M1 Abrams Maintenance Performance Analysis at the US Army's National Training Center

by

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B.S. Systems Engineering United States Military Academy 2008

SUBMITTED TO THE SYSTEM DESIGN AND MANAGEMENT PROGRAM IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ENGINEERING IN SYSTEM DESIGN AND MANAGEMENT AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

FEBRUARY 2019

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Submitted to the Systems Design and Management Program on January 18, 2019 in partial fulfillment of the Requirements for the Degree of Master of Engineering in System Design and Management.

Abstract

To prepare for combat, the US Army utilizes the National Training Center (NTC) to test and certify all units before deployment to combat operations. During the past 5 years, observers have noted below standard Operational Readiness (OR) Rates in the M1 fleet during training at NTC. The Army's Program Manager for the M1 Abrams requested this thesis examine the M1 performance at NTC, possible reasons for the performance, and recommend solutions to those issues.

The first research question asks if M1 OR rates are statistically below the Army Standard. Through collection of OR data throughout the Army, this study confirmed using statistical hypothesis testing that OR rates at NTC are below standard. The next three questions used regression analysis to identify possible reasons for the low performance. During the course of the study, mileage driven on each tank both before and during NTC was proven to have no effect on tank performance. Analysis of the parts stockage breadth at NTC warehouses was shown to be effective at predicting parts failures, but could recover up to 1.3% OR rate by adding 28 additional parts to the normal stockage list. Finally, analysis of individual unit maintenance performance measures showed individual programs have significant effect on M1 OR rates, specifically when examining controlled substitution policy and proper reporting procedures. Recommendations for the correction of the problem include the development of a more reliable mileage reporting system, additional research specifically into the time requirements for each unit, additional training for unit maintenance leaders, and parts failures trends during high-intensity training.

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Disclaimer

The views expressed in this thesis are those of the author and do not reflect official policy of the United States of America, The Department of Defense, The United States Army, Army Material Command, The National Training Center, or the M1 Abrams Program Office.

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Acknowledgements

I would like to thank everyone involved in the creation of this thesis. Specifically, I'd like to thank the members of the PM Abrams office who gave me the subject and assisted in my research. I would also like to thank everyone from AMSAA and OSMIS who assisted in my data collection and analysis. Additionally, I would like to thank all of the officers, NCOs, and civilians across the US Army who gave me some of their limited time to discuss their perspectives on the issues, solutions, and recommendations for the M1s at NTC. Specifically, I would like to recognize my former First Sergeant, who has moved onto become an OC/T at NTC. Without his help, this thesis would not have gone anywhere.

I would also like to thank all of my professors from SDM, Sloan, and across MIT, as well as all of my fellow cohort of SDM students. Your help has been inspiring and invaluable. I would be remiss to not mention the other officers SDM '17, who made this posting both entertaining and successful.

I am forever grateful to my advisor, Chris, and his infinite patience with me. Spending the last 10 years on a tank put me well behind most of my peers here at MIT, but he unwearyingly taught me the new tools and strategies that made this thesis successful.

To my parents, thank you for your help with strategy, direction, and revision of this study. I may not have always taken your advice, but I will always value receiving it.

Finally, to my wife Samantha, thank you for your unwavering support, love, and understanding. Your support, encouragement, and sacrifice are the only reasons this thesis was completed on time.

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1. Introduction

1.1. Problem Identification

A training rotation at the National Training Center (NTC) is the most important event on a US Army brigade's training calendar. It is so important, brigades practice their warfighting tasks in home-station training for over a year in preparation for their rotation. At NTC, a brigade's capability is tested in an environment as close to actual combat as possible. Units of all types, including armor units utilizing the M1 Abrams, rotate to NTC on a monthly basis to complete testing and be certified for combat operations.

Thus, the Army Program Manager for the M1 Abrams (PM Abrams) closely follows the performance of each unit as they go through their month at NTC. Over the last few years, PM Abrams noticed a problem: too many M1s were breaking before or during rotations, and were not repaired quickly enough. This caused M1 Operational Readiness Rates (OR Rate) to drop to unacceptable levels

The Army uses the OR Rate to measure readiness across its formations. OR rate is reported in two ways: officially in the Army's computer and maintenance systems, and unofficially, by word of mouth reporting across the chains of command. Both systems often report slightly different measured OR rates. However, in both systems, PM Abrams personnel were observing OR rates below the Army standard of 90%.

The OR rate is computed using a binary measure, a vehicle is either Fully Mission Capable (FMC), or Not Mission Capable (NMC) and inoperable. To compute the OR Rate in a unit, one sums the number of FMC individual vehicles days, and divides it by the number of unit vehicles, multiplied by the number of days the specific OR rate covers.

$$\frac{FMC\ Tank\ Days}{Number\ of\ Tanks\ in\ Unit * Days\ in\ Examination\ Period}$$

Thus, for a tank company of 14 tanks over a 30-day month (420 Tank Days), with a combined 20 tank days NMC:

$$\frac{(14 * 30) - 20}{14 * 30} = \frac{400}{420} = 95.2\%\ OR\ Rate$$

The recognized Army Standard for a unit OR rate is 90%. However, as noted above, PM Abrams personnel had noticed NTC OR rates seemed to be sub-standard for many NTC rotations. Thus, the objective of this thesis is to determine if there is an actual problem with NTC OR rates, and if so, the root causes of those problems, and make solution recommendations.

1.2. Thesis Research Questions

This thesis addresses four questions:

1. "Are M1A2 Abrams Currently Operating at a sub-standard OR Rate during NTC Rotations?"

This first question determines whether a problem even exists, or if it is merely an anecdotal outlier from NTC personnel, who may be limited in their ability to see the Army as a whole. Since the issue is seen across multiple units and over different periods of time, the initial hypothesis is there is an issue with the OR rates at NTC.

2. "Are the sub-standard OR Rates at NTC caused by the OPTEMPO placed on the vehicles both before and during an NTC Rotation"

If there is an issue with sub-standard NTC OR rates, I must then identify the reason the OR rates are so low. The first question examines if the wear and tear placed on the M1s in train-up and rotational usage causes the sub-standard OR rates. During background interviews, Army leaders identified OPTEMPO as a contributing factor for low OR rates. They felt unit requirements for training placed increased stress on the men and vehicles of their units, and thus contributed to increased wear and lower quality maintenance, and thus lower OR rates. To test this, I compiled the mileage placed on the vehicles during train-up, at NTC, and the total mileage on each vehicle to examine if there is any correlation between an increase in the miles driven and the OR rate found at NTC. The initial hypothesis for this question is as OPTEMPO goes up, there is a negative correlation with OR Rate.

3. "Are the sub-standard OR Rates at NTC caused by a lack of NTC ASL breadth, specifically as rarely demand parts"

The third question examines whether parts availability effects the OR rates at NTC. A second comment from Armor Leaders mentioned that though some parts were available and faults quickly repaired, other faults took long periods of time, because parts were not in the NTC warehouses. To examine this, I analyze the parts required at NTC, their rarity on the warehouse stockage lists, and their usage at NTC. Initial hypothesis for this question is faults whose parts are not on the NTC ASL take a longer amount of time to repair due to transport time.

4. "Are the sub-standard OR Rates at NTC caused by individual unit maintenance program deficiencies"

A multitude of aspects decide the quality of a unit's maintenance program, which subsequently could affect OR rates. The fourth research question examines which individual program aspects have measurable effects on OR Rates. Some are impossible to measure without being present with the unit. However, there are enough aspects which have data drivers allowing analysis to "grade" each unit. During discussions with NTC analysts, support personnel, and Army parts depot personnel, commentary focused on maintenance programs lacking robustness, resulting in lower OR rates. To test this, I looked at aspects of each unit's maintenance program, and compare their various results in a "scorecard" type manner. Comparing this scorecard to their OR gives a picture of the unit's performance efficacy.

1.3. Thesis Outline

This thesis is organized as follows: Chapter 2 outlines the data collection process and results. Chapter 3 discusses the background information for the Army, NTC, and other Maintenance Systems. Chapter 4 reviews the literature sources used in this thesis. Chapter 5 includes the analysis of the data collected to understand the 4 research questions outlined above. Chapter 6 discusses the conclusions from the analysis, recommendations for the Army, and recommended future research to continue the analysis and solutions to this problem.

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2. Data Overview

To understand the problem breadth and see multiple viewpoints on emerging issues, I interviewed various members of every level of the Army's maintenance systems: from Unit Maintenance Sergeants, to ABCT XOs, to AMC ASL personnel. They informed my initial understanding of the problem as they viewed it from their position, and where to gather data to study the problems from.

The Army utilizes a variety of tools to analyze and track the maintenance and parts status of their vehicle fleet. Four major data sources are used as the backbone of this thesis. The major data sources for the daily OR rates for both M1s and M2s at NTC was tracking data collected and collated by the Army Material Systems Analysis Activity (AMSAA) and Daily O26 reports from the 916th Support Brigade stationed at NTC. The Army's Operating and Support Management Information System (OSMIS) provided monthly and NTC miles data for all vehicle sets. OSMIS also provided the parts data that informed the data for the NIIN's of each deadline fault. In addition, other smaller sources were used to add background and assumption confirmation. Secondary sources included AMSAA data on miles usage, parts failure rates, LOGSA monthly OR tracking, and 916th reports on parts usage.

For the 5 years covered in this study, 18 Active Army ABCTs completed a rotation at NTC. Of those 18, 8 complete sets of daily OR rate data were available for both M1 and M2s.

2.1. AMSAA Data

The largest data source was collected from the AMSAA databases. The AMSAA data set contains full M1 and M2 information for six of the brigades covered in the study. The full data sets contain the faults for each NMC vehicle at NTC, including the start and end date, part description, and administrative data. Of the remaining 12 ABCTs, two of the rotations occurred after the data from AMSAA was collected, and will be covered below. The final 10 brigades had no or incomplete daily OR data saved from Army records, and therefore could not be analyzed. There are records from other data sources of the overall daily OR rates on a battalion and brigade level; however, because they did not have the same fidelity as the AMSAA data, they were used only for background data.

For the 6 units with complete records, the data included the daily NTC deadline fault information for the M1s or M2s, specific administrative data for each vehicle, and the parts required for each repair. For the purposes of this study, a vehicle is considered NMC for an entire day if it is NMC for any part of a day. Therefore, in this study, vehicles are considered NMC on both their fault start and end dates. The data also describes the fault, and the major part replaced to fix the fault, including the part NIIN (National Item Identification Number). Finally, for some units, a note of whether this fault was the result of a controlled substitution coming from or going to this vehicle was included. For some tanks on this report, the vehicle was deadlined before it came to NTC during pre-rotation train-up. These tanks were included in the analysis, as many were fixed during the NTC rotation.

The data only included tank serial numbers with faults during NTC. Therefore, I know all other tanks in those units were 100% FMC for the entirety of the NTC rotation. In addition to the fault data, AMSAA also collected partial data on the monthly miles driven for each M1 and M2 Bradley. Using this data, OSMIS data, and data from secondary sources, I cross reference the other serial numbers to create a database with every tank's serial number that completed an NTC rotation. Using this, I created a combined database with the OR rate, miles, and faults for every M1 or M2 at NTC.

2.2. 916th Support Brigade Data

Though AMSAA data covered the rotations completed before November 2017, 2 ABCT rotations occurred after. The final two brigades were used, but their data was collected in a slightly different manner. Through coordination with the 916th Support Brigade, the daily O26 report of each Brigade was collected for each rotation day. The O26 report shows the deadline faults of each vehicle for the commander's understanding. It includes the same administrative data found in the AMSAA database, along with every part order for that vehicle, and the number of days the vehicle has been NMC. With this data, the equivalent information found in the AMSAA database can be collated and added to the overall daily OR rate and parts data. Note, the brigade identified in this study as "F Brigade" was missing the O26 for the final 3 rotation day.

2.3. OSMIS Mileage Data

The OSMIS database collects the usage and costs associated with Army vehicles. Each unit reports their miles driven monthly. The OSMIS data accesses the reported data and provides monthly miles by SN for every tank in the Army. However, this database had some issues with proper reporting, and assumptions are made. For some units, their reported usage during the month they were at NTC was impossibly small. For instance, some units reported average mileage under 2 miles per vehicle, impossible for an armored unit at NTC. However, when the first or second month after the NTC rotation is examined, every vehicle has hundreds of miles driven. However, there is little chance a unit would actually have driven those miles after NTC. This discrepancy often occurs because units do not have time to report given their need to quickly recover vehicles and load railcars. For multiple weeks the tanks are on railcars moving back to home stations; not allowing units to report the data on time. It is not until the unit receives those vehicles a few weeks after NTC that they can actually report the data, resulting in a falsely inflated number after the rotation. Additionally, very few units are focused on major collective training in the months after an NTC rotation, instead conducting recovery tasks. Thus, with the time on the rail cars and recovery tasks from NTC, it is a good assumption that the first large jump of miles from the month before NTC (M-1) to the month of NTC (M) and/or the two months after (M+1, M+2) is most likely the miles which were driven at NTC, and thus included in this database.

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3. Background

3.1. The United States Army

"The mission of the United States Army is to fight and win the Nation's wars through prompt and sustained land combat, as part of the joint force. We do this by - Organizing, equipping, and training Army forces for prompt and sustained combat incident to operations on land; Integrating our capabilities with those of the other Armed Services;
Accomplishing all missions assigned by the President, Secretary of Defense, and combatant commanders; Remaining ready while preparing for the future."

