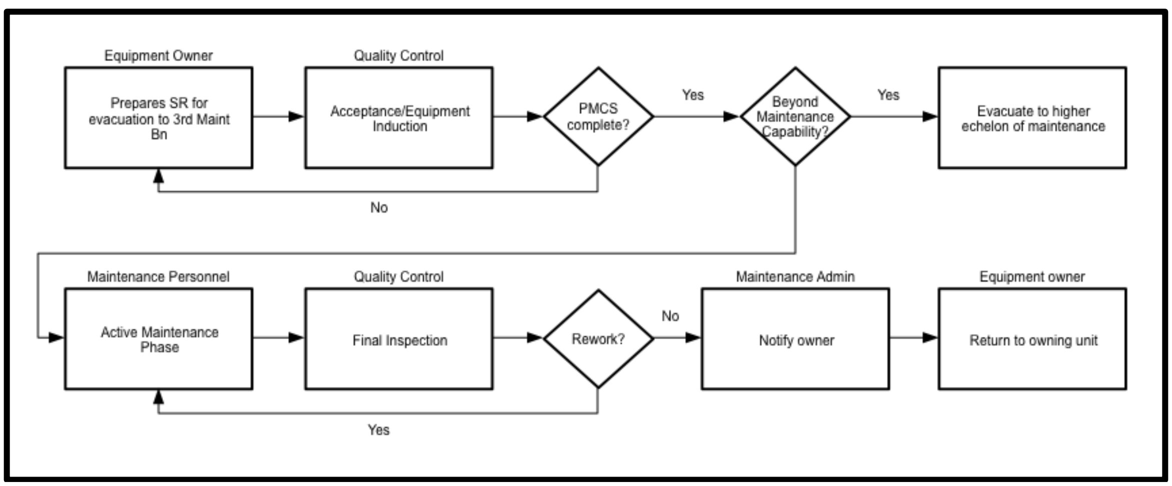

Figure 2. Third Maintenance Battalion Maintenance Process Map

First, the equipment owner determines that equipment is beyond its organic maintenance capability and prepares to evacuate it to a higher echelon of maintenance, in this case Third Maintenance Battalion. Next, the Quality Control (QC) personnel at Third Maintenance Battalion accept the equipment and perform a joint inspection with the owning unit to determine accuracy and completeness of equipment records and assign the equipment to a maintenance section. If the equipment is not current on preventive maintenance, the equipment is returned to the owning unit. If QC determines the required maintenance to be beyond Third Maintenance Battalion's capability, the equipment is evacuated to the next higher echelon. Once accepted and assigned to a maintenance section, the equipment enters the active maintenance phase and required maintenance is performed. After maintenance actions are complete, QC performs a final inspection. If discrepancies are found, the equipment is returned to the active maintenance phase for rework. If the equipment is repaired, the owning unit is notified and retrieves the equipment.

LOGCOM provided demand data and maintenance statistics, drawn from Global Combat Support System Marine Corps (GCSS-MC) data within the MDR. The MDR is managed by the Logistics Command Life Cycle Modeling Integrator (LCMI) to centrally store ground equipment management information. GCSS-MC is the authoritative data source for retail supply and maintenance in the MDR, alongside data sources for warehouse and distribution, procurement and financials, item master and materiel management, and wholesale supply and maintenance.

A set of Third Maintenance Battalion service records was pulled directly from the MDR (see Appendix A) for a two-year period, from 1 October 2015 to 30 September 2017. Because maintenance is an on-going process, data from this period comprises three groups of service records, as shown in Table 3.

Table 3. GCSS-MC Service Records

Group	Opened	Closed
A	prior to 1 October 2015	on or after 1 October 2015
B	on or after 1 October 2015	on or before 30 September 2017
C	on or after 1 October 2015	after 30 September 2017

Group B, the service records opened on or after 1 October 2015 and closed on or before 30 September 2017, consisted of 20,265 service records for Third Maintenance Battalion (see Table 4). Thirty-one different TAMCNs (see Table 2) were serviced in this time period, including 29 different vehicle types and two vehicle maintenance toolkits. For a detailed review of individual service records, only the 705 service records opened by MTM from group B were considered. Although this only represents about 3% of all battalion service requests opened and closed in the same period, they represent 18,418 hours of actual work performed, 35.68% of the battalion's total demand.[3]

Table 4. Service Record Priority and Workload

Maintenance Unit	Priority	Number of SRs	Hrs	% of Total Hrs
Third Maintenance Bn (Organic)	Critical	26	117	0.23%
	Urgent	460	1,612	3.12%
	Routine	3,776	6,267	12.14%
	Total	4,262	7,996	15.49%
Engineer Maintenance Company	Critical	5	11	0.02%
	Urgent	1,304	2,524	4.89%
	Routine	9,263	12,708	24.62%
	Total	10,572	15,243	29.53%
Electronic Maintenance Company	Critical	4	109	0.21%
	Urgent	29	215	0.42%
	Routine	288	1,421	2.75%
	Total	321	1,745	3.38%
Motor Transport Maintenance Company	Critical	50	3,914	7.58%
	Urgent	510	13,183	25.54%
	Routine	145	1,321	2.56%
	Total	705	18,418	35.68%
General Support Maintenance Company	Critical	49	289	0.56%
	Urgent	2,994	4,457	8.64%
	Routine	1,362	3,465	6.71%
	Total	4,405	8,211	15.91%
Grand Total		20,265	51,613	100%

C. PHASE I: DEMAND ASSESSMENT

1. Understanding the Data

Demand on the process is defined as the number of labor hours required to complete the maintenance requirements of the unit's customers. The required labor hours

[3] Note that the scope of this thesis is limited to MTM Company (North and South). No inferences should be made from the results drawn from these 705 records to battalion performance (i.e., only to MTM company performance). These service records represent 100% of the relevant demand for that scope.

are estimated by the Marine Corps standard for each maintenance task as described in the technical publications for the equipment being repaired.[4]

Maintenance repair orders include a breakout of the maintenance tasks required to be performed. The sum of the labor hours required for each task is considered a distinct requirement as some repair orders may include multiple job tasks (e.g., repair or replace transmission and conduct a road test). Preventive maintenance, calibration, and corrective maintenance service requests are opened on multiple maintenance work orders, even if they are for the same piece of equipment.

Labor hours for maintenance service records include the mechanic’s time spent executing the repair tasks, as well as time required for associated administrative actions, as shown in Table 5. Maintenance tasks, quality control/inspection, and administrative requirements all present demand on Third Maintenance Battalion resources. These different service tasks, as well as tasks performed on different vehicle types, are measured in labor hours in order to facilitate aggregate planning.

[4] According to the Maintenance Operations Section at Third Maintenance Battalion, planned maintenance hours in the MDR are not accurate. Although the technical manuals (TMs) for the equipment list expected time to conduct maintenance tasks, maintenance personnel do not routinely enter these times into the “planned” field because individual circumstances vary and are often difficult to discern during induction. However, accurate records are kept of actual time spent conducting maintenance tasks (Sanchez, personal communication, October 18, 2017). This data, entered by maintenance personnel, is used as the basis for assessing aggregate demand for this research.

Table 5. Sample Service Record Information

SR#	Problem Summary	TAMCN	Task Name	Task Description	Task Type	Hrs
20121222	Engine Will Not Start	D00037K	Troubleshoot Vehicle No Start	Troubleshoot vehicle not starting IAW the vehicle technical manual. See Task Notes.	Maint - Troubleshoot	48
20121222	Engine Will Not Start	D00037K	Replace Cab Harness	Replace the cab wiring harness IAW the vehicle technical manual.	Maint - Replace - Wiring Harness	54
20121222	Engine Will Not Start	D00037K	Replace Relays	Replace the starter relay and diode IAW the vehicle technical manual.	Maint - Replace	1
20121222	Engine Will Not Start	D00037K	FINAL INSPECTION	Conduct final inspection of vehicle to ensure proper repairs were completed.	Inspection - Final	1.5
20121222	Engine Will Not Start	D00037K	OWNER NOTIFICATI ON	Maintenance completed. Vehicle is ready for pick up	Admin - Owner Notification	2

Service records entered in Global Combat Support System Marine Corps (GCSS-MC) include a “Planned Time” field where estimated repair time can be entered. According to Sanchez, in practice these estimates are not always used by maintenance personnel when conducting inspections and troubleshooting. As a result, planned maintenance times listed in the service record do not reflect TM repair time estimates but are claimed to accurately reflect time worked on the maintenance activity (personal communication, October 18, 2017).

Although maintenance personnel can select a defect code from a prescribed list of values within GCSS-MC, these values do not always accurately align to the work being performed on a specific task. For example, the defect code “TRAN.INOP” (Major system: Transmission, Defect: Inoperable) does not indicate what repairs will need to be completed in order to correct the issue, nor how long repairs can be expected to take. To annotate this in the record, maintenance personnel enter a descriptive problem summary, for example “Replace transmission.” To analyze the type of maintenance being performed, the researcher analyzed the unique descriptions to sort them into five main work-type categories, “Administrative,” “Inspection,” “Maintenance,” “Modification,” and “Supply,” representing the principal maintenance actions and required task entries in accordance with User Manual (UM) 4400–125, Global Combat Support System-Marine Corps (GCSS-MC) User Manual. These main work-type categories were sorted into sub-categories, such as “Maintenance: Repair,” “Maintenance: Replace,” and so forth. Major equipment sub-systems or components (“Crane,” “Engine,” etc.) were further specified, based on frequency of use and demand (see Table 6).

Table 6. Work-Type Categories for Analysis

Work-type	Sub-category	Sub-system
Admin	Awaiting Pickup	
	Close SR	
	Error	
	Owner Notification	
	Pending Wash	
	Return	
	Update Status	
	Upgrade SR	
	Validation	
	WIR Disposition	
Inspection	Final	
	Acceptance JLTI	
Modification		
Maintenance	Extract	
	PMCS	
	Repair	
	Repair	Crane
	Repair	Electrical
	Repair	Engine
	Repair	Leak
	Replace	
	Replace	Crane
	Replace	Engine
	Replace	Injection Pump
	Replace	Transfer Case
	Replace	Transmission
	Replace	Wiring Harness
	Rework	
	Test	
	Test	Load
	Test	Road
	Troubleshoot	
	Troubleshoot	Crane
Supply	Debrief Parts	
	Order Parts	
	SECREP	
	Turn-in Without Issue	

2. Demand Data – Descriptive Statistics

Of the five major work-type categories, maintenance (including both preventive and corrective) predictably generated the highest demand for the sample set, accounting for 65% of total demand (18,418 hours) in MTM (see Table 7).