Army Doctrine Publication (ADP) 1: The Army (2016)

The US Army is the major land component of the Department of Defense's Joint Unified Land Operations. As such, it must be prepared to accomplish a variety of assigned missions. Currently, the Army is split into a few major commands aiding in accomplishing those missions. For this study, Forces Command (FORSCOM) and Army Material Command (AMC) are the two major commands that effect performance at NTC, and will be referenced herein. (ADP 1 The Army, 2016)

3.1.1. FORSCOM

FORSCOM contains all combat units located within the US, and thus contains the population of units sent to NTC for certification. When a unit deploys to foreign locations for combat or stability operations, the Army detaches that unit from FORSCOM and assigns them to a theater command, such as Europe Command (EUCOM). FORSCOM uses this information to decide which units are to conduct NTC rotations and when. For instance, FORSCOM may assign an ABCT to prepare for a near-peer enemy by having them execute a Decisive Action Training Exercise (DATE) rotation (large tank vs tank battles against another nation) at NTC prior to moving them to their theater of operations. (ADP 1 The Army, 2016)

3.1.2. AMC

Army Material Command is responsible for the logistical support of all Army Units around the globe. Their motto is "If a Soldier shoots it, drives it, flies it, wears it, communicates with it, or eats it – AMC provides it." AMC procures new technologies and equipment, as well as supervise the fielding, support, and repair of said equipment. AMC supervises the lifecycle of the M1, its fuel and ammo, and the ASLs involved in ensuring repair parts are available to units as quickly as possible. When discussing the requirements for any classes of supply, AMC is the provider for that requirement. (FM 4-30 Ordnance Operation, 2014)

3.2. The National Training Center

3.2.1. NTC Purpose

The National Training Center (NTC) is the premier training center for Army units in the world. Located in the Mojave Desert at Ft. Irwin, CA, NTC provides the most realistic and difficult training that any combat force can face short of actual combat. Units arrive at NTC having completed a difficult home-station train-up program, and if successful at NTC, are certified as ready to deploy to combat operations. Units are tested in all six warfighting functions (Movement/Maneuver, Fires, Intelligence, Sustainment, Command and Control, and Protection) while being observed, evaluated, and reviewed by the NTC's cadre of Observer Controllers (OCs). (Chapman, 2010)

After the problems of Vietnam, the Army leadership of the late 1970s analyzed Warsaw Pact capabilities and realized the US Army could not match the quantity of Warsaw Pact forces on the battlefield, and at that time, only maintained technological parity as well. Coupled with the "Big 5 projects" being developed (M1 Tank, M2 Infantry Fighting Vehicle, AH-64 Attack Helicopter, UH-60 Utility Helicopter, and Patriot Missile), Army leaders realized they must create a force that was better trained and ready to fight their prospective opponents. They must "Fight outnumbered and win." The emerging all-volunteer force needed an organized training program with a capstone certification field test encompassing all combat requirements and situations soldiers would face in a real war. (Chapman, 2010) With these goals in mind, the Army established NTC, whose current mission and vision of NTC are:

"The National Training Center conducts tough, realistic, Unified Land Operations with our Unified Action Partners to prepare Brigade Combat Teams and other units for combat.... Develop Leaders at echelon who can prevail in conditions of ambiguity... Leaders that think fast, make sound decisions, exercise disciplined initiative, and give commands. We help leaders learn HOW to think, not WHAT to think." (National Training Center, 2018)

By 1983, NTC completed development, and proved successful. Key to this success was highly realistic training which combined highly skilled resident opposing force (OPFOR) trained in Warsaw Pact doctrine, laser-based combat systems to "umpire" who "killed" who and an OC cadre that was (and is) empowered to identify all issues and shortcomings of a rotational unit in each of the warfighting functions. (Chapman, 2010)

3.2.2. NTC Task Organization

NTC has three major organizations supporting a rotational unit's training exercise: The OCs, the 11th Armored Cavalry Regiment Opposing Forces (OPFOR), and the 916th Support Brigade.

The OCs are the most important element of the NTC organization. OCs evaluate all aspects of a unit's performance, to include tactical fighting ability, to maintenance operations, and fieldcraft proficiency. The 700+ OCs are assigned to evaluate all formations and personnel, from a successful former brigade commander evaluating the rotational ABCT Commander themselves, down to senior NCOs at each platoon and company in the ABCT. This allows unfettered access and analysis of unit performance.

The second major part of the NTC organization is the 11th ACR OPFOR. The OPFOR acts as the "enemy" in all of the rotational unit's operations. They learn and simulate the doctrine of possible enemy formations and then use that knowledge to challenge the rotational unit in simulated combat. Since the OPFOR is permanently stationed at NTC, they are extremely proficient in understanding the NTC battlefield and their capabilities, and more often than not, "win" the majority of the rotation battles. As a result of their skill, it is important that rotational units have the maximum amount of combat power FMC against the OPFOR.

The third major NTC organization is the 916th Support Brigade. The 916th acts as the support brigade of the higher headquarters to which the rotational unit is assigned. Since a brigade primarily operates as a part of a division or corps, and NTC is not large enough to support a full division, the ABCT has support requirement that must come from an outside unit. The 916th provides all logistical support to the rotational units, such as food, fuel, ammunition, and repair parts. Since they are tasked with the maintenance parts support for rotational units, the 916th operates the Supply Support Activity (SSA), providing the baseline repair parts for the ABCTs training.

3.2.3. Train up for NTC

Before coming to NTC, a unit must complete a number of training "gates" to be certified for all of the requirements at NTC. NTC training is split up into 2 major sections, the Brigade

Live Fire Exercise (BDE LFX) and the "Force on Force" Exercise. Each requires certain certifications before arrival.

The BDE LFX requires the most training time and resources. At NTC, the LFX requires the unit to fire live ammunition from all organic weapons (tanks, infantry, and artillery) and enablers (Aircraft, Attack Helicopters, Field Artillery, etc) to destroy automated targets in an engagement area. Use of live ammunition can be catastrophically dangerous, and thus has many requirements to ensure the safety and aptitude of the training soldiers. The training begins at a unit's home station with individual soldier weapons (pistols, rifles, and machine guns) and then proceeds sequentially to each higher system or unit level as soldiers are certified. Thus, each tank crew is certified/qualified on operating their tank in a live fire (Gunnery Table (GT) VI), then moves sequentially to section (2 tanks) live fire (GT IX), platoon (4 tanks) (GT XII), company (14 tanks) (GT XVIII) and finally battalion (29+ tanks) live fire exercises. This training requires up to 6 months to complete and must be completed within 9 months of the unit's arrival at NTC. Each crew or unit must be certified at each level to operate during the BDE LFX. This amount of training creates significant wear and tear on the vehicles and soldiers, and must be managed and properly recovered from to ensure success at NTC.

During the time period covered in this study, requirements changed for LFX completion. Before 2016, units were only required to complete through GT XII. During 2016, that requirement was changed requiring each unit to complete through GT XVIII. This could have effects on the vehicles, which is explained more in the OPTEMPO analysis section of this study.

The Force on Force portion of NTC is where actual combat operations are simulated. This is a 2 week "war" with no timeouts or breaks, simulating all forms of warfare a unit may see in a real war; including offensive, defensive, and counter-insurgency operations. Matched against a numerically superior OPFOR, who is intimately familiar with the terrain, units must clearly understand their doctrine to "win." Units train for the Force on Force portion through Field Training Exercises (FTXs) executed at their home-station. Against an OPFOR from their own unit, units master combat operations before movement to Ft. Irwin. These FTXs are similar to LFXs, in that they normally begin with smaller units, and as tactics techniques and procedures (TTPs) are mastered, larger units are involved. Thus, section, platoon, company, and battalion FTXs are scheduled and executed before arrival at NTC.

Once training is complete, units move all of their equipment to NTC. The equipment is packed in containers and placed, along with their vehicles, on trains for transport to NTC. This process takes the entire month before the unit's NTC rotation, and must also be considered when scheduling training and vehicle maintenance. This transport requirement explains why units see a large drop in vehicle mileage when the OPTEMPO for each is examined the month before a rotation.

3.2.4. NTC Operations

An NTC rotation is split into three major portions:

- Reception, Staging, Onward Movement and Integration (RSOI)
- Rotation (includes Force on Force and Live Fire Exercises)
- Recovery

For this study, I look primarily at OR rates during RSOI and Rotation. Below is a standard schedule for an ABCT NTC Rotation used in this study (excluding Recovery):

TRAINING DAY	1	2	3	4	5	6	7	8	9
TRAINING PERIOD	RSOI				TRANSITION	FORCE ON FORCE EXERCISE			
TRAINING TASK	RECEIVE VEHICLES	MAINTEANCE	MAINTEANCE	MAINTEANCE	MOVEMENT TO TRAINING	BATTLE PERIOD 1 (BP1)	BP 2 PLANNING	BP 2 PLANNNING	BP 2
TRAINING DAY	10	11	12	13	14	15	16	17	18
TRAINING PERIOD	FORCE ON FORCE EXERCISE						LIVE FIRE EXERCISE (LFX)		
TRAINING TASK	BP 3 PLANNING	BP3	BP 4 PLANNING	BP 4 PLANNING	BP 4 PLANNING	BP 4	LFX PLANNING	LFX 1	LFX 2

Figure 1: Sample NTC Training Schedule

RSOI begins with unit personnel flying to NTC and receiving their equipment at the NTC railhead. For this study, the day RSOI begins is considered Training Day 1. RSOI continues for the next 4 days with crews unloading vehicles from rail cars, conducting required maintenance, and preparing vehicles for rotational training. RSOI involves significant maintenance, explaining the jump in OR shown later in the study.

Once ready, the unit moves to the training area to an Assembly Area to prepare for the Force on Force Exercise. After each Battle Period, an After-Action Review (AAR) is completed to discuss successes and failures of the unit. Normally, an NTC rotation consists of 4 major battle periods, with a few days to prepare for each engagement. After Force on Force, the unit conducts their LFX.

When looking at an individual unit's NTC OR rate, there is normally an OR decrease on arrival, followed by an increase through ROSI, before another drop after the first battle on day 5.

After that, units have some variance based on exact dates of battle periods. The sample units' OR rate below shows some clear drops after the battles, which occur every few days, starting on day 6 (Figure 2). Battle Periods are not necessarily on the same training day for each unit, but are generally around the same time. After 13 days of intense training, the unit completes a final overall AAR and should be certified as a combat ready Brigade.

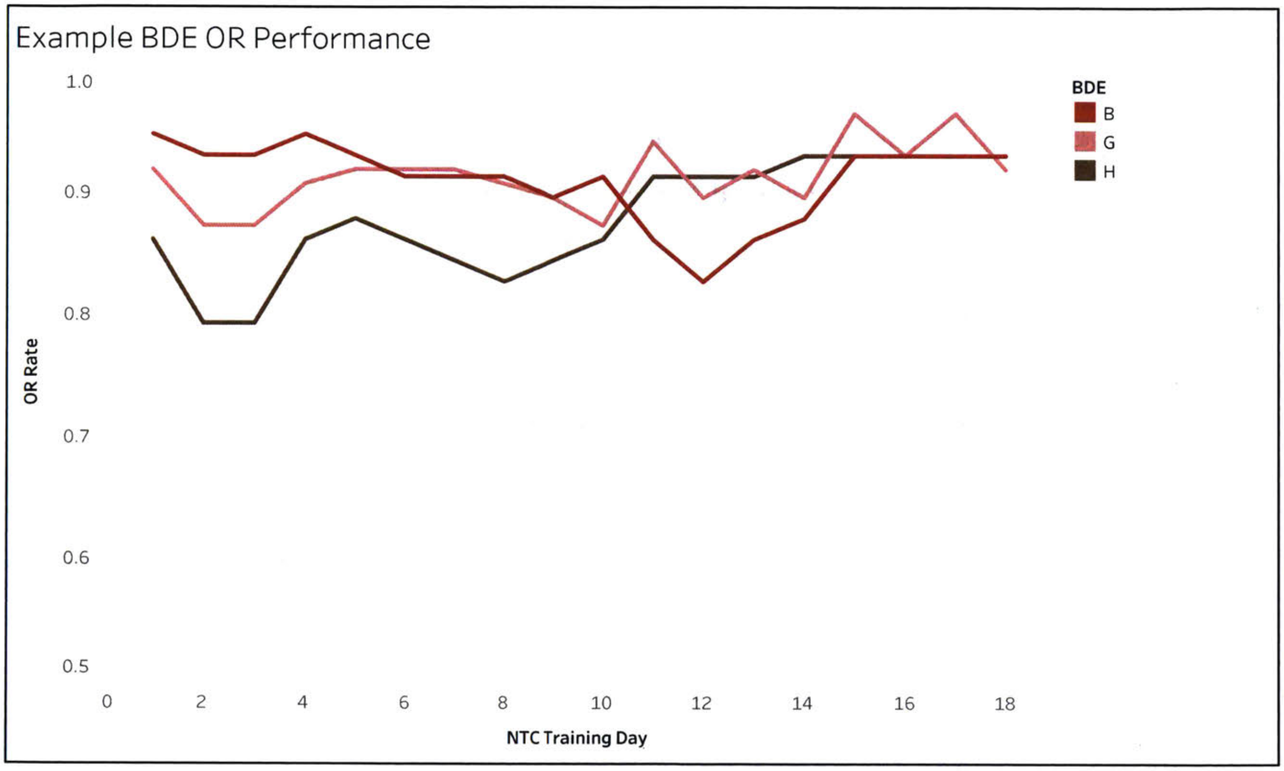

Figure 2: Example Brigade Daily NTC OR Rates

These 13 days are the toughest soldiers and equipment of an ABCT will face short of actual combat. Vehicles and personnel are pushed to their limit and poor maintenance is punished swiftly with reduced friendly combat power and thus the likelihood of simulated battle victory. Ensuring the rotational unit's tanks are FMC at NTC is of the utmost importance for Armor soldiers, commanders, and maintainers.

3.3. The Armored Brigade Combat Team

"The ABCT's role is to close with the enemy using fire and movement to destroy or capture enemy forces, to repel enemy attacks by fire, to engage in close combat, and to counterattack to control land areas, including populations and resources. The ABCT organizes to concentrate overwhelming combat power. Mobility, protection, and firepower enable the

ABCT to conduct offensive tasks with great precision and speed. The ABCT performs complementary missions to the IBCT and SBCT. "

– *Field Manual 3-96: Brigade Combat Team* (2015)

The Brigade Combat Team (BCT) is the baseline deployable unit of the US Army. It is a self-contained unit capable of deploying, fighting, and sustaining itself on the battlefield. There are three types of BCTs in the Army each with a specific mission. The most powerful of these and the only one with the M1A2 Abrams Tank is the Armored Brigade Combat Team (ABCT). Additionally, there are Infantry and Stryker BCTs as well (IBCT and SBCT). Three to four BCTs make a Division. Each BCT has a slightly different primary mission and capability, based on its specialty. They are designed to be modular and capable of deploying separately from their parent Division, thus allowing Army planners to mix and match capabilities based on need. (FM 3-96 Brigade Combat Team, 2015) Below is background information about each entity in the NTC Maintenance System. Additionally, for further information, the system decomposition and analysis is found in Appendix A.