Table 7. Demand by Work Type

Work type	Demand (hrs)	% of total
Administrative	526	3%
Inspection	1,029	5%
Maintenance	11,960	65%
Modification	4,747	26%
Supply	156	1%
Total	*18,418*	*100%*

Unlike corrective and preventive maintenance that result from equipment use or schedule, equipment modifications are directed by administrative instruction and therefore cannot be easily predicted or scheduled. Under most circumstances (except critical), however, modification instructions allow for application to take place over a time window that allows some flexibility in scheduling. Equipment modifications generated 26% (4,747 hours) of total demand over the period studied.

Service record task time for each type of equipment is reflected in Figure 3. For all types of maintenance tasks performed, the D00037K (Truck, Cargo, 7 Ton, Armored, w/o Winch, AMK23/AMK23A1) generated 102 service records and represented the highest demand at 3,731 hours over the period studied, or 20.3% of total demand. Of this demand, however, 2,732 hours were due to modifications.

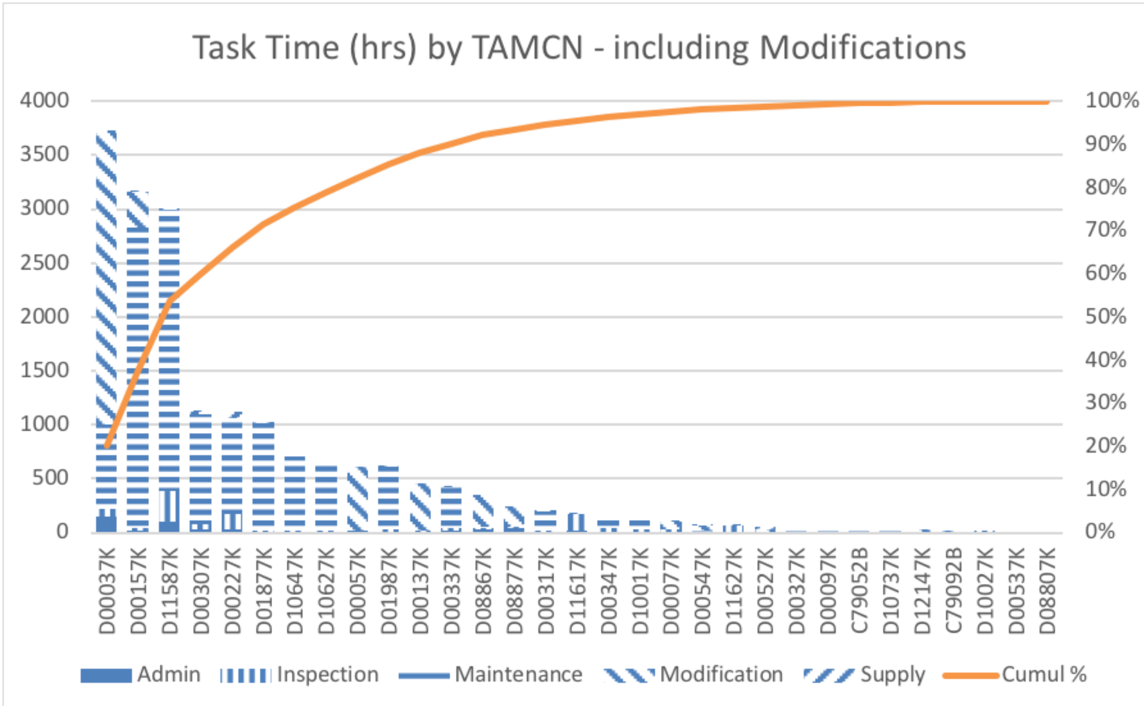

Figure 3. Service Record Task Time (Hours) by TAMCN, Including Modifications

For all types of maintenance tasks performed besides modifications, the D11587K (Truck, Utility, Heavy Variant/Cargo/Troop Carrier, M1123) generated 158 service records and represented the highest demand at 2,997 hours over the period, or 21.9% of total demand. The D00157K (Truck, Wrecker, 7 Ton, Armored, AMK36) generated 2,838 hours, or 20.8% of total demand (see Figure 4).

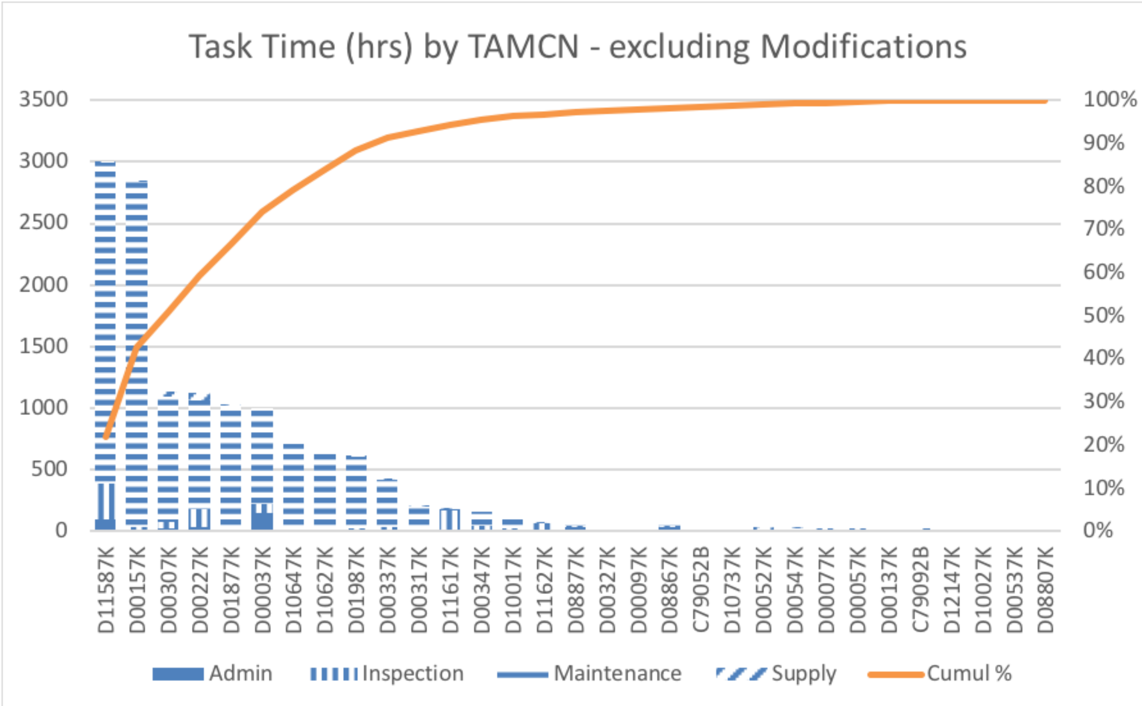

Figure 4. Service Record Task Time (Hours) by TAMCN, Excluding Modifications

D. AGGREGATE DEMAND ANALYSIS

To analyze aggregate demand, demand in labor hours was considered in the context of different time cycles designated by each service record. These cycles are defined by several significant dates: “Opened Date” (the date the owning unit opens a service record for higher echelon maintenance), “Date Received in Shop” (the date the equipment arrives at the maintenance location), “Closed Date” (the date the service record is closed out in the system following owner notification), “Actual Start Date” (the date maintenance work actually begins), and “Actual End Date” (the date maintenance work ends). These dates and cycles are depicted in Figure 5.

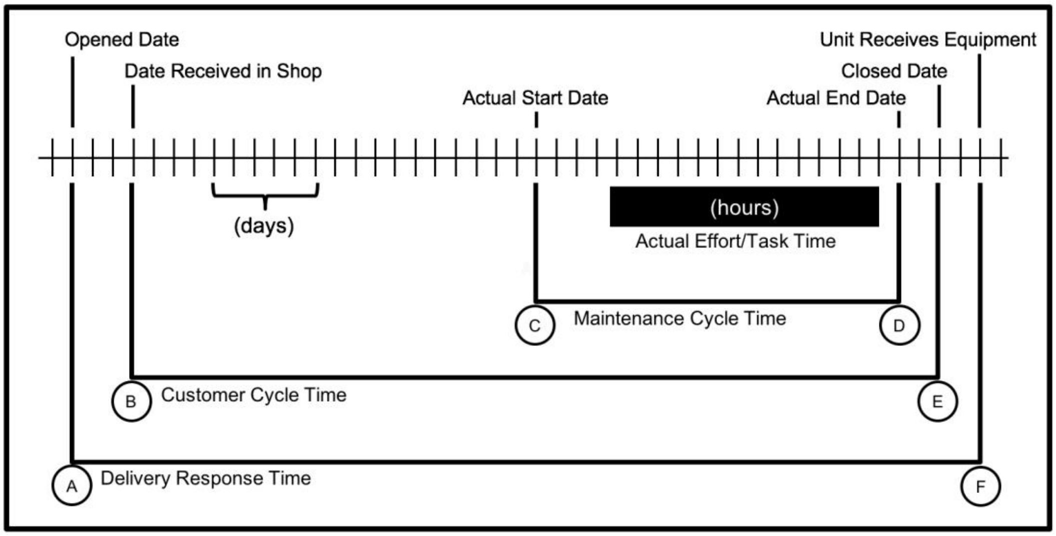

Figure 5. Service Record Cycle Times

Delivery Response Time, depicted in Figure 4 as the time between points A and F, is). From the customer's (i.e., owning unit's) perspective, the time between when the need for maintenance is established and when the equipment is ready for use by the owner, ready for use. This cycle includes time between when a service record is opened and when the equipment is received by MTM for service, as well time between when the equipment owner is notified that equipment is ready for pickup and when equipment is actually picked up and transported back to the owning unit. Because Delivery Response Time includes time during which the equipment is not in MTM's custody, it was not considered in this analysis.

The time between when the equipment is delivered to MTM ("Date Received in Shop") and the time it is picked up ("Closed Date") represents the customer cycle time, depicted in Figure 5 as the time between points B and E. Equipment is in MTM custody during this time, which includes administrative, supply, and maintenance tasks.

Maintenance cycle time is the time during which maintenance tasks are being performed, depicted in Figure 5 as the time between points C and D. Within this time period are the hours recorded in GCSS-MC as "Actual Effort," the amount of time spent actually completing the task.[5] These hours represent the value-added time for the maintenance process, or the portion of the maintenance process where the work performed is "essential to deliver the service or product to the customer" (George et al., 2005, p. 50).