3.3.1. ABCT Task Organization

Each ABCT contains 3 maneuver battalions (known as Combined Arms Battalions, CABs), 1 cavalry (reconnaissance) Squadron (equivalent to a battalion), 1 field artillery battalion, 1 engineer battalion, and 1 support battalion. The capabilities of each battalion type are different. This study focuses on the 2 battalion types containing the M1A2 Abrams in their organic force structure, the CAB and the Cavalry Squadron. All current Active Duty ABCTs contain this same task organization. (FM 3-96 Brigade Combat Team, 2015)

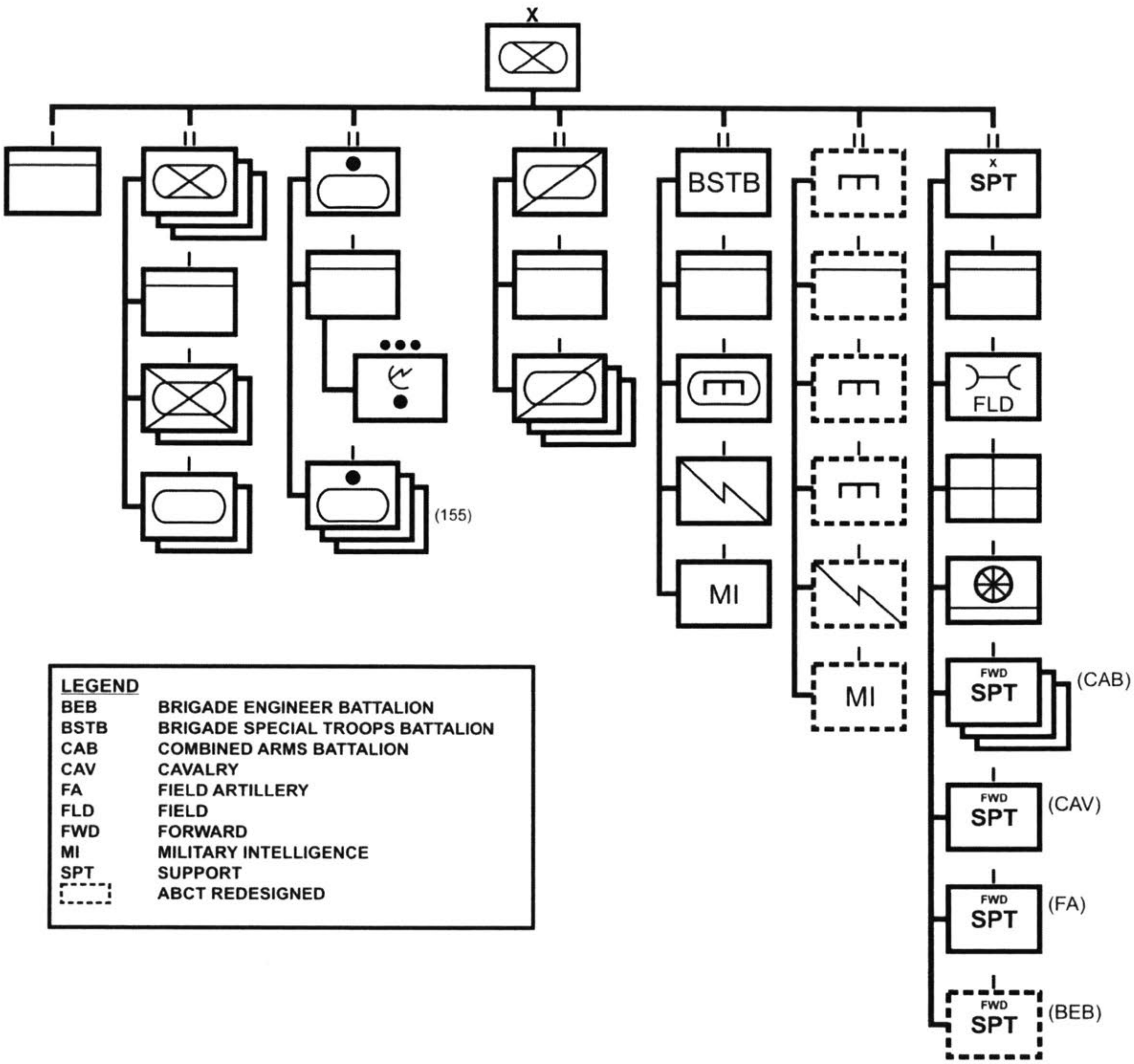

Figure 3: Organization of the ABCT (FM 3-96 Brigade Combat Team, 2015)

3.3.1.1. Battalion Task Organization

Before 2016, each maneuver battalion (known as a Combined Arms Battalion) had 2 Armor companies, and the battalion regimental nomenclature had no bearing on the structural organization of the unit. Thus, 2-7 Infantry Battalion had the same capability as 3-69 Armor Battalion; namely, both units included 2 mechanized infantry companies and 2 armor companies. Following the reorganization to the "triangular" structure of the ABCTs in 2016, the organic units are now based on the nomenclature of the unit. Currently, an ABCT has 2 Armor Battalions and 1 Infantry Battalion. The Armor Battalions have 2 Armor companies and 1 Mechanized Infantry Company, while the Infantry Battalion has of 2 Mechanized Infantry

Companies and 1 Armor Company. Simultaneously, the post-2016 ABCT has 1 Armor Company in the Cavalry Squadron. Therefore, there are still 6 Armor Companies in each brigade. (ATP 3-90.5 Combined Arms Battalion, 2016)

3.3.1.2. The Tank and Mechanized Infantry Company

All M1A2 Abrams are located in one of the tank companies in the ABCTs. A tank company has 14 tanks split across a Headquarters section (2 tanks) and 3 tank platoons (4 tanks each).

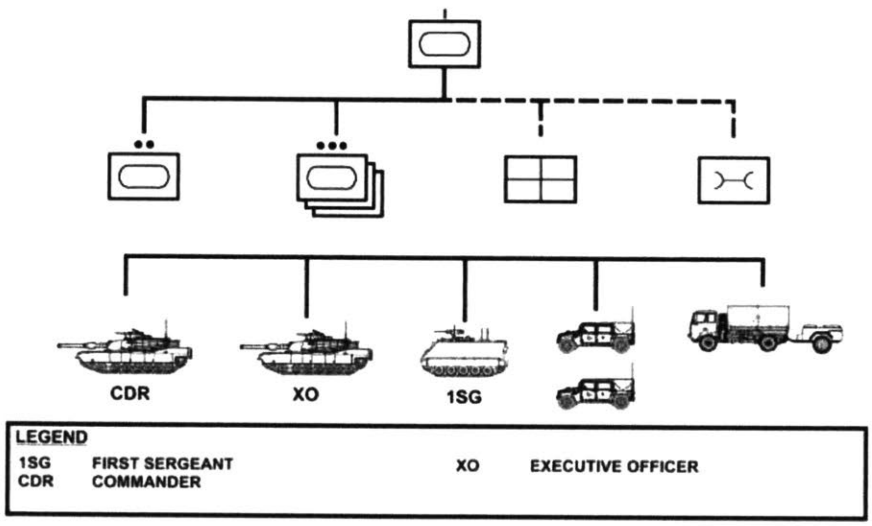

Figure 4: Armor CO Organization (ATP 3-90.1 Armor and Mechanized Infantry CO, 2016)

The Armor company's mission is to close with the enemy by maneuver to destroy or capture the enemy, repel the enemy's assault by fire, and engage in close combat and counterattack. (ATP 3-90.1 Armor and Mechanized Infantry Company Team, 2016) The company maneuvers in all terrain types, weather, and visibility conditions. It capitalizes on long-range, direct fire combat with enemy mechanized or armored units in open terrain with speed and shock effect. (ATP 3-90.1 Armor and Mechanized Infantry Company Team, 2016)

A Mechanized Infantry Company mirrors a Tank Company almost exactly. Each company contains 14 M2 Bradleys: 2 in the HQ section, and 12 in 3 infantry platoons. The major difference between the tank and infantry platoon, is the infantry platoon also has 3 squads of dismounted personnel, who ride in the back of each M2. (ATP 3-90.1 Armor and Mechanized Infantry Company Team, 2016)

3.3.1.3. ABCT Tank Maintenance Assets

The brigade, along with each subordinate unit down to company level, has organic maintenance units to supervise and execute maintenance operations.

At the lowest level, the soldiers that operate the tanks do basic preventative maintenance and repairs. This work is supervised by a company maintenance team of 10-15 personnel, called the Unit Maintenance Team (UMT), or Maintenance Section. This team is led by the Unit Maintenance Sergeant, and is administratively under the command of the Forward Support Company (FSC) in each battalion. This team confirms faults found by the soldiers and executes higher level maintenance tasks with specialized assigned maintenance equipment. This team can conduct all maintenance while in the field that does not require a depot to execute. (DA PAM 750-1 Commander's Maintenance Handbook, 2013)

The FSC is responsible for all sustainment operations, including supplying food, fuel, and maintenance service at the battalion level. During combat operations, the FSC maintenance section is located at the Unit Maintenance Collection Point (UMCP), where malfunctioning or damaged vehicles are taken for repair. The UMCP is supervised by the Battalion Maintenance Officer (BMO) and Maintenance Chief. An additional Headquarters maintenance team is normally located at the UMCP as well. The FSC maintenance section clerks, in conjunction with the Company Maintenance Team, handle the fault reports and subsequent ordering from the Army System. As repair parts arrive from higher headquarters, they are transported by the Brigade Support Battalion (BSB) to the UMCP for installation. (ATP 4-33 Maintenance Operations, 2014)

In addition to the FSC, the ABCT also has the Field Maintenance Company (FMC) assigned to the Brigade Support Battalion (BSB). The FMC decides whether repair requirements meet field-level maintenance guidelines or if equipment must be evacuated to national level support units. Additionally, the FMC contains low density testing and repair capability, such as the Direct Support Electrical Systems Test Sets (DSETS) which specializes in repairing the computer/electronic hardware necessary in today's fighting vehicles. (ATP 4-33 Maintenance Operations, 2014)

For additional background, Appendix B covers the personnel requirements within a brigade's maintenance system.

3.4. Army Maintenance Program

The Army's Maintenance Program is a major part of the success that the US Army's Armored Forces have had over the past few years. The ability to prevent malfunctions, and quickly fix them when they do occur, is a core reason for the US Army's success in power projection around the globe. The basis of the Army's program is found in ATP 4-33 *Maintenance Operations.* From ATP 4-33:

> *"The purpose of the Army maintenance system is to generate/regenerate combat power, and to preserve the capital investment of weapons systems and equipment to enable mission accomplishment.....Maintenance is a combat multiplier central to operational success across unified land operations. The maintenance system is designed to be fast, agile, and responsive to the needs of the Soldier as far forward as possible. Maintenance managers anticipate maintenance requirements by utilizing robust communications networks, tracking and analyzing maintenance reporting, and soon, by being enabled by equipment sensor data to monitor and evaluate equipment performance. The commander that combines skillful use of assigned equipment with effective maintenance management processes has a decided advantage. "* (2014)

Army maintenance operations are split into two levels: Field-level and Sustainment-level. This study limits its scope to Field-level operations. Sustainment operations are major repairs that require depot-level work and are not completed on the brigade or even division level. For a sustainment level fix, the equipment ownership is transferred to a depot or contractor for repairs, and a new vehicle is issued to the unit. Sustainment-level work cannot be done at NTC, and additionally is rare enough that it does not affect OR rate in a major way. (ATP 4-33 Maintenance Operations, 2014) To see the flow of maintenance malfunctions between Field and Sustainment levels, see the Maintenance Allocation Decision Matrix in Appendix C.

For additional understanding of the NTC Maintenance System, Appendix A has a hierarchy decomposition, System OPM, and Stakeholder Value Network to help describe the System as a whole. An explanation of each of these tools is found in Chapter 4.1.

3.4.1. Field-Level Maintenance Operations

Field-Level Maintenance is also split into two different levels: crew maintenance and maintainer maintenance. Crew level maintenance is performed by the soldiers assigned to each tank. This maintenance includes Preventative Maintenance Checks and Services (PMCS) and low-level repair operations. Maintainer level maintenance is performed by each tank company's maintenance team. This level includes of QA/QC of each crew's PMCS, parts ordering, and any required higher-level maintenance (such as major part replacement, engine repairs, and computer issues). (ATP 4-33 Maintenance Operations, 2014) The doctrinal flow of a field level maintenance issue can be seen in Appendix C.

As discussed above, there are 2 major types of field maintenance conducted by both crews and maintainers: preventative maintenance, and reactionary maintenance. Much like a factory or company, units conduct preventative maintenance to ensure the equipment properly functions, and to reduce unplanned malfunctions during actual operations. These checks occur both before, during, and after the operation of all equipment. (ATP 4-33 Maintenance Operations, 2014)

PMCS is an important part of the ABCT schedule. When not training, once each week, crews perform a PMCS on their tank using their technical manual (for the Abrams: TM 9-2350-388-10) and 5988-E form as guides to check and record issues. Once the checks are complete, problems are validated by the unit mechanics, reported/tracked, and parts ordered against each fault. This order is confirmed through the maintenance chain and identified in the Army supply system for shipment to (if the part is not local) or pick-up (if the part is local) by the unit. (DA PAM 750-1 Commander's Maintenance Handbook, 2013) More information about this PMCS process can be found in Appendix D.

For any fault found and part needed, there are three types of parts. For major parts which cause a tank to go from FMC to NMC (such as a malfunctioning fire control system), parts are labeled as O2. For less important problems that do not affect the mission, (a ripped seat cushion) they are labeled as 05 or 12 faults. For this study I will limit scope to O2 part failures, as they are the only ones which can deadline a tank. (Army Regulation 710-2: Supply Policy Below the National Level, 2008)

In addition to weekly maintenance, M1s must go through two weeks of significant maintenance every 6 months, called "Services." Services ensures that major preventative maintenance is done, and vehicles are ready for operations over the next 6 months. Due to the importance of Services and their emphasis and supervision by Army headquarters, this study assumes all Services for the studied units were completed on time and properly. (DA PAM 750-1 Commander's Maintenance Handbook, 2013)

Reactionary maintenance is performed when a vehicle breaks down during operations. When this happens, the crew again uses the TM and 5988-E to record and report the fault to mechanics for validation and parts ordering. Faults which cause NMC tanks, and thus effect overall OR rates, can come from either type of maintenance. (ATP 4-33 Maintenance Operations, 2014) The parts ordering flow varies depending on whether the need is during training at home station or NTC (and thus wartime). A longer explanation of each is described in Appendix D.

3.4.2. Supply Support Activity (SSA) and ASL Management

The SSA is the "warehouse" that supports all ABCT parts requests. With over 1.4 million parts in the Army's inventory, it is impossible to store all parts in every unit SSA. Instead, individual units, along with Army /AMC advisors, decide which parts should be stocked on the Authorized Stockage List (ASL) during an annual ASL review conducted by each unit SSA. The supply personnel examine their unit's parts usage, along with other similar units' usages, to decide which parts need to be listed on the ASL. At times, upcoming operational requirements mean other specialized or expected parts can be added to the ASL despite not being used in the past. For instance, a unit, knowing it is deploying to a desert environment from a non-sandy environment, may want more air filters than had been stocked in the ASL. (ATP 4-42.2 Supply Support Activity Operations, 2014)

One tool AMC and ASL managers use to identify important parts in the Army System (parts that routinely deadline vehicles) is to classify them as Maintenance Significant Parts (MSP). Each year, AMC examines what parts have caused the most NMC time for vehicles in the Army's inventory. These are then identified as MSPs. However, just because a part has been labeled as MSP, does not mean it is included on all ASLs. In fact, the NTC ASL only contains 27% of the M1's MSP listing. This will be analyzed later in Chapter 5.

3.4.3. Army Standards of Maintenance

As mentioned before, the Army has certain standards for maintenance performance. This allows units and requirements to be compared against each other and evaluated for future operations. The standard most important for this study is the OR rate. The Army tracks OR rates very closely for some vehicles, while allowing for some leeway with others. Vehicles that are closely monitored are called "pacers," and include both the M1 and M2. Vehicles that are not pacers are common and exchangeable vehicles, like FMTV cargo trucks or HMMWVs. As a result of their importance, pacers (specifically M1s and M2s), have a 90% OR rate standard. Thus, a unit is expected to have 90% of their vehicles ready in a set time period, usually a month. This allows for variability in the day to day OR rate, but is a good judge of maintenance quality over longer periods of time. (DA PAM 750-1 Commander's Maintenance Handbook, 2013)

Though not necessarily set in doctrine, most units also have a standard for vehicle repair when a part is available. These standards are especially true at NTC, where maintainer rest and personal time is subordinated to the requirements of a combat simulation. First, diagnosing faults is not stopped until the unit knows exactly which parts have failed. Additionally, if a part is on hand for an NMC vehicle, work continues until that vehicle has been fixed. Normally, at NTC, both take less than 12 hours to complete. Given this information, a number of assumptions can be made for the study. First, is the amount of time needed to diagnose and then fix issues is assumed to be 24 hours. Thus, if a tank is NMC for 5 days, one of those days is due to the combination determining which parts to order and then replacing them after arrival. The remainder of the time is waiting for the part to arrive. Two aspects drive arrival time. The first is the time needed for transport from the ASL to the unit. As discussed above all parts no matter their importance, size, or cost, are taken on LOGPACs from the warehouses to the units. Thus the second assumption is regardless of part, it takes 12-24 hours to get to a unit.

3.5. M1A2 Abrams

The M1A2 Abrams is the main battle tank fielded by all active duty US Army ABCTs. A highly mobile, lethal, and armored vehicle, the Abrams is widely regarded as one of, if not the, best main battle tank in the world. (DeJohn, 2018)

The Abrams was first developed by Chrysler Defense (General Dynamics today) as 1/5th of the "Big 5" Army acquisition projects of the 1970s. Along with the M2 Bradley Infantry Fighting Vehicle, M60 Blackhawk helicopter, AH-64 Apache Attack Helicopter, and Patriot Air Defense Program, the Abrams was a key part of the revolution that occurred in the post-Vietnam Army. Designed with cutting-edge technology, the Abrams was built with flexibility for future upgrades. These upgrades have been installed throughout the program lifetime, ensuring that though the tank hulls may be dozens of years old, the technology within is still the best in the world. (DeJohn, 2018) By 2013 when this study started, all Army units that rotated to NTC were equipped with the M1A2.

The Abrams, at over 70 tons, is classified as a heavy tank. Much of this weight comes from the armor, ensuring that the crew is a safe as possible from enemy fire. The crew is made up of 4 soldiers, the tank commander, gunner, driver, and loader. The tank is armed with the M256 120 mm smoothbore main gun, 1 M2 .50 Caliber heavy machine gun, and 2 M240 7.62 mm medium machine guns. To move the tank, the tracks are powered by a 1500 horsepower turbine engine; making the tank capable of 42 mph (governed). To connect with other tanks and units, the Abrams has 2 radios, and satellite communication and mapping capability. All of these features make for an effective and lethal tank, as long as maintenance is properly completed. In this study, the use of the term M1 will mean M1A2, unless otherwise stated. (DeJohn, 2018)

3.6. M2 Bradley

The M2 Bradley is the most widely used of the Army's armored vehicles. It is utilized for a variety of missions, from carrying/protecting infantry in combat, scouting, artillery forward observing, and, formerly air defense. Each of these Bradley types comes with it's own nomenclature. For a few reasons, This study is limited to the M2A3 Bradley Infantry Fighting Vehicle. First, Bradley variants like the M3A3 Cavalry Fighting Vehicle or the M2A2 Engineer Vehicle are utilized by units different from the Combined Arms Battalions found in an ABCT. As a result, their OPTEMPO and usage may vary greatly from those of the CAB. In addition, some, variants, are much older and more prone to break downs than the newer M2A3s. In this study, the use of the term M2 will mean M2A3, unless otherwise stated. (Dejohn, 2018)

The M2 was another of the Big 5 Army defense development projects of the late 1970s. The Army needed a vehicle that could accomplish the different missions outlined above. After a much-publicized design process marred by requirements creep and delays, the Army finally began receiving the first M2s in 1981. Much like the M1, the M2 has undergone multiple updates that have kept it on the cutting edge throughout its lifecycle. (Dejohn, 2018)

The M2 has three crewmen, and can carry up to seven soldiers in the crew compartment in the rear of the vehicle. For armament, M2 has a 25mm chain gun, as well as a TOW missile launcher, and a M240 machine gun. The Bradley is powered by a 600 horsepower engine, which makes it capable of keeping up with the M1 in all terrain. (Dejohn, 2018)

3.7. M1 versus M2 Comparison

Although they are not the same vehicle, the M1 and M2s in an ABCT are similar enough that they warrant comparison to gain insights about the other. As discussed in the Task Organization of the ABCT section, a modern US Army CAB has both M1 and M2 Companies. Thus, when a CAB develops it's training schedule, both unit types receive about the same amount of training time, resources, and distractions (such as guard duty, etc.). Additionally, companies within these battalions also have the same leadership. The culture, command emphasis, or maintenance program for an M1 company in a particular CAB is the same as the M2 companies in that same CAB.

In addition to the units themselves, the Army's doctrine for training for both M1s and M2s is also almost exactly the same. For both vehicles, employment of the weapons system is the most important part of their mission. To prepare each echelon of combat vehicles, the Army has established the doctrine for ABCT gunnery. (FM 3-20.21 Heavy Brigade Combat Team Gunnery, 2009). The doctrine outlines each training process step, starting at the single vehicle (M1 and M2) level, and moving up to the Company and Battalion live fire exercises. Additionally, in both of the units, higher brigade or battalion headquarters attempts to provide evenly distributed field maneuver training exercises. Each of these training events puts approximately the same requirements on both vehicle sets, allowing for the analysis to control for different training schedules within battalions and brigades. (FM 3-20.21 Heavy Brigade Combat Team Gunnery, 2009)

The one area where the M1 and M2 units differ is in the requirements for the dismounted infantry squads. An infantry company has 9 dismounted infantry squads assigned to it, and thus must also train those squads in dismounted operations. (FM 3-20.21 Heavy Brigade Combat Team Gunnery, 2009) However, a few aspects of this training allow us to minimize the difference in resources, specifically time, that infantry units require when compared to tank units. First, the crews performing the majority of the vehicle maintenance are responsible for those vehicles, and have limited participation in dismounted operations. Though they may assist in training, their focus is on vehicle care on a day to day basis. Second, dismount training at the team and squad level primarily occurs during the very early portion of NTC train-up. Thus, before moving onto more advanced mounted requirements, units have normally completed dismounted requirements. Additionally, this study focuses primarily on the 9 months before an NTC rotation. Much of this training could have been accomplished before the study. Though each unit is different, it is acceptable to assume each unit completed these dismounted training events in the first 3 months of a train-up cycle. As a result of these mitigating circumstances, this study uses the M2 performance as a baseline to compare M1 performance. Though it is not a textbook control or placebo group, it is as close as one can get within the Army's armor units.

3.8. The Cost of NMC Vehicles at NTC

A tank NMC at NTC costs more than just the cost of the broken part. There are a multitude of costs occur in addition to just maintenance dollars, and in some ways are more important. To show this, I will examine the two major costs: 1) is the dollar cost involved in a missed training day at NTC; 2) the intrinsic value lost with a tank crew not participating in an NTC rotation.

The simple cost calculation is the dollars lost per tank day NMC. To calculate this, I used the cost of an NTC rotation overall. Currently, an ABCT rotation costs the taxpayer $33 million in transport, fuel, food, ammo, and other assorted costs. Splitting the costs evenly across each battalion (6), company (6), platoon (4, including HQ Platoon), and tank (4) the cost of a lost tank day costs $3,182.87.

However, this cost is probably higher for the combat companies than for other support companies, because of more expensive ammunition, fuel, and personnel size. To predict the higher overall cost, the CABs are assumed to use 60% of the overall ABCT cost, while the tank/infantry companies inside the CAB use 75% of the overall CAB cost. Using this calculation, the cost of a lost tank day is $5,729.

The second cost calculation, analyzes who misses training when a tank is NMC. The first and most obvious is the crew themselves. Since there are no "jump" tanks the crew can transfer to, the crew of an NMC tank must wait with that tank until it is FMC. Snowballing the effect, the platoon leadership lose out on valuable training experience, because they are not operating with a full platoon. Fighting with a 3-tank platoon is different from fighting with 4 tanks because of the different ways you must maneuver your vehicles. The 4th tank adds complexity and difficulty to a PL's operations which cannot be duplicated with only 3 tanks. Though there is value in being forced to fight with only 3 tanks, in almost any battle period at NTC, a platoon will lose tanks to simulated enemy action; thus, the PL will eventually train with only 3 tanks without having to rely on an NMC tank for the experience.

The next question then: what is the intrinsic costs of a lost tank day that are not only dollar based? The whole purpose of NTC is to prepare soldiers and leaders to fight America's wars. NTC training is as close to wartime conditions as possible. At the end of an NTC train-up and rotation, units are as ready as possible to fight in an actual combat environment. Much of that experience comes from the time at NTC. Tank crews who miss this training miss lessons and experiences that could eventually save themselves or fellow soldiers in combat. Additionally, knowledge gained during an NTC rotation is passed onto future soldiers, ensuring those junior soldiers and leaders learn from an NTC rotation of which they were not a part. However, it is extremely difficult to quantify the dollar value of a soldier's life. The Department of Defense, Army, and taxpayer could pay trillions of dollars to procure equipment or technologies to possibly save a soldier's life, but it is impossible to accomplish this given the understandable limitations of political willingness to pay infinite defense budgets. However, given the amount of experience gained at NTC, as compared to home-station training, it is of the utmost importance to minimize days NMC.

4. Literature Review

4.1. Systems Architecture and Analysis

"The whole is more than the sum of the parts"

-Aristotle, *Metaphysics*

Crawley, Cameron, and Selva define a system as a group of entities whose emergent performance is greater than the sum of the individual entities. (2016) Every individual part in a racecar is a pile of metal, but placed together and carefully engineered, the car can move at over 200 mph. In the same way, nine individual players on a sports team, such as the Atlanta Braves, can come together to create emergent performance, hopefully of victory on the baseball diamond. Systems can take the form or function of almost anything, from cars to sports teams, to a computer program, train station, or water pump. Analyzing these systems allows us to better understand each part, and also the emergent qualities which come from their combinations.

4.1.1. Stakeholder Analysis

Although commonly identified using the term "stakeholders", there are two non-mutually exclusive descriptions of entities that can make up three different categories All systems have stakeholders and beneficiaries, and many entities in a system can be described as both. These three categories are: pure beneficiaries, pure stakeholders, and beneficial stakeholders. (Crawley, Cameron, & Selva, 2016)

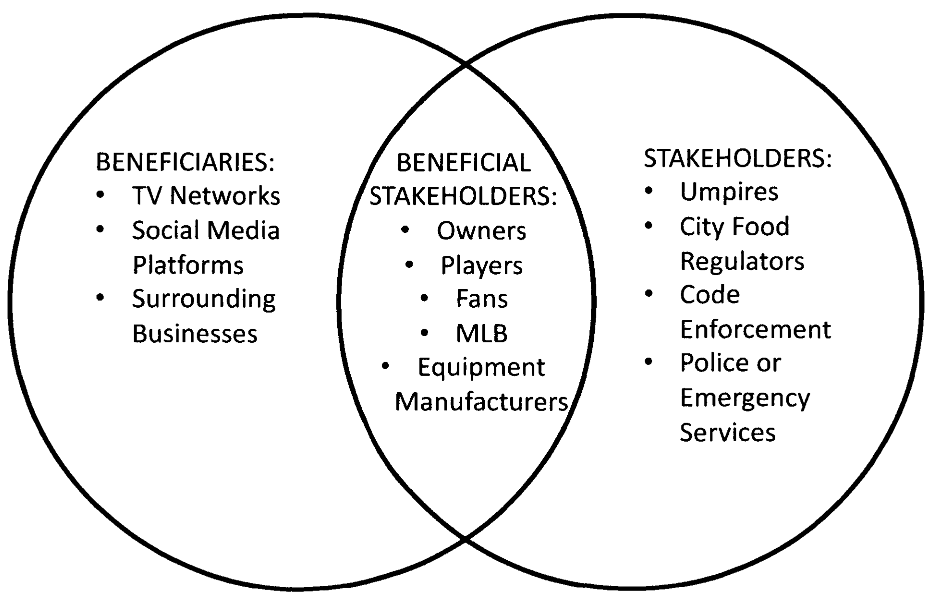

Figure 5: Baseball Team Stakeholder vs Beneficiaries Venn Diagram

Beneficiaries are defined as anyone who benefits from the system's value. (Crawley, Cameron, & Selva, 2016) The benefit could be money, experience or using an item or service. Using the Atlanta Braves, the fans are beneficiaries because they receive entertainment from the game. The owners are beneficiaries because they receive the profits from the team, players are also beneficiaries because they gain money, (hopefully) fun, and baseball experience. Pure beneficiaries would be a sports TV network, who uses the highlights of the game to generate viewers, but does not have a stake in the team itself.