For the service records analyzed previously, average customer cycle time was 114 days, maintenance cycle time was five days, and actual work time was nine hours. Averages for different work types are listed in Table 8.[6]

Table 8. Average Customer Cycle Time, Average Maintenance Cycle Time, Average Maintenance Time, and Value-Added Ratio

Work Type	Avg Cust Cycle Time (Days)	Avg Maint Cycle Time (Days)	Avg Maint Time (Hrs)	Value-Added Ratio
Administration	72.75	1.06	0.80	0.14%
Inspection	88.32	3.35	2.10	0.30%
Maintenance	225.72	14.37	24.61	1.36%
Modification	60.94	2.33	17.51	3.59%
Supply	153.09	3.22	2.59	0.21%
Total	*114.54*	*5.12*	*9.39*	*1.02%*

This value-added ratio (VAR) is on par with most industries, according to Patrick Shannon's research (1997) reported in *Quality Progress*. In the apparel industry, for example, the VAR is often below 1%. Mortgage lenders showed similar results (Patrick, 1997).

1. Determining Aggregate Demand

To determine the aggregate demand placed on MTM's production capacity, the data set was expanded to include all service records open during the period studied

[5] GCSS-MC data does not indicate how many personnel are assigned to a particular task. Therefore, hours recorded as "Actual Effort" may result in under-reporting of labor when work is performed by multiple personnel.

[6] Although only Maintenance and Modification are considered value-added work from the customer's perspective, Administration, Inspection, and Supply are considered "business non-value-added." They are activities that must be performed in order to execute the value-added work (George et al., 2005 p. 50). As a full value analysis is beyond the scope of this research, value-added and business non-value-added times are included in the actual effort computations.

(Groups A, B, and C, from Table 3). This larger data set included a total of 913 service records opened between April 2015 and September 2017, depicted in Table 9. Service record data was expanded to a Gantt chart based on received date, customer cycle time (in days), actual start date, maintenance cycle time (in days), and workload.[7]

Table 9. Modification and Other Service Records, FY16–FY17

	FY16	FY17	Total
Modification	282	7	289
All Others	379	307	624*
Total	661	314	913*

* includes 62 non-modification records that were opened in FY16 and closed in FY17

To create the Gantt chart, first a PivotTable was created in Microsoft Excel consisting of TAMCNs and service record numbers in rows, maintenance tasks in columns, and total hours as values. Next, two separate worksheets were created that listed each service record in rows and used the VLOOKUP function to reference the PivotTable and original service record data. These worksheets also included columns to represent each calendar day for the two-year period studied. The first worksheet populated the calendar day cells for each service record with the total customer cycle time on each day the service record was open by referencing the received and closed dates. Values within each day (column) could then be counted to compute the number of service records open, and the average customer cycle time of open requests could be computed. The second worksheet populated the calendar day cells for each service record with the actual workload divided evenly across the maintenance cycle time.[8] Values within each day (column) could then be averaged and summed to find total workload for that day.

Data from these worksheets were first examined for seasonal patterns (see Figure 6). There was no observed correlation in labor hours worked between FY16 and FY17 for

[7] The Gantt chart used is too large for inclusion in this report, but is available upon request.

[8] GCSS-MC data does not specify when the actual effort occurs, thus this technique was used to represent work throughout the recorded maintenance cycle time. An artifact of this technique is the elimination of day-to-day variance in workload, thus analysis is limited. Further research is required to determine how to better represent workload with regard to maintenance cycle time.

the first or second halves of the year (first half: $r = -0.05$, $N = 183$, $p = 0.54$, second half: $r = 0.04$, $N = 183$, $p = 0.63$). Hours worked in FY16 displayed more volatility than in FY17 (see Figure 7), perhaps due to the Battalion Maintenance Officer's efforts during FY17 meant to balance capacity between MTM South and MTM North (C. Galbraith, personal correspondence, October 5, 2017).

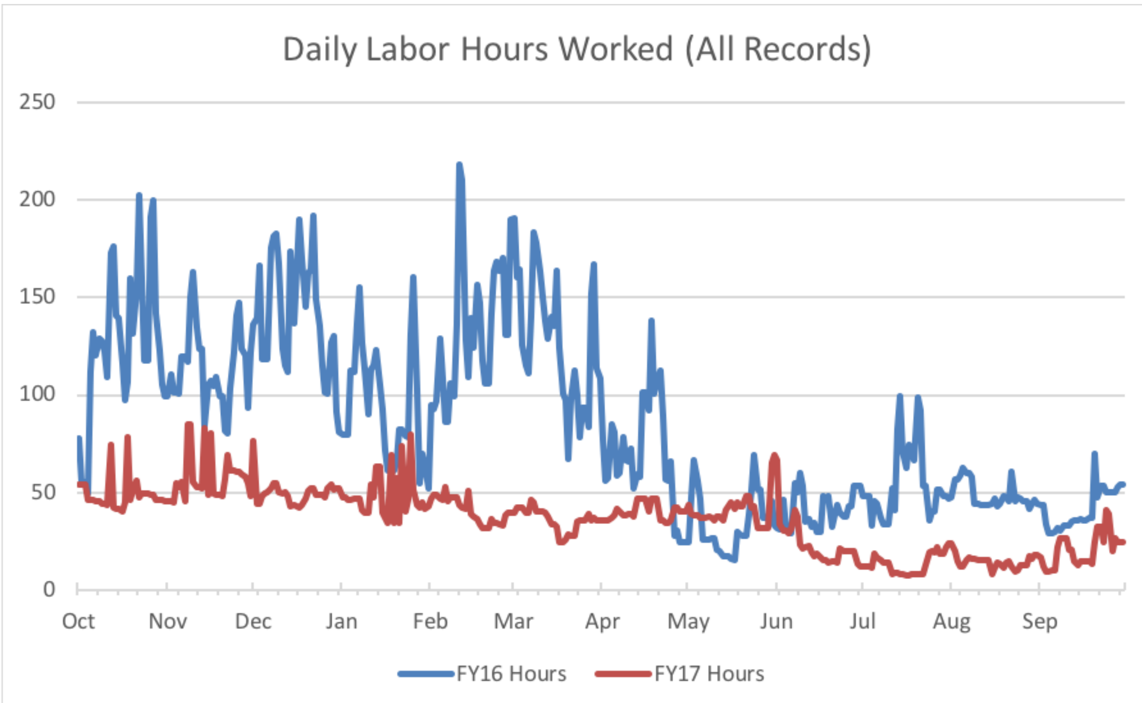

Figure 6. Daily Labor Hours Worked, FY16–FY17

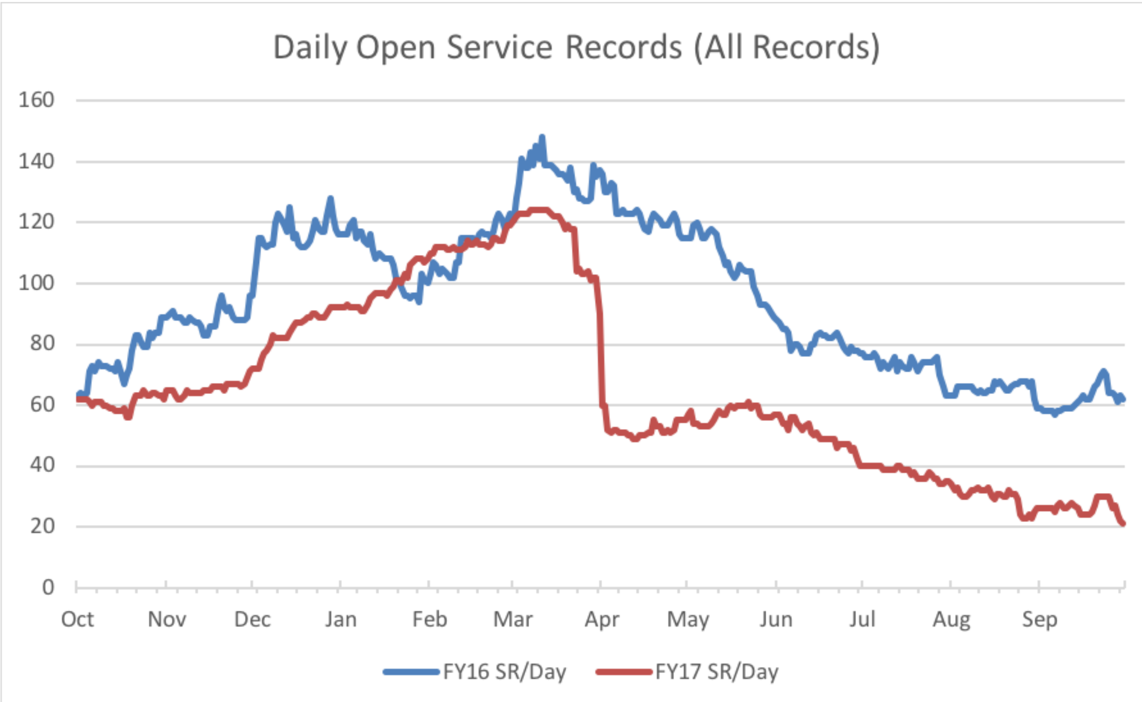

Figure 7. Daily Open Service Records, FY16–FY17

There was, however, a correlation found between the number of service records opened in FY16 and FY17. The first quarter (October through December) showed a rising number of open service records in both years ($r = 0.93$, $N = 92$, $p < 0.001$), most likely due to the availability of funds in the beginning of the fiscal year. Correlation was strong over the first and second halves of the year, at ($r = 0.82$, $N = 183$, $p < 0.001$) and ($r = 0.81$, $N = 183$, $p < 0.001$) respectively. The sharp decline in open service records in April of 2017 can be attributed to closing out records in preparation for inspection.

The records from FY16 and FY17 were sorted into two main groups: modification service records and all other service records. Modification service records are considered distinct from other service records because the demand they generate is based on administrative instructions from Headquarters Marine Corps rather than customer requirements. Hence, modification service records can be more easily planned.

For service records that were open during FY16, 282 modification records were open with an average customer cycle time of 74 days and average total workload of 34 labor hours per day. In contrast, only seven modification records were open during FY17, with an average customer cycle time of one day and average total workload of eight labor hours per day. These results are depicted in Figure 8.