Stakeholders are anyone who throughout the system has an output or an outcome that addresses the overall needs of the system. (Crawley, Cameron, & Selva, 2016) In the Braves example, the players, umpires, opponents, and grounds crew are all stakeholders. The umpires provide a judgement input to each game, which provides guidance about close plays. A pure stakeholder example would be the regulatory bodies which govern the construction of a new stadium. They have an output (licensing, build permits, etc) which a team needs to build, but does not benefit from anything the team provides.

A beneficial stakeholder is someone that provides both the inputs to the system and receives some sort of benefit from it as well. Most of the examples given above are beneficial stakeholders. The owner of the teams provides inputs, while also receiving monetary benefit from the team. The fans provide money in the form of tickets, but also receive the entertainment value of the team.

4.1.2. Form vs Function

A system has two major characteristics that inform the system's purpose: its form and its function. Each allows someone to understand the system's goals or performance. Form is the physical manifestation of the system existing in the world. These are the things that can be placed in space or time relative to other forms. (Crawley, Cameron, & Selva, 2016) For instance, in baseball, the catcher crouches behind the plate, while the pitcher stands on the mound. These are their physical locations within the system, which is dictated by their job on the team. Function is what a system does, it is the systems emergent capabilities, that occur based on its form. For the Braves, their function is to score runs, which they do through hitting, running, and eventually touching home plate.

Each entity in a system has both a function and a form, and often on many different levels when decomposed. Using the Braves, the system function we are looking for this example is a double play. The system form is the Braves in the infield. Each entity is a position in that system form, as short stop, 2nd baseman, and 1st basemen. Their entity functions are the jobs they must do to reach the system function. Thus, the shortstop's entity functions are: field the ground ball and throw to the second baseman, the second baseman's entity functions are to catch, touch the base, and throw to first basemen, who catches the ball and tags first base. These entity functions create the emergent function of the double play. Moving up or down these system aspects to entity aspects is known as aggregation and decomposition, and is key to understanding the systems to be analyzed. (Crawley, Cameron, & Selva, 2016)

4.1.3. Analysis of Form and Function

To analyze a system's architecture, there are certain steps where one logically identifies, defines, and examines the system holistically. The first task identifies the system as a whole, its form and then its function. Second, one identifies the entities, and their organic form and function. Third, one establishes and identifies the relationships amongst those entities. While accomplished in many ways, for this study, I will use spatial relationship diagrams. This includes identifying the form and functional relationships between entities, as well as establishing the system boundary. Finally, we identify the emergent aspects of the system. This is done both for system successes (scoring a run) or system failures (making an error).

4.1.4. Descriptive Decomposition Tools

The first tool to decompose the system form is a multi-level hierarchy decomposition. This decomposition groups entities into multiple levels and sub-systems. By grouping entities in this way, it allows for complex relationships to begin be better understood and examined. (Crawley, Cameron, & Selva, 2016) Below is a simple sample of that decomposition, using again, a baseball team:

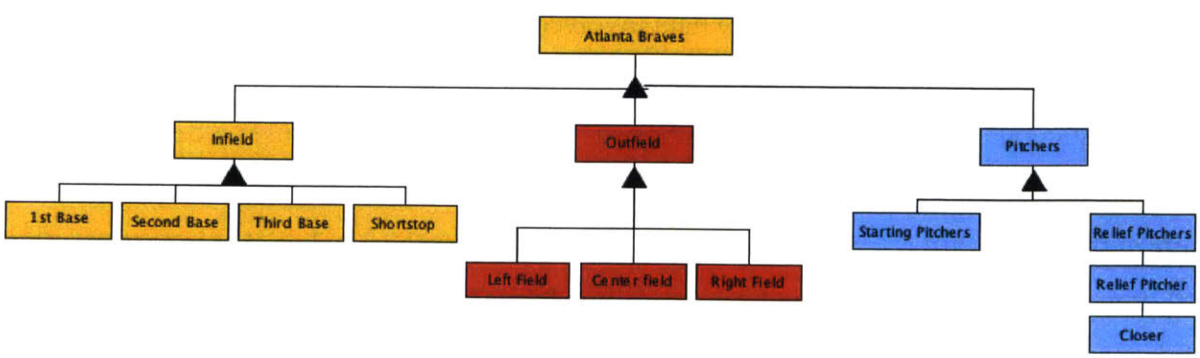

Figure 6: Example System Decomposition

The second tool used to understand systems is an Object Process Methodology (OPM) diagram with formal and functional spatial relationships to understand the operands and processes involved in a system. In this diagram, formal entities are surrounded by a rectangle, while functional processes are inside ovals. The arrows connecting each form and show the order that processes are completed. (Crawley, Cameron, & Selva, 2016) Appendix A shows the OPM for the Army's Maintenance System.

4.2. Statistical Hypothesis Testing

When a researcher utilizes a data set to understand the inherent truths of said data, they make, or have already made, a hypothesis about the meaning of that data. This creates two separate scenarios: one where the initial hypothesis is accepted and another where it is rejected. Analyzing whether a hypothesis is correct is called hypothesis testing. Hypothesis testing is extremely useful in deciding whether or not statistical evidence supports assumptions and analysis of data. (Devore, 2004)

There are two hypothesis possibilities: what is initially believed to be true, known as the null hypothesis (H_0); and the alternate hypothesis (H_a), which is contradictory to the null hypothesis. An example of the two hypothesis could be the average of a data set. The null hypothesis is the average is over 50, while the alternate hypothesis is that the average is less than or equal to 50, thus covering all possible averages not covered by the null hypothesis. Thus, a test of these two hypotheses is used to decide if the null hypothesis should be rejected and the alternate accepted. (Devore, 2004)

To test the hypotheses, two numeric values are used to decide whether to accept or reject the null hypothesis: the test statistic value and the rejection region value. The test statistic uses aspects of the sample data to compute a particular value for use in comparison to the rejection region value. The aspects of the sample data involved are the assumed null average, the data average, data standard deviation, and the number of data points. The rejection region is the set of all test statistic values where the null hypothesis is rejected. This region uses a desired confidence interval, decided by the researcher, to set the values. If a researcher desires to minimize the possibility of error (either rejecting the null hypothesis when it is in fact true (type I error) or not rejecting the null hypothesis when it is false (type II error), they increase the confidence interval. (Devore, 2004) Increasing the confidence interval decreases the rejection region, making either error type less likely. Since the alternate hypothesis can also establish whether the sample is equal to a hypothesized value, the rejection region can come in either a single or dual tailed test. (Devore, 2004) Additionally, statistical hypothesis testing can be used to compare two data sets, to make statistical conclusions about their relative values.

4.2.1. Single Sample Null Hypothesis Testing

The simplest of null hypothesis testing comes when comparing a data set against its assumed hypothetical value. In this study, there are enough data points to not have to assume their distribution. Therefore, we use a z-statistic to compute our test statistic. The formula is:

$$Test\ Statistic: z = \frac{x - \mu_0}{\frac{s}{\sqrt{n}}}$$

where x is the hypothesized mean data value, μ_0, is the sample mean value, s is the sample standard deviation, and n is the sample size. Next, the rejection region significance level, α, is chosen. For this study, all significance levels are .01. If the hypothesis is a two-tailed test, the significance level is halved (.005 for this study). This significance level then provides the rejection region value, and we compare the rejection region value and the z-statistic value. If, in a lower tailed test the z value is lower than the rejection region value, then the null hypothesis is rejected. If it is higher, there is not enough evidence to reject the null hypothesis. The equivalent applies for an upper-tailed test: if the z value is higher than the rejection region, the null hypothesis is rejected, and it is not rejected if the z value is lower. For a two tailed test, the test statistic can be higher or lower than the negative or positive rejection region value. (Devore, 2004)

4.2.2. Two Sample Null Hypothesis Testing

The single sample null hypothesis testing is used when examining one population; however, when two different samples are collected, for comparison, it is insufficient. Thus, two sample test statistics are used in the testing of two sample hypotheses. In this testing, we use the z statistic and S^2 instead of σ^2 because the Central Limit Theorem guarantees there is an approximately normal distribution between the differences of the samples. Thus, the formula used is:

$$Test\ Statistic: z = \frac{x - y - \Delta_0}{\sqrt{\frac{s_1^2}{m} - \frac{s_2^2}{n}}}$$

where x is the hypothesized mean of sample 1, and y the hypothesized mean of sample 2, Δ_0 is the difference between the sample means of x-y, and s^2 is the respective variances of the samples, and m/n the respective sample sizes. The rejection region calculations are the same as the single tailed test, and the z value is compared to the rejection region value in the same manner. (Devore, 2004)

4.4. Statistical Regressions

Regression analysis examines the correlations of two or more variables to each other. In many statistical outcomes, an independent variable correlates to a certain effect in another dependent variable. Using the Atlanta Braves, there is probably a correlation between the team's season batting average and season win total. However, there is not an exact deterministic correlation between the two, since the team could have an excellent pitching staff, and thus win more games with a lower average batting average, or vice versa. Yet some sort of correlation between the two measures is still probable. Regression analysis attempts to fit an equation to those functional correlations allowing researchers to understand how each independent variable effects the dependent variable. This can be a simple linear model, or a more complex exponential, multivariable, or cyclical model. Once the model is created, researchers can then use other analysis tools to rate or understand the model's actual fit. (Devore, 2004)

4.4.1. Simple Linear Regression Model

The simplest regression is a one-variable linear regression with one independent variable and one dependent variable. This regression model is almost identical to the slope intercept formula from algebra: y=mx+b. The simple linear regression model is:

$$y = \beta_0 + \beta_1 x + \epsilon$$

where y is the dependent variable, β_0 is the y-intercept, β_1 is the independent variable coefficient, x is the independent variable, and ϵ is the random error inherent in the model. The model must have an inherent error value, otherwise it would be impossible to match a data set, as the data would have to fall along an exact line. Given that few data sets have a correlation that sterile, an error function is included. The difference between values of the data and the model at each x-value are also called residuals. (Devore, 2004) To calculate the values of each of these numbers, statisticians attempt to minimize the least squared error of the equation line. To do this, they establish a line, and calculate the residuals. (Devore, 2004) This gives the researchers a number, either positive or negative. As a result of the ability for those numbers to be positive or negative, the differences are squared, to make each a positive number. All of those numbers are added, and a total summed error value is reached. The formula is:

$$\text{Sum of Squared Error: SSE} = \sum(y_i - \hat{y}_i)^2$$

Where y_i is the actual data point, and $\hat{y}_i$ is the regression line value. After that is computed, additional possible lines are created, and their total squared error is calculated, until one model has the least total squared error. (Devore, 2004) This would take a significant amount of time by hand, but a computer can do the calculations in a matter of seconds. Below are examples of a data set with an independent and dependent variable and a simple linear regression line (with least total squared error) computed from that data set.

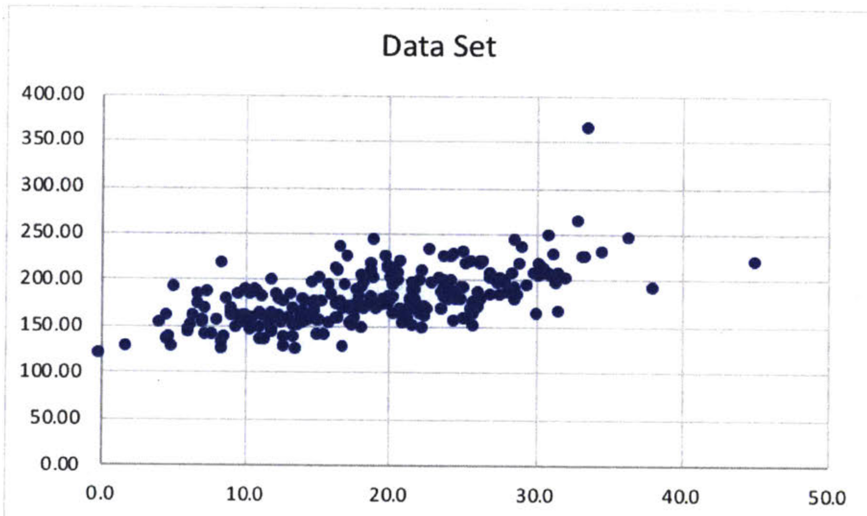

Figure 7: Example Data Plot

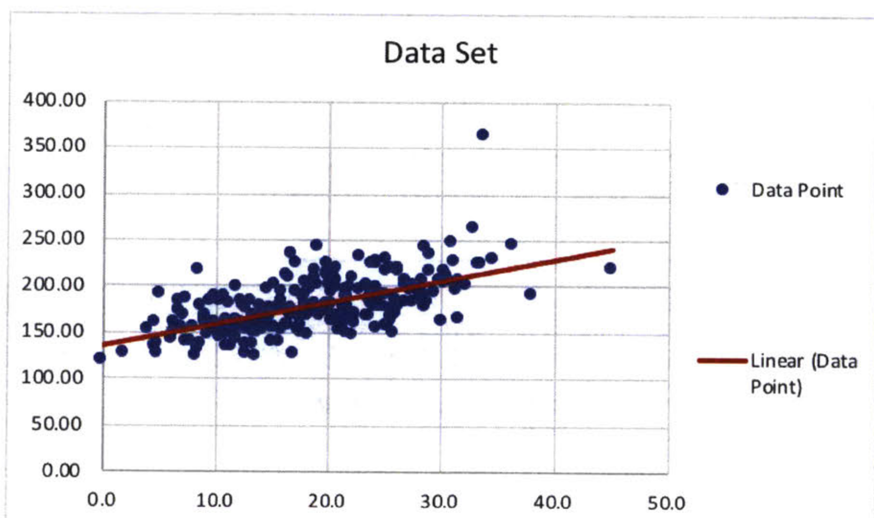

Figure 8: Example Data Plot With Trendline (y = 134 + 2.32(x))

After establishing a trendline, a statistician analyzes the quality of that trendline, and whether it shows correlation between the two values, by computing the coefficient of determination, r^2 and adjusted r^2. To do this, the coefficient of determination also needs the total sum of squares. (Devore, 2004) To calculate the total sum of squares, the following formula is used:

$$\text{Total Sum of Squares: } SST=\sum(y_i - \bar{y})^2$$

where y_i is the actual data point data, and $\bar{y}$ is the data set mean value. Thus, SSE calculates deviations above and below the modeled line, and SST calculates deviations above and below a horizontal line set at the average. Once SST has been computed, it can be used to compute r^2:

$$r^2=1-\frac{SSE}{SST}$$

Which can then be used to compute the adjusted r^2:

$$\text{Adjusted } r^2=1-\frac{(n-1)r^2-k}{n-1-k}$$

Where k is the degree of the polynomial in the model. In this study, all references to r^2 are the adjusted r^2 value in the regression. We use r^2 and adjusted r^2 to determine the success or failure of the model to explain the correlation between the variables. The closer r^2 is to 1, the more of the variance in Y is explained. As with the SSE, the r^2 is easily computed with computer programs, such as Microsoft Excel. Below is the Excel output for the above data sets in Figure 8, with an adjusted r^2 of .373.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.61315611
R Square	0.37596042
Adjusted R S	0.37346426
Standard Err	23.2626988
Observations	252

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	81506.1136	81506.1136	150.615612	2.059E-27
Residual	250	135288.289	541.153155		
Total	251	216794.402			

	Coefficients	*Standard Erro.*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	134.893868	3.87546051	34.8071843	7.6573E-98	127.261155	142.526581	127.261155	142.526581
X Variable 1	2.32492305	0.18944083	12.2725552	2.059E-27	1.95181964	2.69802646	1.95181964	2.69802646

Figure 9: Example Microsoft Excel Regression Results

4.4.2. Multiple Variable Regressions

More than one independent variable may effect the value of the dependent variable. Using our baseball example, the Braves season wins (dependent variable, y) may not be due only to the team batting average (independent variable 1, β_1) but may also include the team's starting pitching Earned Run Average (independent variable 2, β_2) and number of fielding errors (independent variable 3, β_3). Thus, the following formula is used:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \in$$

Similar to the simple linear regression, the multiple variable regression also uses SSE and SST to compute r^2. (Devore, 2004)

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5. Data Analysis

5.1. Data Introduction

5.1.1. US Army Operational Security Requirements and Explanation

Since this study is public record, some information is omitted, substituted, or otherwise changed to avoid providing detrimental information to possible Anti-American actors and states. First, the names or units of interviews are omitted; instead, only positions are identified. Second, no failed parts are identified; by NIIN or other identifying aspects. Last, all units are identified an alpha-numeric code. The eight brigades studied are labeled A-H, while each battalion within a brigade is numbered. Each company within a battalion is labeled with A or B. Thus, a BN in the D ABCT is D3, and a company in that BN is D3A. The chart below identifies the number of data points for each unit size, along with basic computed OR and mileage values.

	M1 OR DATA	M1 MILES DATA	M2 OR DATA	M2 MILES DATA
Brigades	8	6	8	6
Battalions	23	12	19	10
Companies	39	27	33	23
Tanks	565	391	476	356
Average NTC OR Rate	87.4%		92.0%	
Average Train up Miles		269.7		451
Average NTC Miles		104.1		217.2
Average Lifetime Miles		2724		2938

Figure 10: Data Breakout

5.1.2. Required Data Assumptions

Though a majority of the data is adequate for analysis, a lack of data in some areas forced some assumptions to be made in determining OR Rates, OPTEMPO levels, and controlled substitutions. Though not major, they are discussed below.

5.1.2.1. OR Rates

When examining the unit reported OR rates from BDE internal maintenance meetings during NTC rotations, the OR rate reported in the meeting often did not match the OR rate in the Army maintenance computer systems (SAMS-E or GCSS-A). This is often due to reporting latency or the use of shop stock parts. Throughout the reporting, almost 100% of BDE internal reports showed a lower OR rate than the Army system. Since there is no way of knowing the full picture of a units internal situation without being present at the time of the rotation, this study only uses data in the system. This strengthens the hypothesis analysis that there was an OR rate issue, because even the artificially higher AMSAA/O26 OR rate was below the Army's 90% standard.

5.1.2.2. Miles OPTEMPO

Miles reporting from OSMIS is assumed to be correct for this study. However, there are some issues with the monthly reported miles. Some units had unreported months of usage. However, since those units did report the next month, a null value was entered for each vehicle during the missing month, and the entire mileage entered in the subsequent month. Even with this missing data, each BDE and BN showed a similar train up mileage pattern, namely increasing monthly usage from month to month, until the month prior to NTC, when it dropped to 50-75% of its peak; this is intuitive given the training requirements necessitating increased vehicle use as NTC rotation approaches.

Additionally, impossible or unlikely data was reported in OSMIS. For instance, some tanks were reported as having driven negative miles in a month, or a number impossibly high (such as 50,000 miles). Those data points were each examined. Some were obviously clerical error, with the next month returning to acceptable levels. In those cases, a null value was entered. For those without an obvious error corrected the next month, the data point was thrown out.

5.2. M1 OR Rate Performance Analysis

The first use of the data analysis is to evaluate whether there is a statistical answer to the first research question. I utilize statistical hypothesis testing using the data provided for the M1s and M2s. First, an examination of the overall OR rates for both M1s and M2s gives clues as to the performance of each during training and at NTC.

5.2.1. Research Question 1: Is M1 OR Rate at NTC Below the Army Standard?

To analyze M1 OR rates and the first research question, I look at the sample daily OR rate for the Army overall during a rotation at NTC in Figure 11, as well as breaking the sample Army average out into the individual brigade OR rates in Figure 12.

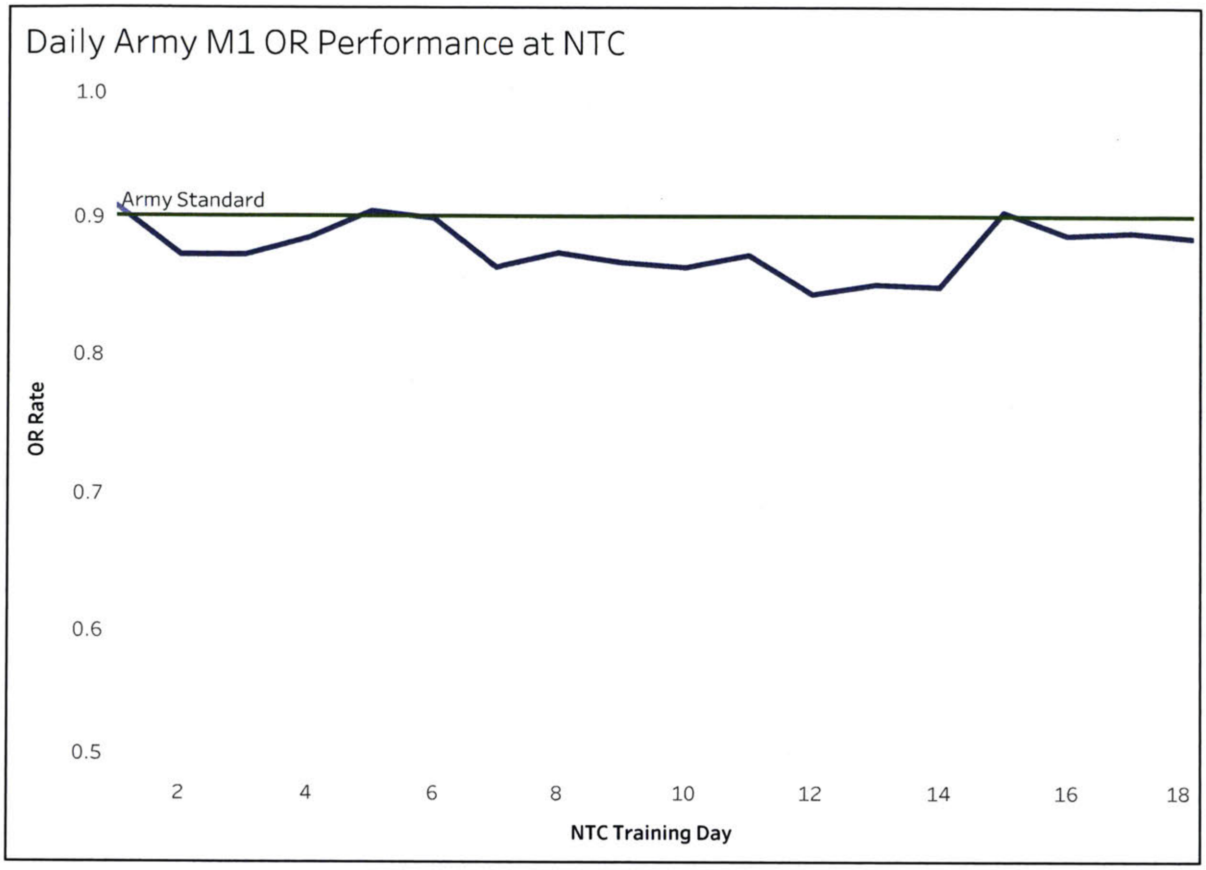

Figure 11: Army Average NTC Daily OR Rate

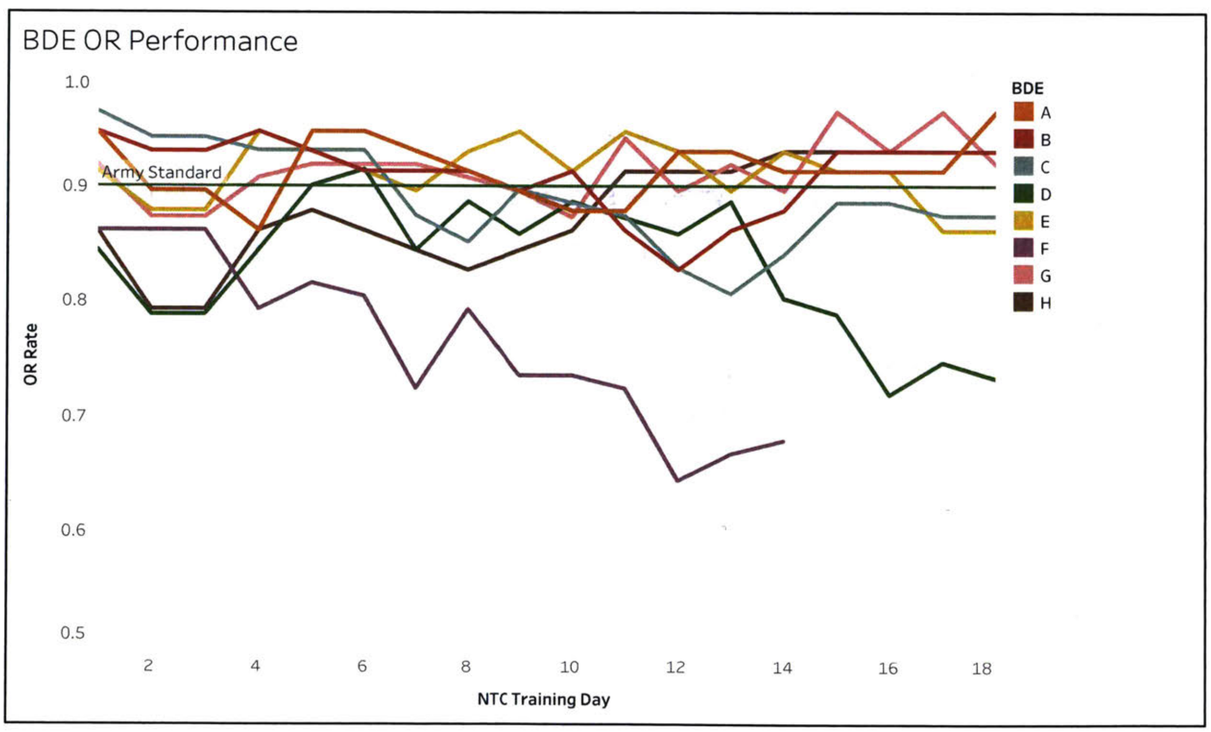

Figure 12: Brigade Daily NTC OR Performance

A few trends can be gathered from this information. On only 3 days at NTC did the overall average even reach 90%, thus supporting the hypothesis of a sub-standard OR rate. Second, there are certain days where OR rates decrease for almost every brigade. Overlaying this data with the NTC training schedule, the trends make sense. First, the units know their OR rate only on Day 0 for tanks that were broken when loaded onto railcars at their home-station. After arrival at NTC, crews inspect their tanks on the first day and often identify additional faults. This drop is not a surprise, tanks routinely break when not in use, whether on a railcar, in a home station motor-pool, or otherwise. Thus, the 3% drop in Army-wide OR rates on the first day is not unexpected. Throughout the rest of RSOI (Training days 1-4), a stabilization and then increase in OR rate occurs. Each unit focuses on getting vehicles ready for the upcoming training; while the parts warehouse is in close proximity, meaning parts (when available) arrive quickly.

This continues until Training Day 5, when the unit moves to the training area, and the first battle period occurs. This is the first-time units exercise their vehicles this intensely, so long, over rough terrain, and in a combat setting. This causes a drop in OR rate. These post battle-period drops are also seen on day 10 and day 14, typical battle period days (although a unit's schedule can have some variation). Averaging the daily OR rate for the Army sample overall, gives a 87.4% OR rate at NTC. With the average overall OR rate below the 90% standard, and the majority of daily OR rates below standard as well, hypothesis testing can be used to statistically prove the sub-standard OR rate.

As discussed in Chapter 4, the hypothesis testing uses a z-statistic to decide whether to accept or reject the null hypothesis. This initial test answers the question: "Is the M1 OR rate at NTC below the 90% Army standard."

Null Hypothesis: H_0= M1 OR rate $\geq$ the 90% Army OR rate standard

Alternate hypothesis: H_a= M1 OR rate < the 90% standard

Sample Mean = .874

Null Hypothesis Mean = .90

Standard Deviation = .22

Sample Size = 565

α = .01 (significance level)

Rejection Region: < -2.58

This computes to a z-statistic of:

$$\frac{.874-.9}{\frac{.107}{\sqrt{565}}} = -2.81$$

Since the test statistic (-2.81) is lower than the rejection region (-2.58), the data statistically supports rejecting the null hypothesis, and thus supports the statement that the OR rates for M1s are below the Army standard at NTC.

Next, the OR rates for the 9 months before each unit's rotation at NTC was examined to see if there is a statistical difference between performance before and during NTC. Initially, the hypothesis is these OR rates will be the same. For the brigades in the study, Army systems provided the brigade monthly OR rate. This information compiled to compute an average of 87.2% OR rate.