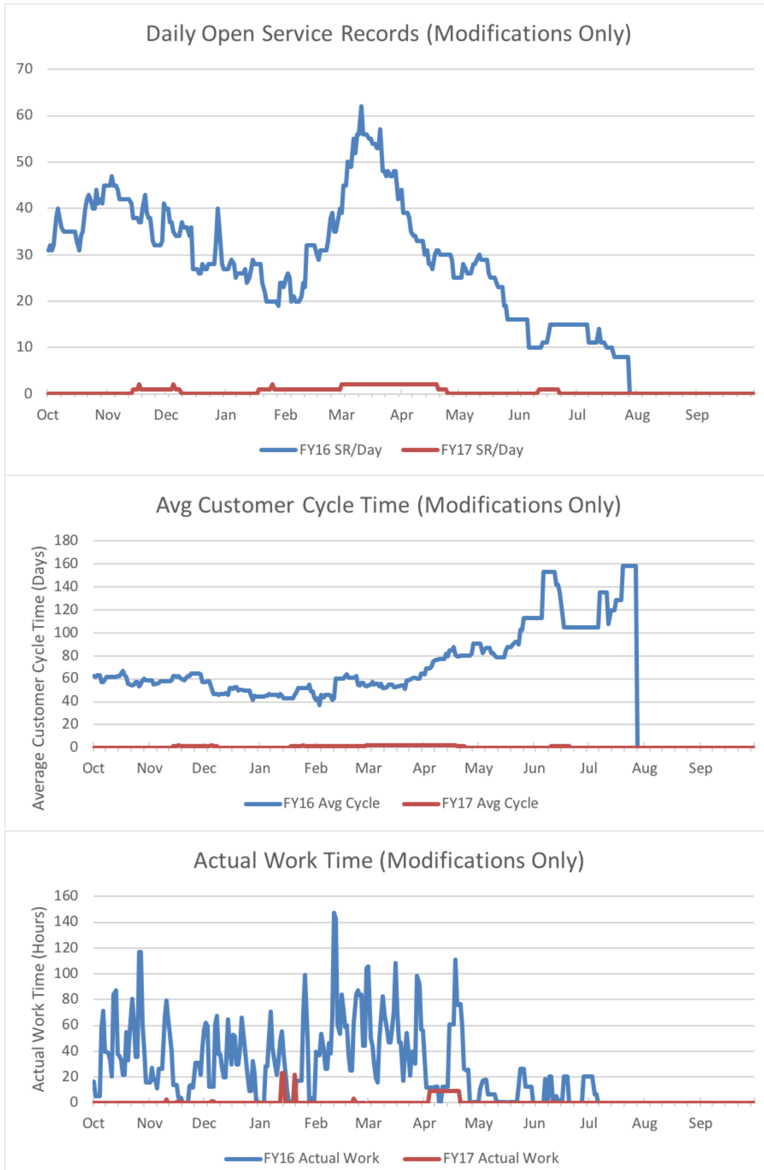

Figure 8. Modifications Service Records, Average Customer Cycle Time, and Actual Work Time, FY16–FY17

For the 379 other service records open during in FY16, the average customer cycle time was 116 days and average total workload per day was 62 hours per day. The 307 non-modification service records open during FY17 had an average customer cycle time of 119 days and an average total workload of 35 labor hours per day. These results are depicted in Figure 9.

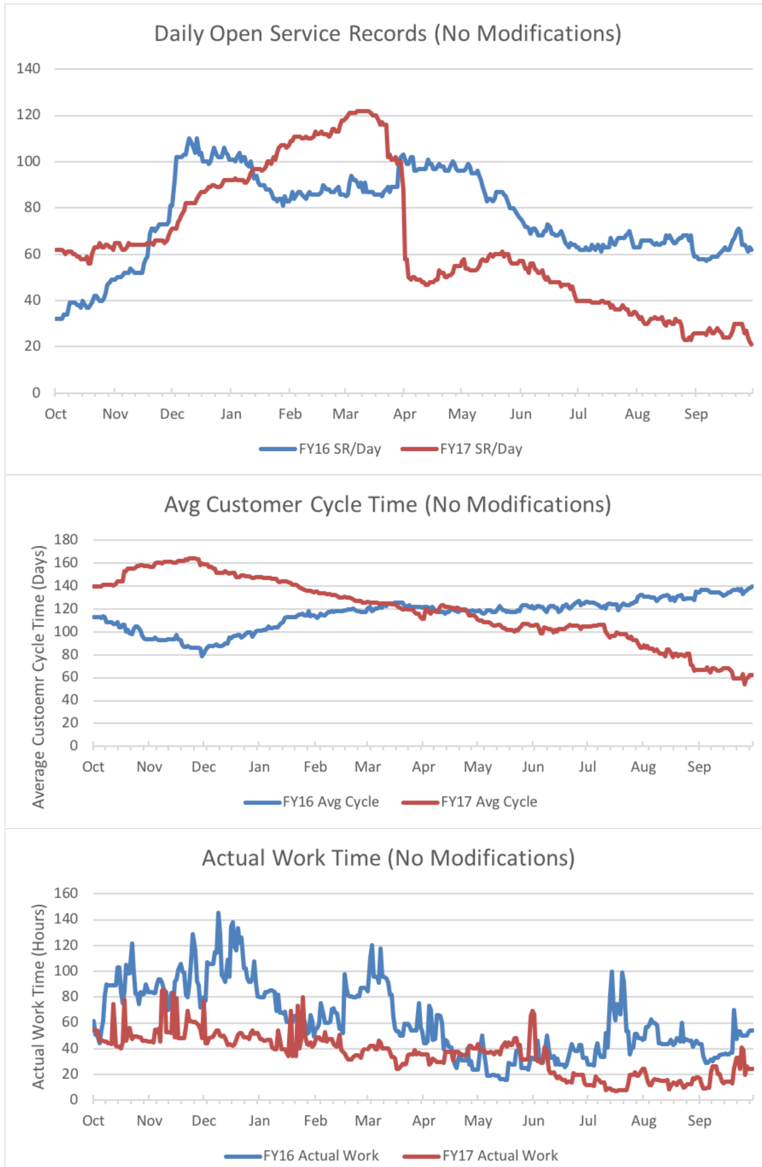

Figure 9. Other Service Records (Excluding Modifications), Average Customer Cycle Time, and Actual Work Time, FY16–FY17

Overall, the average customer cycle time over both years was similar, with an average of 108 in FY16 and 119 in FY17. The average total workload per day was considerably greater in FY16 than FY17, 86 labor hours and 36 labor hours, respectively. These results are depicted in Figure 10.

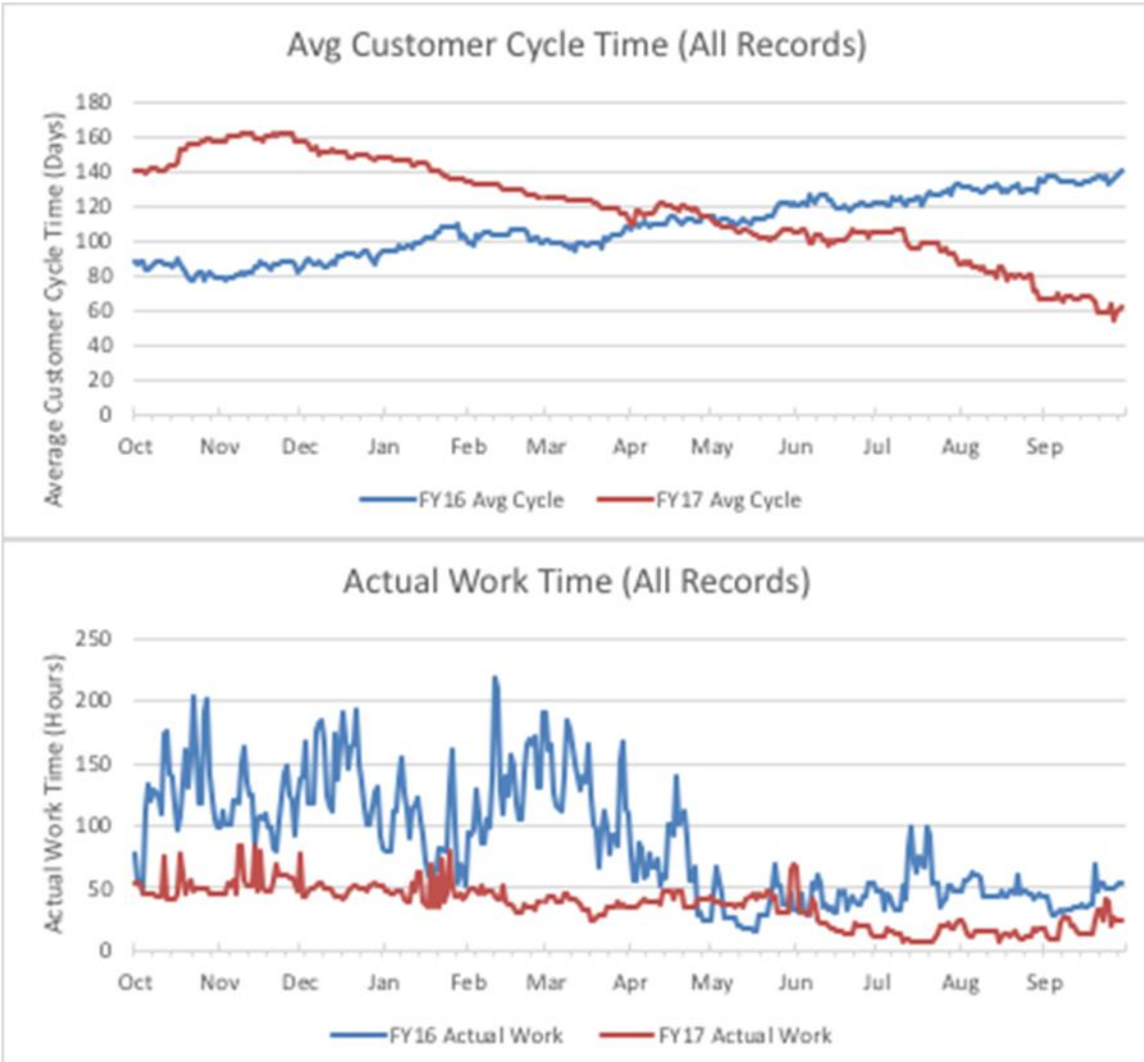

Figure 10. Average Customer Cycle Time and Actual Work Time (All Records), FY16–FY17

As shown in Figure 11, average customer cycle time and workload in FY16 showed a negative correlation for both modification service records ($r = -0.35$, $N = 256$, $p < 0.001$) and non-modification service records ($r = -0.77$, $N = 366$, $p < 0.001$).