Null Hypothesis: $H_0 = \mu_{\text{NTC}} - \mu_{\text{TRAIN UP}} = 0$

Alternate hypothesis: $H_a = {}_{\text{NTC}} - \mu_{\text{TRAIN UP}} \neq 0$

NTC Sample Mean = .874

Train-up Sample Mean = .872

$\Delta_0 = 0$

NTC Standard Deviation = .107

Train-up Standard Deviation = .31

NTC Sample Size = 565.

Train-up Sample Size = 42

$\alpha = .01$

Rejection Region: < -2.58 or > 2.58

This computes a z-statistic of:

$$\frac{.874-.872-0}{\sqrt{\frac{.107}{565}-\frac{.31}{42}}} = 1.25$$

Since 1.25 is not in the rejection region, the statistics support not rejecting the null hypothesis, and thus the analysis shows that units have approximately the same OR rates throughout their operations both at home and NTC.

The third hypothesis tested compares the performances of the M1 population against the performance of the M2 population at NTC. Figure 13 displays the relative performances of M1s and M2s during each day of NTC. This graph clearly shows the superior M2 performance for the majority of the NTC rotations.

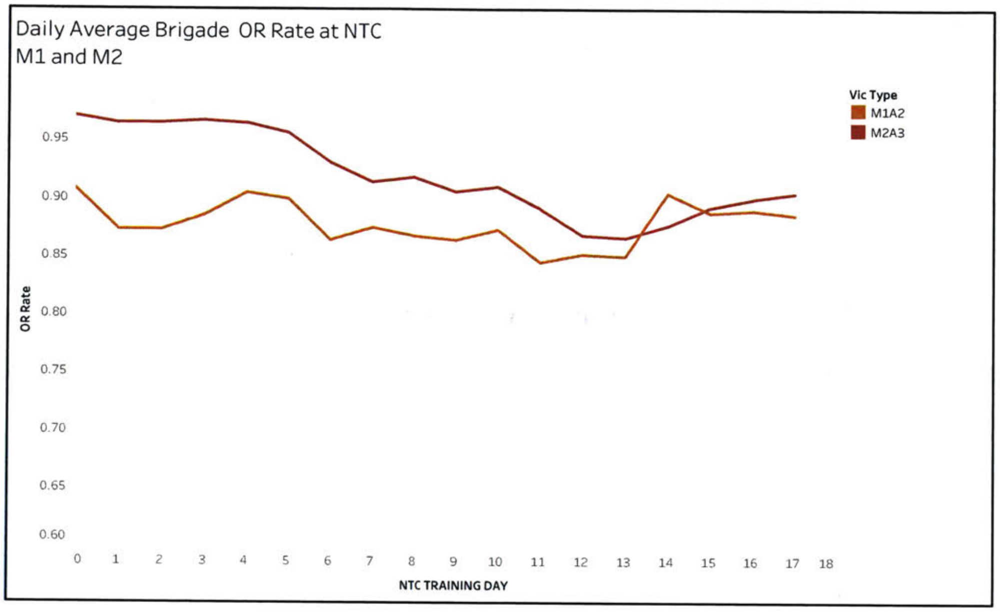

Figure 13: M1 vs M2 Daily OR Rate Comparison

When computed, the M2 sample average OR rate for NTC rotations of 92.0% is superior to the M1's sample mean of 87.4%. However, to ensure this is statistically verifiable, another two-sample test is conducted.

Null Hypothesis: H_0: $\mu_{M1} - \mu_{M2} \geq 0$

Alternate hypothesis: $H_a = \mu_{M1} - \mu_{M2} < 0$

M1 Sample Mean = .874

M2 Sample Mean = .920

$\Delta_0 = 0$

M1 Standard Deviation = .107

M2 Standard Deviation = .073

M1 Sample Size = 565.

M2 Sample Size = 476

$\alpha = .01$

Rejection Region: < -2.58

$$\frac{.874-.920-0}{\sqrt{\frac{.107}{565}-\frac{.073}{476}}} = -3.77$$

As -3.77 is below the rejection threshold of -2.58, the data statistically supports rejecting the null hypothesis.

Therefore, from the data analyzed in this study, the following hypotheses are statistically supported:

1. M1 OR rates at NTC are below the 90% Army OR standard
2. M1 OR rates at NTC are not statistically different from OR rates during train-up at home station
3. M1 OR rates are lower than M2 OR rates at NTC.

5.3. Research Question 2: Does Mileage OPTEMPO Impact OR Rate at NTC?

The second research question to be answered is whether Operating Tempo (OPTEMPO) effects the performance of M1s at NTC. In the Army, OPTEMPO is defined as the rate of military actions or missions conducted by a unit. (JP 1-02 Department of Defense Dictionary of Military and Associated Terms, 2016) This metric is measured in a variety of ways. It can consist of training events, miles driven, hours used, extra training or duty requirements, or deployment needs. In almost all interviews conducted with rotational brigade personnel, OPTEMPO was identified as a major reason for the sub-standard OR performances. The two major OPTEMPO issues for rotational brigades were the number of (or lack thereof) days to conduct maintenance or recovery operations prior to NTC and the total amount of use conducted of the tanks themselves.

This study was unable to collect enough training schedules with the required fidelity from rotational units to create statistically significant data about the number of days training versus recovery. This is a result of units not keeping training schedule records more than 12-18 months after training is complete. Therefore, the one data source that was collectable, miles driven per tank/unit, is the OPTEMPO measure which can be measured and tested. Note, one BDE, C, had to have their information excluded due to a lack of consistent reporting into the Army's system.

5.3.1 Basic OPTEMPO Measurements

Once collated and statistically evaluated, the data revealed insights which were not surprising. Below are 3 charts showing the results of those basic measurement. Figure 14 is the mileage results for all M1s and M2s in the study. Figure 15 compares the total of each individual M1 and M2 company's mileage. Figures 16 and 17 are the box and whisker plots of the training and NTC mileage (NTC mileage is month 0) for both M1s and M2s.

	M1		M2	
Month Prior to NTC	AVERAGE MILES	Standard Deviation	AVERAGE MILES	Standard Deviation
-9	11.25	63.76	16.85	63.83
-8	16.83	64.93	37.19	108.38
-7	21.73	79.95	28.91	95.34
-6	25.51	56.45	21.7	68.69
-5	25.17	48.48	35.51	106.04
-4	50.24	95.64	48.44	129.93
-3	49.05	116.02	126.15	178.54
-2	42.18	93.94	83.98	133.65
-1	28.00	69.25	52.63	126.9
NTC	104.11	126.89	217.17	162.80
Total Odometer	2724.72	9986.05	2934.87	6135.43

Figure 14: M1 and M2 Mileage Results

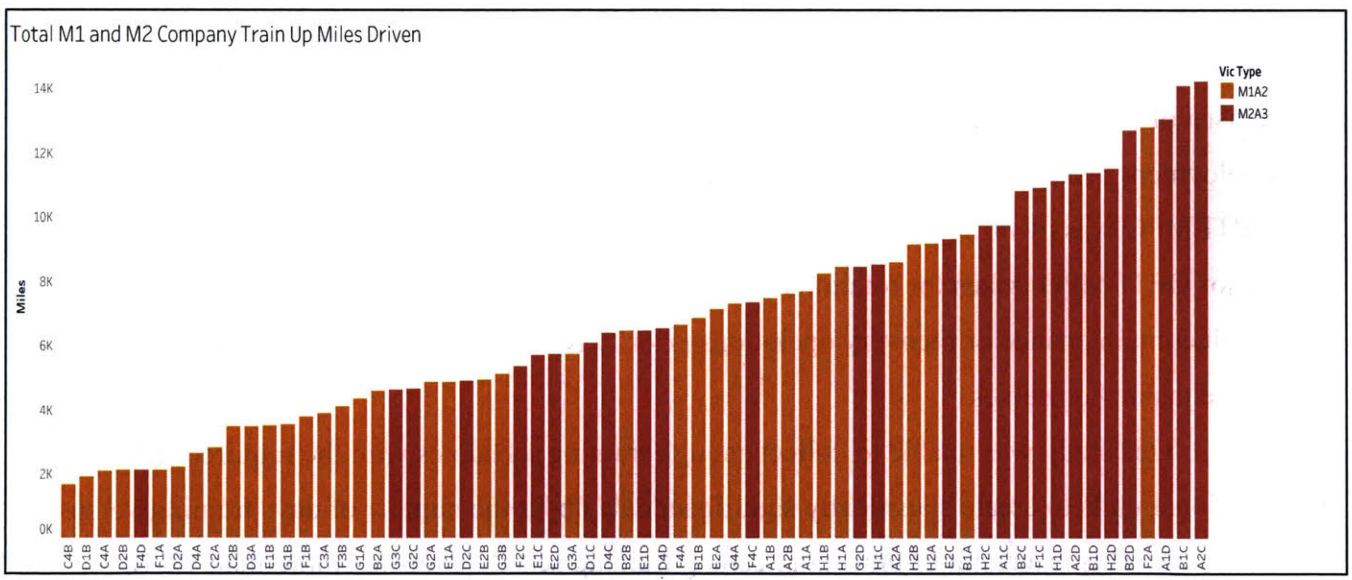

Figure 15: M1 and M2 Company Total Train-up Mileage

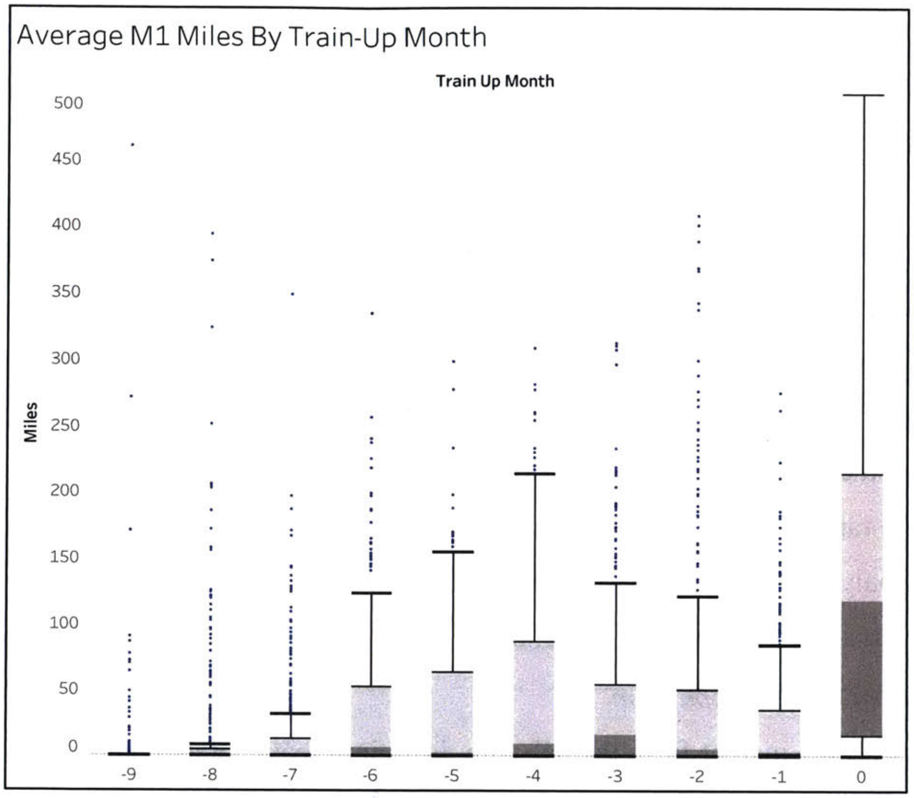

Figure 16: Average M1 Train-up Monthly Mileage

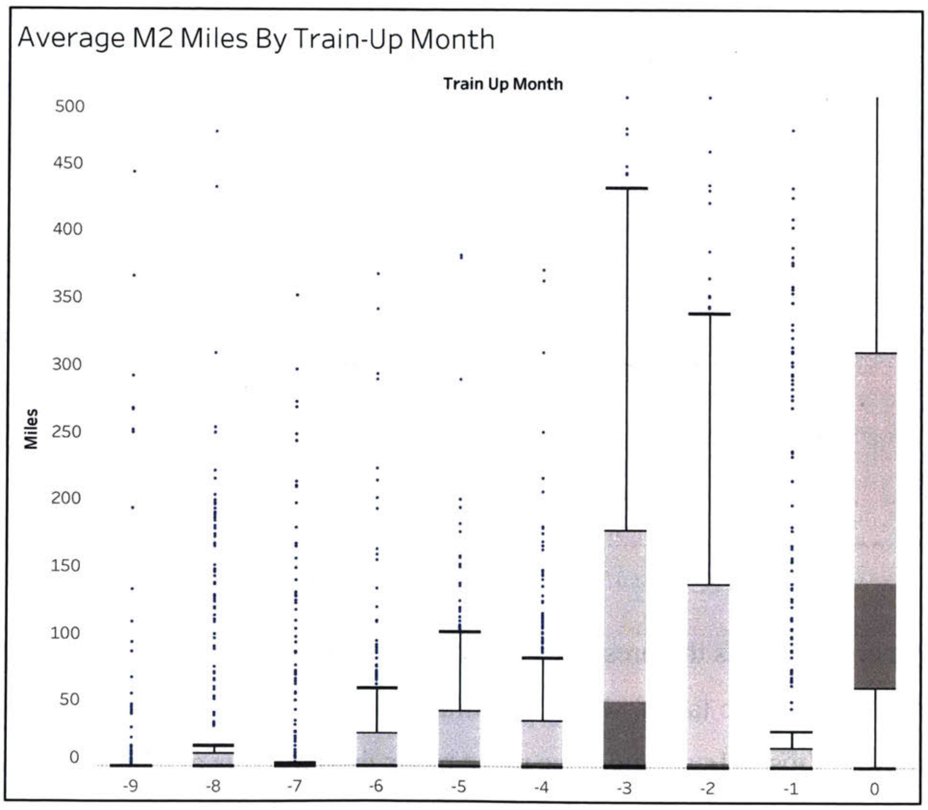

Figure 17: Average M2 Train-up Monthly Mileage

Immediately obvious is the gradually increasing mean monthly mileage from M-9 to M-3, before decreasing slightly going into M-2 and -1. This follows closely with units plans to accomplish pre-requisite training prior to NTC. During the early periods, units conduct preparatory training such as individual rifle ranges and simulator training, which do not require vehicles. As months pass, more complex training is executed, requiring increasingly larger formations and vehicle usage. Normally, this peaks with final BDE or BN training exercises in month M-3/2. Then maintenance recovery is completed before the non-mileage intensive railhead operations are done in M-1. At NTC itself, units see an expected spike in mileage because NTC is the most intense training done in a unit's year. Finally, the company comparison graph shows the range of a company's total miles is between 1800 and 12000 miles for a train-up. The same analysis for the M2 is similar to the M1, a consistent increase of miles is seen from M-9 to M-3, with a decrease in M-2 and 1, before a large spike during the NTC rotation.