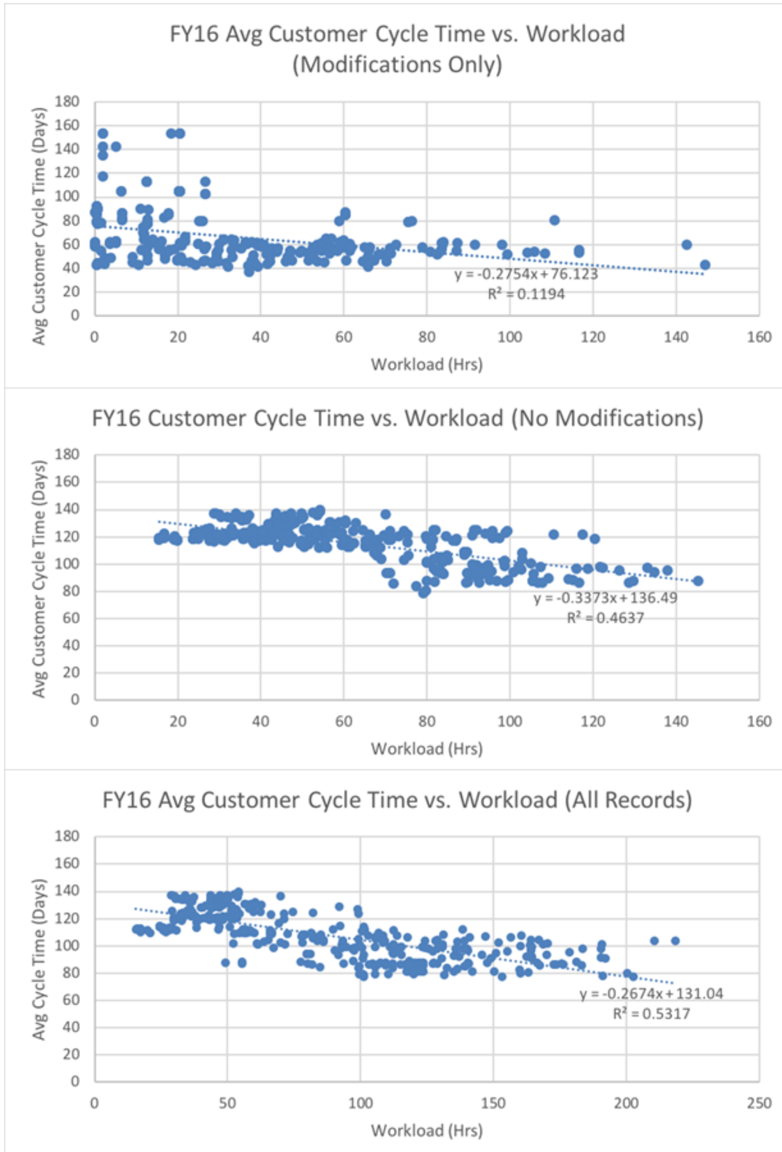

Figure 11. Average Customer Cycle Time vs. Workload, FY16

These results are counter-intuitive: As workload increased, cycle time was expected to increase as well.[9] A possible explanation for this negative relationship between workload and cycle time is that the unit prioritized heavy workload service records over lighter workload records. Alternatively, as modification service records are

[9] Although the relationship between customer cycle time and workload is understood to be non-linear, a linear regression was used to understand trends in the data. Further analysis is required to describe the non-linear relationship in more detail.

dictated by policy and may include required delivery dates for large quantities of equipment (rather than by supported units' requirements), all records may have been affected by modified dispatch rules. This could have caused delays for lower-priority and smaller workload records. This and other possible causes are diagrammed using a cause-and-effect diagram (i.e., a fishbone chart) in Figure 12.

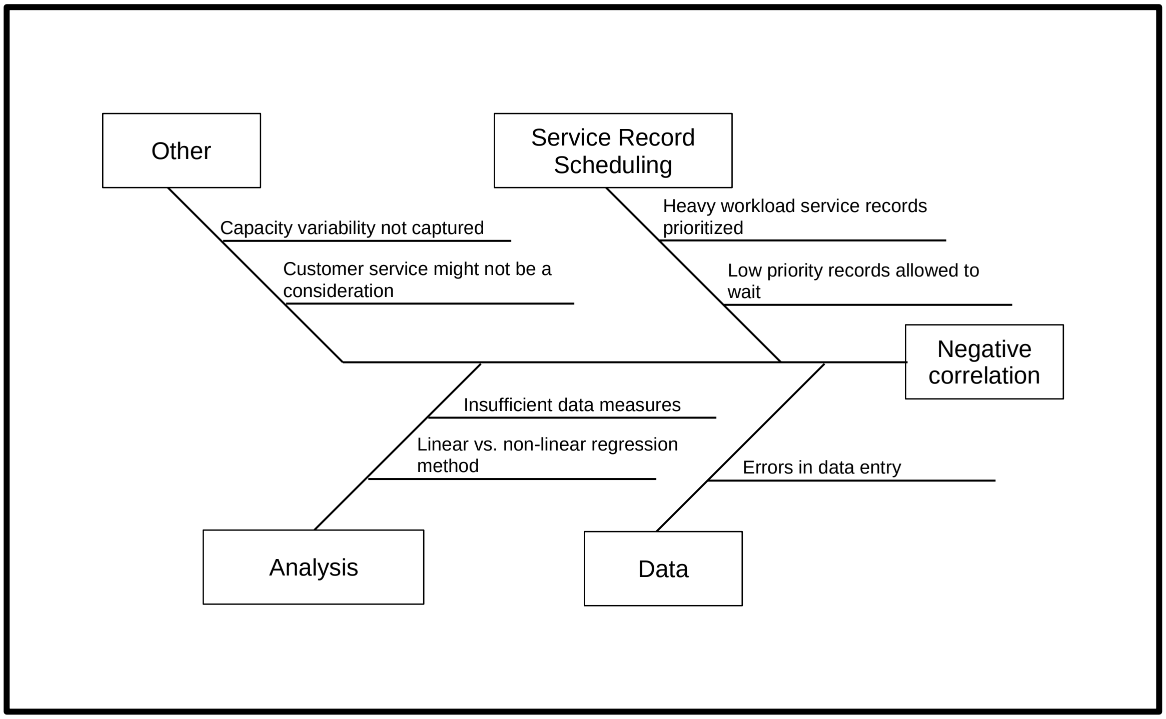

Figure 12. Cause-and-Effect Diagram.
Adapted from Krajewski and Ritzman (2005).

If the negative relationship between customer cycle time and workload in FY16 can be explained (at least in part) by the high number of modification records, then fewer modification records in FY17 should have resulted result in a positive relationship between customer cycle time and workload. Indeed, in FY17 when very few modification service records were open, average customer cycle time and workload were more positively correlated ($r = 0.77$, $N = 365$, $p < 0.001$), strengthening the assumption that FY16 modification service records impacted maintenance production. As shown in Figure 13, as workload increased, average cycle time increased as well. This was expected, as more demand placed on the unit can reasonably be expected to extend the average waiting time for work to be completed. As such, the equation of this line ($y = 1.3x + 70$) could be used to approximate customer cycle time.

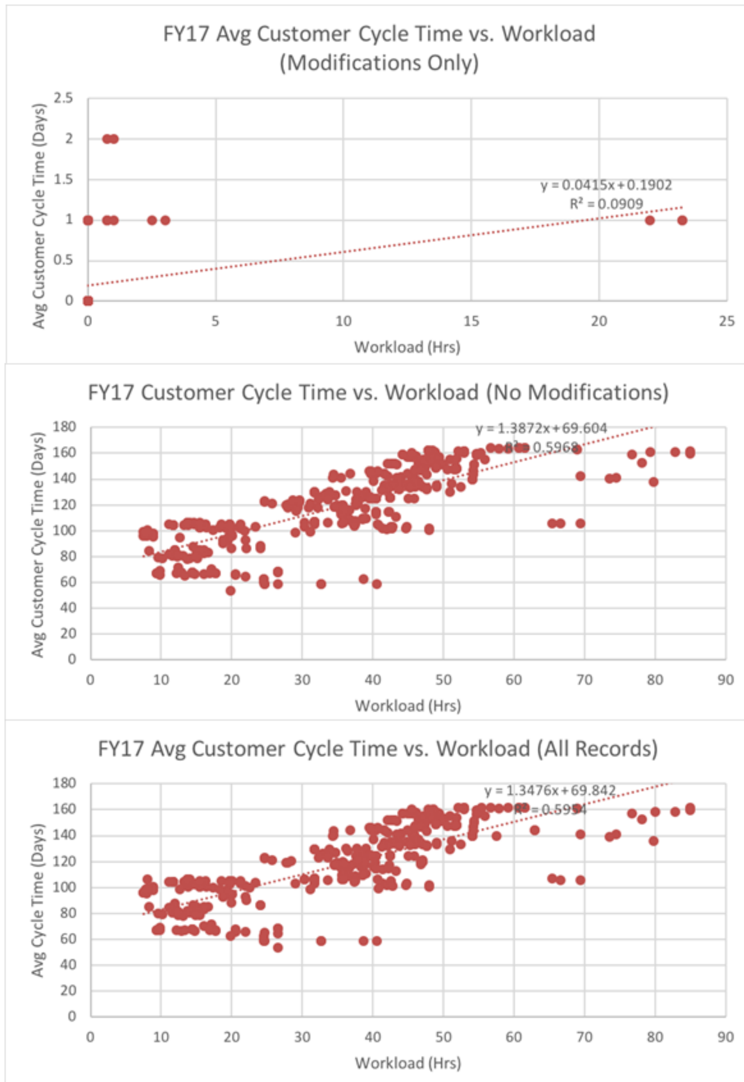

Figure 13. Average Customer Cycle Time vs. Workload, FY17

E. PHASE II: CAPACITY ASSESSMENT

In order to apply aggregate planning techniques, capacity of maintenance personnel is also presented in labor hours. Total labor hours available were calculated based on the number of personnel available to perform maintenance-related tasks including maintenance execution, quality control/inspection, and maintenance-related administrative functions. Capacity was determined at the resource level, broken down by military occupational specialty and billet assignment for personnel. Time spent waiting for maintenance tools, equipment, and facilities was not considered excess or idle capacity. Idle personnel who are cross-trained for other maintenance-related activities can provide temporary excess capacity to those other functions.

Capacity is determined at the facility level for the Intermediate Maintenance Activity (IMA) of each subordinate company or section of Third Maintenance Battalion. At this level, available capacity is determined for each general type of equipment (e.g., communications, engineering, ordnance, motor transport) at each of Third Maintenance Battalion's facilities in Okinawa.

To determine the capacity for a single maintenance Marine, time spent doing activities other than performing maintenance is subtracted from a standard eight-hour day, as shown in Table 10, resulting in a daily availability of 5.57 hours per Marine.

Table 10. Available Capacity

Requirements (events)	**Hours**	**Frequency**	**Total Time (hours/year)**
Battalion Physical Training (PT)	3	hours/month	36
Company PT	1	hours/month	12
Back-in-the-Saddle Training (BITS)	8	hours/year	8
Annual Training	20	hours/year	20
Subtotal			*76*
Requirements (8-hour days lost)	Hours	Frequency	Total Time (hours/year)
Annual Leave (accrued)	240	30 days/year	240
Rifle Range	80	10 days/year	80
96-hr Liberty	160	20 days/year	160
Subtotal			*556*
		Frequency	Total Time
Total Hours (52 wks * 40 hrs/wk)		annually	2080
Less Non-Maintenance time		annually	(632)
Adjusted Total Hours (per year)		annually	1448
Adjusted Weekly Hours		weekly	27.85
Daily Available Hours (5-day week)		daily	*5.57*

Although the table of organization (T/O) for MTM reports a total of 151 maintenance technicians, MTM is typically staffed at 70% due to staffing goals (dictated by Headquarters Marine Corps) and personnel turnover (Salm, 2017a). This results in an average daily capacity of 105 maintenance technicians, each performing up to 5.57 labor hours. These available hours, however, are unlikely to be spent entirely on performing maintenance work on open service records. Time may be spent transitioning between tasks, performing general tasks unrelated to a specific service request (e.g., cleaning maintenance areas, attending formations), transiting between maintenance facilities, or traveling to remote exercise/maintenance locations. A reasonable estimate of availability would be 70% of this daily capacity, or 3.89 hours per day of a five-day (40-hour) work week.

Because the demand analysis did not distinguish between "work days" and "non-work days," this research uses a seven-day week for analysis, resulting in 2.78 labor hours available per calendar day. With 105 available personnel, the total capacity for MTM is an average of 292 labor hours per calendar day.

F. PHASE III: DETERMINING CAPACITY UTILIZATION

During FY16, the average daily demand for modification service records was 24 labor hours. For all other service records, daily demand was 62 labor hours. The average daily demand for all service records was 86 labor hours. With 292 available hours, this demand represents an average capacity utilization of 29% for the year (see Table 11). For FY17, the average daily demand for modification service records was less than one labor hour. For all other service records, daily demand was 35 labor hours. The average daily demand for all service records was 36 labor hours. This demand represents an average capacity utilization of 12% for the year.[10]

[10] For this research, demand and capacity analysis both relied on assumptions to facilitate this research. As such, the capacity utilization calculations based on these assumptions should be evaluated with this in mind. Factors such as actual staffing level, deployments, facility downtime, and resource non-availability were not accounted for and may cause utilization levels to appear artificially low.

Table 11. Capacity Utilization, FY16–FY17

	Mod Avg		Other Avg		All Avg	
	FY16	FY17	FY16	FY17	FY16	FY17
Q1	11.8%	0.0%	32.0%	17.8%	43.8%	17.8%
Q2	15.9%	0.3%	24.6%	14.0%	40.5%	14.3%
Q3	4.8%	0.6%	11.7%	11.3%	16.5%	11.9%
Q4	0.3%	0.0%	16.2%	5.5%	16.5%	5.5%
Annual	8.2%	0.2%	21.1%	12.2%	29.3%	12.4%

During the first half of both FY16 and FY17, MTM experienced higher capacity utilization than the second half. The maximum daily capacity utilization in FY16 was 75% (218 labor hours), and the maximum daily capacity utilization in FY17 was 29% (85 labor hours).

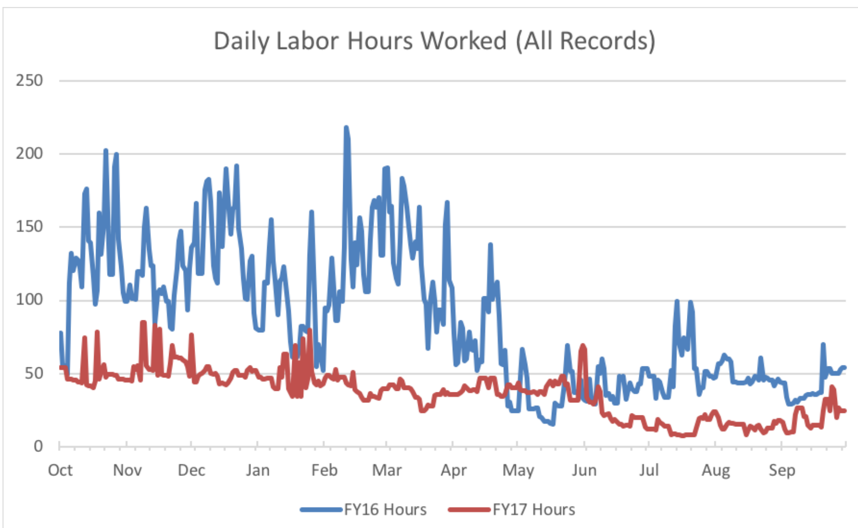

Figure 14. Daily Labor Hours Worked (All Records), FY16–FY17

Capacity utilization at these levels indicates that MTM has sufficient capacity to meet demand, and that it has spare capacity on average.[11]

[11] Although this research was originally planned to include a capacity risk analysis, such an analysis was considered unnecessary with the excess capacity available.

G. SUMMARY OF FINDINGS

Of 913 service records studied, those records opened in FY16 included more modification records than those opened in FY17, which may have impacted work scheduling. The number of non-modification records and average customer cycle time stayed relatively constant from FY16 to FY17 and were positively correlated, although workload tended to be shorter in FY17. This suggests that although battalion efforts to improve work time in FY17 were effective, there were other factors impacting overall customer cycle time, such as delays in the supply chain or administrative processes.

In FY16, the apparent negative correlation between customer cycle time and workload suggest that scheduling and dispatch rules, required delivery dates, or the large number of modification service records impacts the performance of maintenance on other service records. The effect of these factors likely led to a counterintuitive negative correlation between customer cycle time and workload. In contrast, and in spite of possible errors outlined in Figure 12, the relationship between customer cycle time and workload indicated a strong positive correlation in FY17 when very few modification service records were open, suggesting that modification service records impacted the prioritization of maintenance production.

Capacity utilization was calculated at 29% in FY16 and 12% in FY17, based on assumptions of available daily capacity made by the unit. These calculations likely underestimate actual utilization as available daily capacity is variable and determined by factors beyond the scope of this research.

V. RECOMMENDATIONS FOR FUTURE RESEARCH

A. INTRODUCTION

This chapter first discusses limitations to the analysis conduct in this research. Next, it outlines recommendations to Third Maintenance Battalion on how customer service might be improved. Third, it outlines a methodology that can be used to assess aggregate demand placed on the available capacity of a ground equipment intermediate maintenance activity to determine capacity utilization. The chapter concludes with recommendations for future research.

B. RESEARCH LIMITATIONS

The greatest limitation on this research was time available to collect data on cycle time beyond data available in GCSS-MC. Within the 18-month program of the Materiel Logistics Support Management curriculum, the scope of this project was necessarily constricted. As such, this report does not include a study of factors that can greatly impact customer cycle time, such as delays in the supply chain. Specifically, although Third Maintenance Battalion receives direct support from Third Supply Battalion (also located in Okinawa, Japan), this study did not address Third Supply Battalion's processes.

Time also restricted the level of detail that could be considered in the dataset. Without sufficient time to perform direct observation of maintenance processes or collection of detailed data over a significant period, this project relied heavily on recorded data in GCSS-MC. As with any database requiring manual entry, human error can result in inaccurate data recorded in GCSS-MC. Considering the data in aggregate serves to lessen the impact of errors, yet limits the detail in conclusions drawn from the data.

Actual work performed was accurate to the nearest half hour as recorded in GCSS-MC, but GCSS-MC records only elapsed time and does not necessarily reflect man-hours (i.e., the labor of personnel working concurrently on a service record). For capacity, maintenance personnel availability and work capacity were based on the expert opinion of the maintenance officer, not direct observation over time. As such, calculations made from these data can only provide a general characterization of MTM's overall capacity utilization.

The technique used to create the analysis Gantt chart eliminated day-to-day workload variance. By evenly dividing the actual workload over the maintenance cycle time as recorded in GCSS-MC, the analysis could not consider actual work performed on specific days. Further, using linear regression techniques to describe the relationship between demand variables limited the precision with which the relationship could be described.

The capacity analysis assumed a constant 70% staffing level over the period studied. If daily manpower availability were used, capacity utilization could be calculated more accurately based on actual available capacity. This assumption will cause variability in utilization to be underestimated. The low utilization rates reported must also be understood in the context of this assumption: when staffing levels were actually below 70%, utilization rates are under-reported. Additionally, although MTM operates two maintenance facilities, both demand and capacity were considered in aggregate. As such, imbalance in demand or capacity between MTM North and MTM South could result in different capacity utilization levels.

C. RECOMMENDATIONS FOR THIRD MAINTENANCE BATTALION

This research found no indication that customer wait times were unacceptable or that Motor Transport Maintenance Company (MTM) failed to meet demand. The following recommendations are made only in an effort to improve upon the level of customer service already provided. All recommendations are subject to the limitations noted in the report's introduction and to those listed in the data and findings.

Consider the impact of scheduling and dispatch rules on overall turnaround time. In FY16, service records with smaller workloads tended to be open longer. While this could have resulted from a number of different causes, leadership should be mindful of the impact of work prioritization on service record cycle times and customer service. Servicing equipment with smaller workload requirements first can improve customer service by returning equipment to a supported unit, thereby potentially increasing their readiness while they wait for larger workload records to be completed. However, this may cause volatility and delays over time. For service records with required delivery dates, Third Maintenance Battalion might consider using a critical ratio dispatch rule, in which service records with the smallest ratio of remaining time before the RDD to remaining work effort are completed first.

Utilize unused capacity to improve customer service. This research indicates that MTM possesses sufficient capacity to meet demand. Over two years, capacity utilization rarely exceeded 50% (only on 45 days). At times when capacity utilization is low, maintenance personnel can be released to perform other tasks or deploy as contact teams to support exercises or provide on-site support to customer units. Under-utilized personnel could move between maintenance facilities to provide additional capacity when demand is imbalanced.

Provide cycle time estimates to set customer expectations. In FY16, the time spent performing modifications appeared to increase customer cycle time. In FY17, greater workload in the system apparently led to increased customer cycle time. To the extent that the system workload and the work completion rate are known, MTM can inform customers of a predicted customer cycle time. For example, MTM might inform customers that work accepted during periods in which current workload is heavy may experience longer customer cycle times. Additionally, if Third Maintenance Battalion can exercise control over when equipment modifications are made, they should be scheduled during periods where less demand is experienced or expected (e.g., before or after exercises and deployments). If MTM is unable to address or predict delays to customer cycle time stemming from external issues, MTM may nevertheless be able to update customers with predicted maintenance cycle times once work actually starts.

Compare actual to planned workloads to assess performance. The GCSS-MC data did not include accurate estimates for planned work days or workload. Without this data, the unit cannot accurately assess its performance or provide accurate estimates to customers. Quality Control (QC) personnel should enter planned repair time and estimated repair times into GCSS-MC. Once a defect has been identified, QC can use technical manuals to estimate repair times. Once repairs are complete and actual effort is recorded, the planned and actual data can be compared. The planned data can be used to provide customers with an idea of how long repairs might take, and actual data, over time, can be used to measure performance or update technical manuals.

Apply an aggregate planning methodology to inform personnel decisions. This research project developed and applied aggregate planning concepts to analyze demand and capacity. This methodology, subsequently outlined, can be used to assess capacity utilization that can aid personnel decision-making.

D. RECOMMENDED METHODOLOGY FOR CAPACITY PLANNING

This approach to demand and capacity analysis can be employed by any maintenance unit. Applying this methodology during steady-state operations will help unit leadership respond to demand surges or reduced capacity.

1. Collect Demand Data

Data can be collected from direct observation, GCSS-MC reports, or from the MDR. Direct observation and collecting more data points will improve the accuracy and understanding of demand level. GCSS-MC reports and the MDR provide the same data. Without direct user access to GCSS-MC, data collection can be difficult and might only be available from the unit itself. Accessing data through the MDR allows researchers to gain full access to the entire GCSS-MC dataset. The benefit to MDR access is more data availability, but researchers must apply for access through LOGCOM.

2. Assess Demand

Demand assessment consists of three steps. First, the data must be understood. Next, cycle times and workload are determined. Finally, aggregate demand can be determined.

a. Understand the Data

Data is assessed on multiple levels: the customer view of cycle time (in this research referred to as customer cycle time), maintenance cycle time, and actual workload. Workload can be categorized by the type of work being done (e.g., repair, replacement, modification) or the type of equipment being maintained. Sources of demand should be considered, for example whether service records represent modifications required by administrative instruction or corrective maintenance required by supported units.

b. Determine Customer Cycle Time, Maintenance Cycle Time, and Actual Workload

Cycle time from the customer perspective (customer cycle time) includes the time beginning when equipment is turned over to the maintenance activity and ending when the repaired equipment is retrieved. Maintenance cycle time represents the time within the total cycle time when maintenance is performed, and actual workload is the recorded hours to complete the required task. The actual work time recorded in GCSS-MC includes both business non-value-added time and value-added time, depending on the type of work being performed (e.g., administrative, supply, maintenance). The value-added ratio (VAR) can be used to assess performance and determine where cycle times might be improved by reducing non-value-added time.

c. Determine Aggregate Demand

Customer cycle time, maintenance cycle time, and actual workload are used to determine daily demand. Daily totals and averages can be used to develop a picture of demand placed on the unit over time.

3. Assess Capacity

Capacity is based on the availability of unit resources. Data can be collected from policy and staffing documents, but is most accurately obtained from direct observation. In addition to personnel, capacity is determined by other resources, for example tools, facilities, and other maintenance equipment. Different units and environments affect resource availability differently, and thus direct observation is best.

4. Determine Capacity Utilization

The work performed as a percentage of capacity available represents the capacity utilization of the unit. Capacity utilization reflects the stress a unit faces and can provide an understanding of the additional stress the unit can face. Capacity utilization, properly measured, will never reach 100%, and should be expected to normally fall below 70%. A higher percentage represents more stress and should be met with increased capacity, whereas a lower percentage indicates there might be excess or under-utilized capacity.

5. Make Personnel Decisions

Excess capacity can be used to improve customer service without increasing cost. Extra personnel can reduce backlog or relieve stress on other resources. If capacity utilization is high, maintenance and customer cycle time will likely increase, and customers will experience delays until demand is met. Over the long term, staffing may be adjusted to reach a desired capacity utilization level. With limited resources, understanding available capacity and capacity utilization will allow leadership to determine, for example, whether to re-allocate personnel between facilities or deploy contact teams.

E. RECOMMENDATIONS FOR FURTHER RESEARCH

Future research should improve upon the methodology presented in this research. Larger data sets can be studied to better understand trends over time or the effectiveness of maintenance policy. Different units can be studied in different operating environments. More detailed analysis could provide granularity of detail.

This analysis included evenly dividing actual work performed over the maintenance cycle time. Direct observation and research would lead to better modeling of workload with regard to maintenance cycle time. Additionally, although a linear regression analysis was used to determine the relationship between customer cycle time and workload, nonlinear regression techniques would depict this relationship more precisely. Adding this level of detail to the analysis would help to capture and represent day-to-day variance in workload.

Average daily workload varied drastically between FY16 and FY17. More research should be conducted to determine root causes for this difference. Understanding the difference will enable more accurate models to better predict future workloads. Given the large observed differences, data from a longer period should be analyzed to better understand annual fluctuations and trends.

For all records, customer cycle time was much longer than the maintenance cycle time when work was being performed. A Lean Six Sigma project with the goal of reducing customer cycle time would identify sources of delay both internal and external to the maintenance unit. An analysis of supply chain impacts on customer cycle time would highlight areas to be addressed in future research.

Motor Transport Maintenance Company is a homogenous unit where few occupational specialties perform maintenance actions on a limited variety of equipment. As such, maintenance demand and resource capacity are largely homogenous as well. This methodology should be applied to units that maintain a larger variety of equipment or where more occupational specialties are employed. The methodology presented in this research can be applied to any maintenance unit, at the organizational, intermediate, or depot level. Each of these levels provides a different challenge and includes a different mix of equipment and occupational specialties.

This research focused on a forward-deployed unit that operated in garrison facilities. Future research could include study of forward-deployed units operating in austere environments without access to garrison facilities or dedicated, co-located supply activities. Research could also include the effects of deployed capacity on remain-behind element resources. The methodology could be applied across a full spectrum of maintenance activities, from CONUS units during peacetime to forward-deployed units in wartime.

Finally, the methodology provided here should be tested with a more detailed and rigorous analysis. Data on both demand and available capacity should be collected directly by researchers. Researchers should use technical manuals and direct observation to compare theoretical customer and maintenance cycle time to actual cycle times.

Customer feedback should be considered to determine other ways service might be improved. For maintenance units experiencing high capacity utilization, risk analysis techniques should be applied to assess the unit’s ability to respond to demand or capacity stress.

APPENDIX A. ACCESSING THE MASTER DATA REPOSITORY (MDR)

Although the maintenance section of Third Maintenance Battalion was willing to provide data reports from their local GCSS-MC records, continually revised data requirements as the project took shape quickly became taxing for the unit. It seemed logical to contact LOGCOM for access at the enterprise level. This appendix outlines the process of obtaining access to the data and formatting it for analysis in Microsoft® Excel

To obtain access to the Master Data Repository (MDR), several administrative steps must be taken through LOGCOM. A minimum secret clearance is required to access the MDR. Also, users must be on a .mil domain network in order to access the MDR. From another domain (including the NPS.edu domain), a virtual private network (VPN) must be established. The Marine Corps uses Pulse Secure software to access a VPN (https://sslquantico.usmc.mil), which requires a Common Access Card (CAC).

At the time of this project, LOGCOM guidelines/requirements for MDR access were as follows:

1. All requests pertaining to MDR access, changes to privileges or consolidation of requested documentation must be routed to (smblogcomlccmdr@usmc.mil).

2. Individuals requesting MDR access must provide Information Assurance (IA) and Personally Identifiable Information (PII) training certificates for the current fiscal year.

3. Individuals requesting MDR access must provide a SAAR (DD Form 2875) containing detailed justification, signatures and initialed addendum pages. Completed SAAR should be sent to the LOGCOM Security Manager's SAAR mailbox (smb_logcom_sec_mgr@usmc.mil) for processing, and a "cc" of the email sent to smblogcomlccmdr@usmc.mil.

4. Individuals requesting MDR access must send a separate follow-up (encrypted) email containing the user's Social Security Number (SSN), along with a brief description of its purpose to the LOGCOM Security Manager's personal email address (lawrence.floyd@usmc.mil). He will use this information to process the SAAR.

5. Once the LOGCOM Security Manager validates that the individual has the appropriate security clearance, a trouble ticket will be submitted to C4 for IA review and approval. Once approved, a request will be submitted for the creation of the Open Database Connectivity (ODBC) user account.

6. The new user will be provided an ODBC username & password, tnsnames.ora file, and the latest copy of the MDR Data Dictionary via email.

7. If additional assistance is needed, contact C4 Customer Support at (SMBLOGCOMC4CSC@usmc.mil).

After several unsuccessful attempts to access the MDR via ODBC within Microsoft Access, an alternate option was offered. This was essentially a workaround that used Oracle® SQLDeveloper software instead of a database and did not require manually configuring Microsoft® Access or system configuration files. With SQLDeveloper, users can access data tables within the MDR and build structured query language (SQL) queries to join tables and select data. The resulting data can then be exported in several formats for further processing, including comma-separated values (.csv) and Microsoft® Excel (.xlsx).

The query used to pull the data for this project is as follows:

```
SELECT
    ldrdba.gcss2_sr_header_hst.service_request_type,
    ldrdba.gcss2_sr_header_hst.problem_summary,
    ldrdba.gcss2_sr_header_hst.sr_number,
    ldrdba.gcss2_sr_header_hst.tamcn,
    ldrdba.gcss2_sr_header_hst.nsn_in_maintenance,
    ldrdba.gcss2_sr_header_hst.quantity_inducted,
    ldrdba.gcss2_sr_header_hst.serial_number,
    ldrdba.gcss2_sr_header_hst.master_priority_code,
```

```
    ldrdba.gcss2_sr_header_hst.defect_code,
    ldrdba.gcss2_sr_header_hst.hold_unit_ident_code,
    ldrdba.gcss2_sr_header_hst.opened_date,
    ldrdba.gcss2_sr_header_hst.date_received_in_shop,
    ldrdba.gcss2_sr_header_hst.date_closed,
    ldrdba.gcss2_sr_task_hst.task_name,
    ldrdba.gcss2_sr_task_hst.description,
    ldrdba.gcss2_sr_task_hst.task_type,
    ldrdba.gcss2_sr_task_hst.task_number,
    ldrdba.gcss2_sr_task_hst.task_status,
    ldrdba.gcss2_sr_task_hst.owner,
    ldrdba.gcss2_sr_task_hst.planned_start_date,
    ldrdba.gcss2_sr_task_hst.actual_start_date,
    ldrdba.gcss2_sr_task_hst.planned_effort,
    ldrdba.gcss2_sr_task_hst.planned_effort_uom,
    ldrdba.gcss2_sr_task_hst.actual_effort,
    ldrdba.gcss2_sr_task_hst.actual_effort_uom,
    ldrdba.gcss2_sr_task_hst.planned_end_date,
    ldrdba.gcss2_sr_task_hst.actual_end_date,
    ldrdba.gcss2_sr_header_hst.sr_holder,
    ldrdba.gcss2_sr_header_hst.owner_unit_address_code,
    ldrdba.gcss2_sr_header_hst.unit_name,
    ldrdba.gcss2_sr_header_hst.job_status_code,
    ldrdba.gcss2_sr_task_hst.operational_status,
    ldrdba.gcss2_sr_header_hst.meter_reading,
    ldrdba.gcss2_sr_header_hst.equip_oper_time_code
FROM
    ldrdba.gcss2_sr_header_hst
    INNER JOIN ldrdba.gcss2_sr_task_hst ON
                               ldrdba.gcss2_sr_task_hst.sr_number      =
ldrdba.gcss2_sr_header_hst.sr_number
    AND
                         ldrdba.gcss2_sr_task_hst.legacy_file_dttm     =
ldrdba.gcss2_sr_header_hst.legacy_file_dttm
WHERE
    (
            ldrdba.gcss2_sr_header_hst.hold_unit_ident_code = 'M29021'
        OR
            ldrdba.gcss2_sr_header_hst.hold_unit_ident_code = 'M29022'
        OR
            ldrdba.gcss2_sr_header_hst.hold_unit_ident_code = 'M29023'
        OR
            ldrdba.gcss2_sr_header_hst.hold_unit_ident_code = 'M29024'
        OR
            ldrdba.gcss2_sr_header_hst.hold_unit_ident_code = 'M29025'
        OR
            ldrdba.gcss2_sr_header_hst.hold_unit_ident_code = 'M29026'
        OR
            ldrdba.gcss2_sr_header_hst.hold_unit_ident_code = 'M29027'
    ) AND
        ldrdba.gcss2_sr_header_hst.opened_date >= '01-OCT-15'
    AND
        ldrdba.gcss2_sr_header_hst.opened_date <= '30-SEP-17'
    AND
        ldrdba.gcss2_sr_header_hst.date_closed <= '30-SEP-17'
```

```
ORDER BY
    ldrdba.gcss2_sr_header_hst.tamcn NULLS FIRST,
    ldrdba.gcss2_sr_header_hst.opened_date,
    ldrdba.gcss2_sr_header_hst.sr_number NULLS FIRST,
    ldrdba.gcss2_sr_header_hst.serial_number NULLS FIRST,
    ldrdba.gcss2_sr_task_hst.task_number
```

LIST OF REFERENCES

Allen, M. (2005). *Alignment of organizational level workload and maintenance manning in the United States Navy F/A-18C community* (Master's thesis). Retrieved from Naval Postgraduate School website: http://hdl.handle.net/10945/9960

Apte, U., & Kang, K. (2006). *Lean Six Sigma for reduced cycle costs and improved readiness* (NPS-LM-06-033). Retrieved from Naval Postgraduate School website: http://hdl.handle.net/10945/33971

Gansterer, M. (2015). Aggregate planning and forecasting in make-to-order production systems. *International Journal of Production Economics, 170*(B), 521–528. doi:10.1016/j.ijpe.2015.06.001

George, M., Rowlands, D., Price, M., & Maxey, J. (2005). *The Lean Six Sigma process toolbook*. New York, NY: McGraw-Hill.

Goh, M., & Tay. G. (1995). Implementing a quality maintenance system in a military organization. *International Journal of Quality & Reliability Management 12*(4), 26–39, doi: 10.1108/02656719510087300

Goldratt, E. (2014). *The goal: A process of ongoing improvement* (4th Rev. ed.). Great Barrington, MA: North River Press.

Goodwin, K. (2016). *Optimizing maintenance manpower for USMC F/A-18 squadrons* (Master's thesis). Retrieved from Naval Postgraduate School website: http://hdl.handle.net/10945/49470

Jafar, E., Yang, C., & Mejos, T. (2006). *Naval aviation maintenance: A case study for process improvement* (NPS-LM-06-043). Retrieved from Naval Postgraduate School website: http://hdl.handle.net/10945/33802

Kang, K., & Apte, U. (2007). Lean Six Sigma implementation for military logistics to improve readiness. In *Proceedings of the Fourth Annual Acquisition Research Symposium of the Naval Postgraduate School*. Retrieved from Naval Postgraduate School website: http://hdl.handle.net/10945/33190

Krajewski, L., & Ritzman, L. (2005). *Operations management: Strategy and analysis* (7th ed.). Upper Saddle River, NJ: Pearson Education.

McCarty, T., Daniels, L., Bremer, M., & Gupta, P. (2005). *The Six Sigma black belt handbook*. New York, NY: McGraw-Hill.

Ohno, T. (1978). *Toyota production system*. New York, NY: Productivity Press.

Salm, D. (2016). *Third Maintenance Battalion handbook* [Unit handbook]. Okinawa, Japan: Third Maintenance Battalion.

Salm, D. (2017a). *Third Maintenance Battalion: Company capability brief* [PowerPoint slides]. Okinawa, Japan: Third Maintenance Battalion.

Salm, D. (2017b). *Third Maintenance Battalion: Deployment schedule* [PowerPoint slides]. Okinawa, Japan: Third Maintenance Battalion.

Shannon, P. (1997). The value-added ratio. *Quality Progress, 30*(3), 94–97. Retrieved from https://search.proquest.com.libproxy.nps.edu/docview/214520141

Srinivasan, M., Jones, D., & Miller, A. (2004). Applying Theory of Constraints principles and Lean thinking at the Marine Corps Maintenance Center. *Defense Acquisition Review Journal*, 134–145. Retrieved from www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA435317

Third Marine Logistics Group (3DMLG). (2014). *Maintenance management standing operating procedures* (3DMLGO 4790.1G). Okinawa, Japan: Author.

United States Marine Corps (USMC). (n.d.). III Marine Expeditionary Force. Retrieved October 15, 2017, from http://www.iiimef.marines.mil

United States Marine Corps (USMC). (2010). *Principal technical characteristics of U.S. Marine Corps motor transportation equipment* (TM 11240-ODA). Washington, DC: Author.

United States Marine Corps (USMC). (2014). *Ground equipment maintenance program* (MCO 4790.25). Retrieved from http://www.marines.mil/Portals/59/MCO%204790.25.pdf

United States Marine Corps. (2015). *Total force structure process* (MCO 5311.1E). Washington, DC: Author.

United States Marine Corps (USMC). (2016a). *Electronics Maintenance Company, Third Maintenance Battalion, Combat Logistics Regiment 35, Third Marine Logistics Group: Fiscal year 2017 table of organization and equipment report*. Washington, DC: Deputy Commandant for Combat Development and Integration.

United States Marine Corps (USMC). (2016b). *Engineer Maintenance Company, Third Maintenance Battalion, Combat Logistics Regiment 35, Third Marine Logistics Group: Fiscal year 2017 table of organization and equipment report*. Washington, DC: Deputy Commandant for Combat Development and Integration.

United States Marine Corps (USMC). (2016c). *Field-level maintenance management policy* (MCO P4790.2). Washington, DC: Deputy Commandant for Installations and Logistics.

United States Marine Corps (USMC). (2016d). *General Support Maintenance Company, Third Maintenance Battalion, Combat Logistics Regiment 35, Third Marine Logistics Group: Fiscal year 2017 table of organization and equipment report*. Washington, DC: Deputy Commandant for Combat Development and Integration.

United States Marine Corps (USMC). (2016e). *Headquarters and Service Company, Third Maintenance Battalion, Combat Logistics Regiment 35, Third Marine Logistics Group: Fiscal year 2017 table of organization and equipment report*. Washington, DC: Deputy Commandant for Combat Development and Integration.

United States Marine Corps (USMC). (2016f). *Logistics* (MCDP 4). Washington, DC: Author.

United States Marine Corps (USMC). (2016g). *Maintenance operations* (MCTP 3–40E). Washington, DC: Author.

United States Marine Corps (USMC). (2016h). *Motor Transport Maintenance Company, Third Maintenance Battalion, Combat Logistics Regiment 35, Third Marine Logistics Group: Fiscal year 2017 table of organization and equipment report*. Washington, DC: Deputy Commandant for Combat Development and Integration.

United States Marine Corps (USMC). (2016i). *Ordnance Maintenance Company, Third Maintenance Battalion, Combat Logistics Regiment 35, Third Marine Logistics Group: Fiscal year 2017 table of organization and equipment report*. Washington, DC: Deputy Commandant for Combat Development and Integration.

United States Marine Corps (USMC). (2016j). *Organization of the United States Marine Corps* (MCRP 5–12D). Washington, DC: Deputy Commandant for Combat Development and Integration.

United States Marine Corps (USMC). (2016k). *Third Maintenance Battalion, Combat Logistics Regiment 35, Third Marine Logistics Group: Fiscal year 2017 table of organization and equipment report*. Washington, DC: Deputy Commandant for Combat Development and Integration.

Yalcin, A., & Boucher, T. (2004). A continuous-time algorithm for disaggregation of hierarchical production plans. *IIE Transactions, 36*(11), 1023–1035. doi:10.1080/07408170490438546

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