5.3.1.1 Vehicle Mileage Comparison

One noticeable insight from the M2 data, is their mileage totals seem higher than the M1 totals. When I compare the mileage within each brigade, Figure 18, this difference is even more striking. In 3 of the 7 brigades, all M2 companies had more miles than all M1 companies, while in 6 of 7, the M2s had the majority of the top half of mileage totals within each brigade.

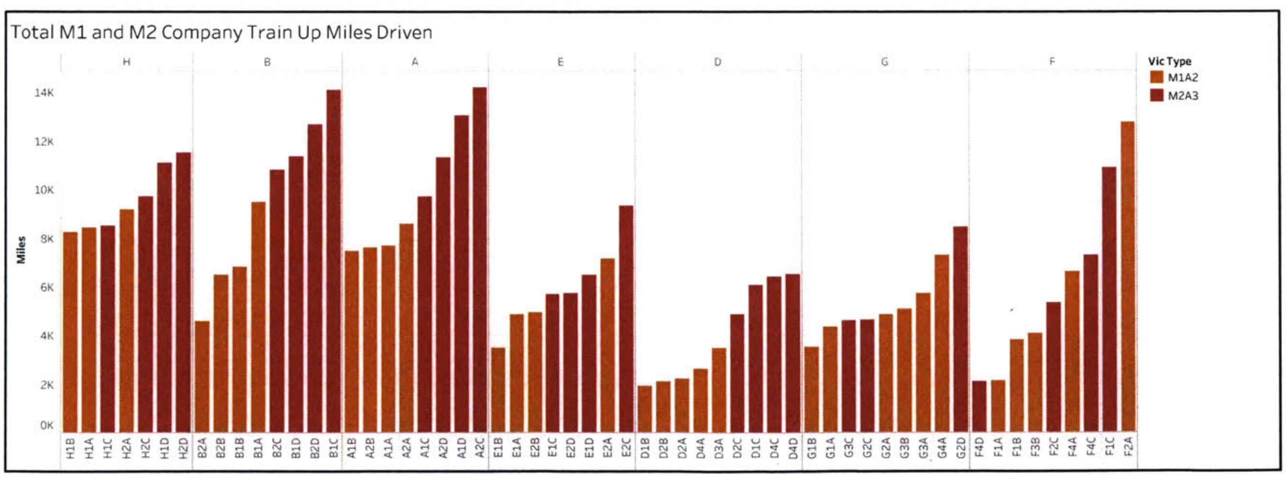

Figure 18: Total M1 and M2 Train-up Miles Organized by Brigade

This is initially perplexing, as the presumed reality would be M1 companies do almost all of their training on their organic tanks, while M2 infantry companies do a significant amount of dismounted training; thus M1s should have more miles driven. This assumes M2 units have been allocated the exact same amount of training time and resources as M1 units. However, depending on the unit, this may not be the case. Infantry units may drive in their M2s to dismounted training events, may fire gunnery exercises on ranges further away than the M1 ranges, or due to the nature of the training cycle have been allocated more training events. Since the training schedules for these units are mostly missing, there is no concrete way to test or observe these factors. However, the data shows M2s drive more miles, but have a higher OR rate than the M1 units.

5.3.2. M1 NTC Overall OR Rate versus Train-up Mileage

If the anecdotal information received from interviews with the NTC rotational units is correct, there should be a direct negative correlation between the OR rates at NTC (the dependent variable) and the mileage (the independent variable) each unit has driven. As mileage goes up, OR rate should go down. To examine this, I plot each individual tank's mileage against its OR rate at NTC. This plot is seen in Figure 19. Inserting a linear trend line to see the effects of mileage shows there was a slight positive correlation between the miles driven and OR Rate. Thus, as train-up miles increased, OR rate slightly increased as well. This is obviously surprising given the anecdotal evidence from rotational unit personnel.

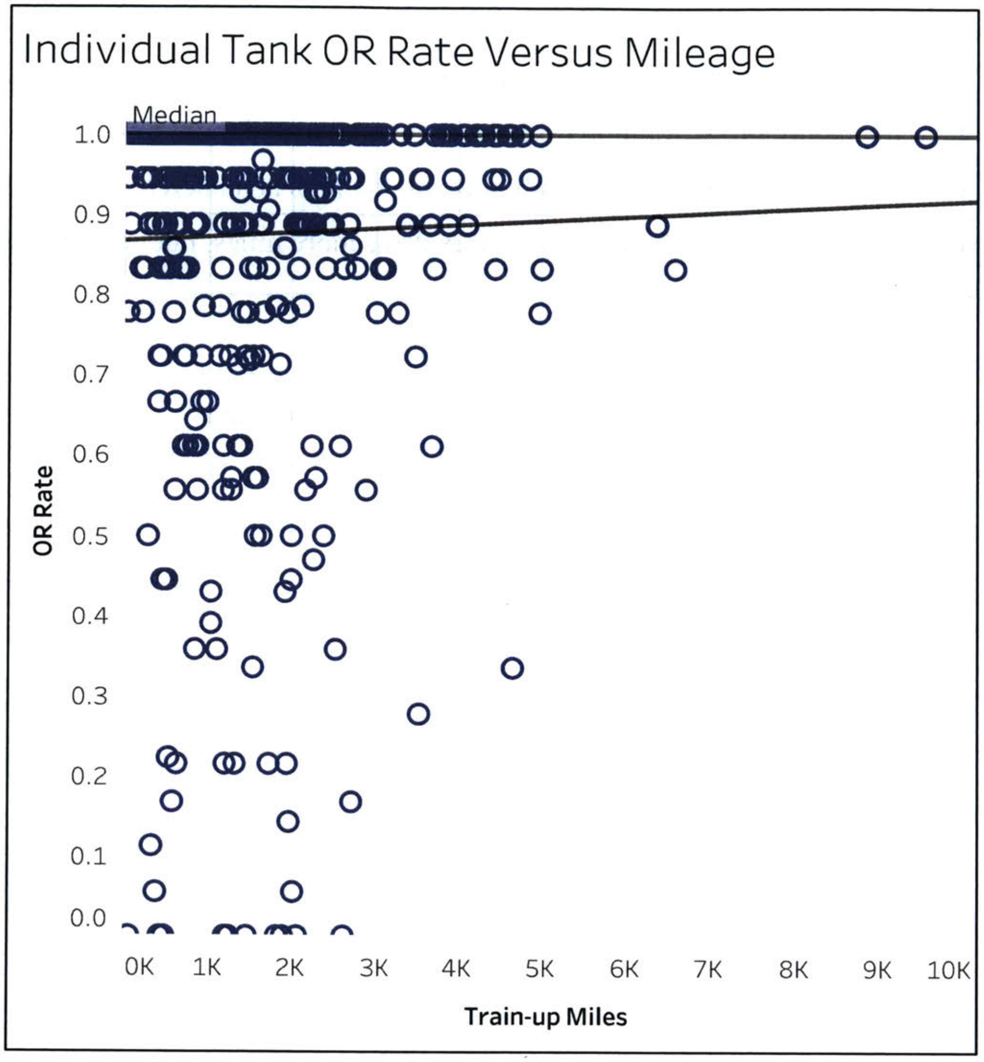

Figure 19: Individual M1 NTC OR Rate versus Train-up Miles

The regression of these variables for correlation reveals an r^2 value of .0029, showing there is almost no correlation between these two variables. When I completed this for the M2, similar results were seen, with an r^2 of .012.

If individual vehicles do not have a correlation, combining the vehicles into their parent units (company in this case) may relate. The resulting plot of each unit and it's OR rate is found in Figure 20.

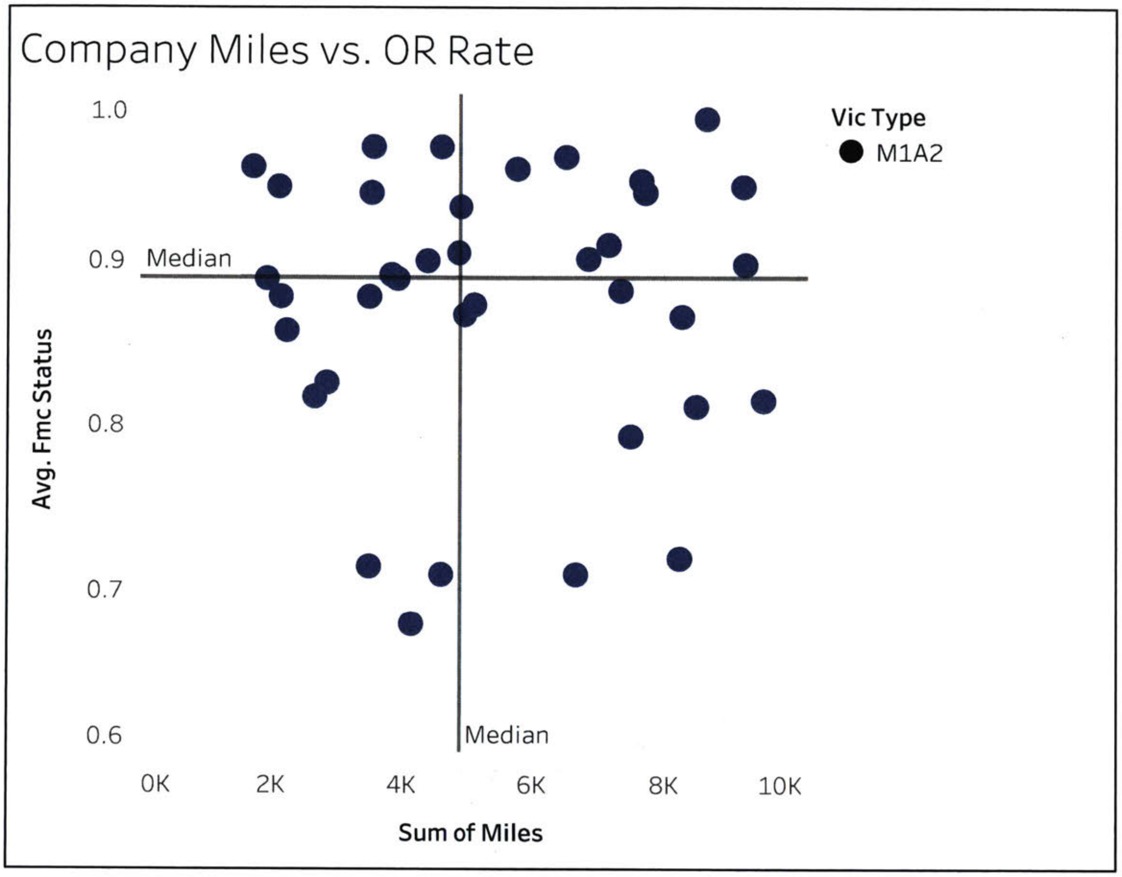

Figure 20: M1 Company OR Rate vs Train-up Mileage

Again, the data and trendline shows very little causation in the model from mileage driven. **The r^2 for this equation was .0002, again showing mileage has little to do with OR performance.**

However, when the data is separated by year, it becomes immediately obvious that the year of a rotation has a direct effect on the performances of units at NTC.

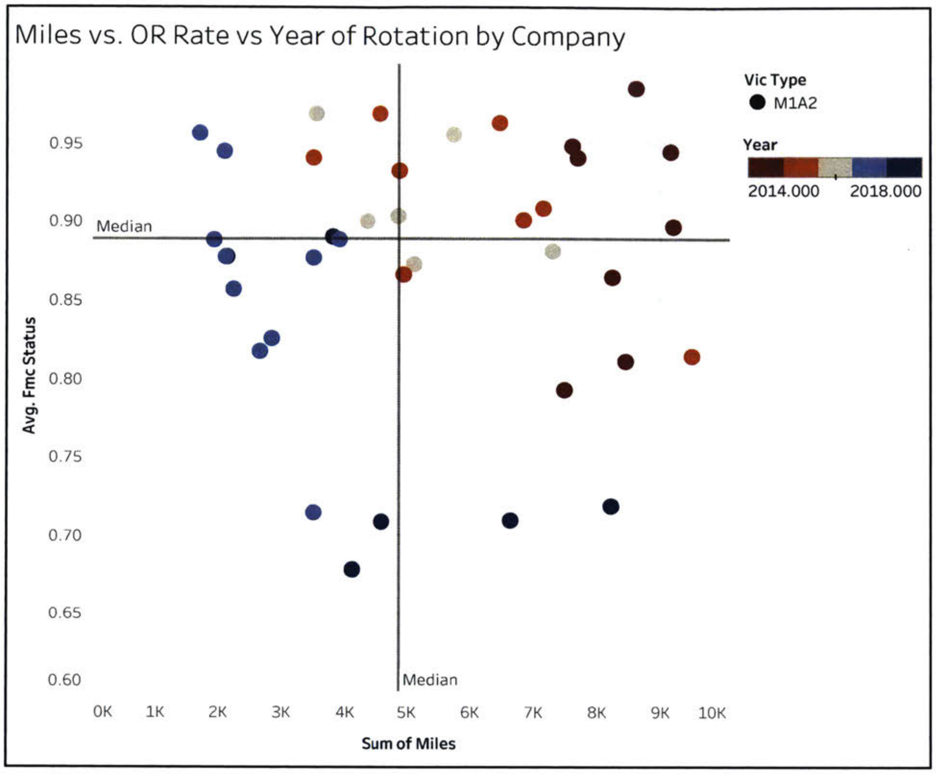

Figure 21: M1 Company OR Rate vs Train-up Mileage vs Rotation Year

Units conducting NTC earlier in the study (2014-2016) had a much better OR rate than units training later. For the most part, older rotations drove more miles and had better OR rates than more recent ones. Numerically, 78% of the older rotations companies were above the OR rate median for a company, while 89% of those companies were above the median for miles driven. Additionally, when the "best" (high miles and high OR) and the "worst" (low OR and low mileage) quadrants are examined, only older rotations were in the best quadrant, while only recent rotations in the worst. Thus, for some reason, older rotations performed better overall.

The M2 population reveals a similar result. As mentioned before the r^2 for individual M2s was .012. When combined into companies, this r^2 improved slightly to .22, however, that is still too low to utilize as the causational factor for the OR rates. Yet despite this, when the year of rotation is included, again the better performance of the older rotations emerges.

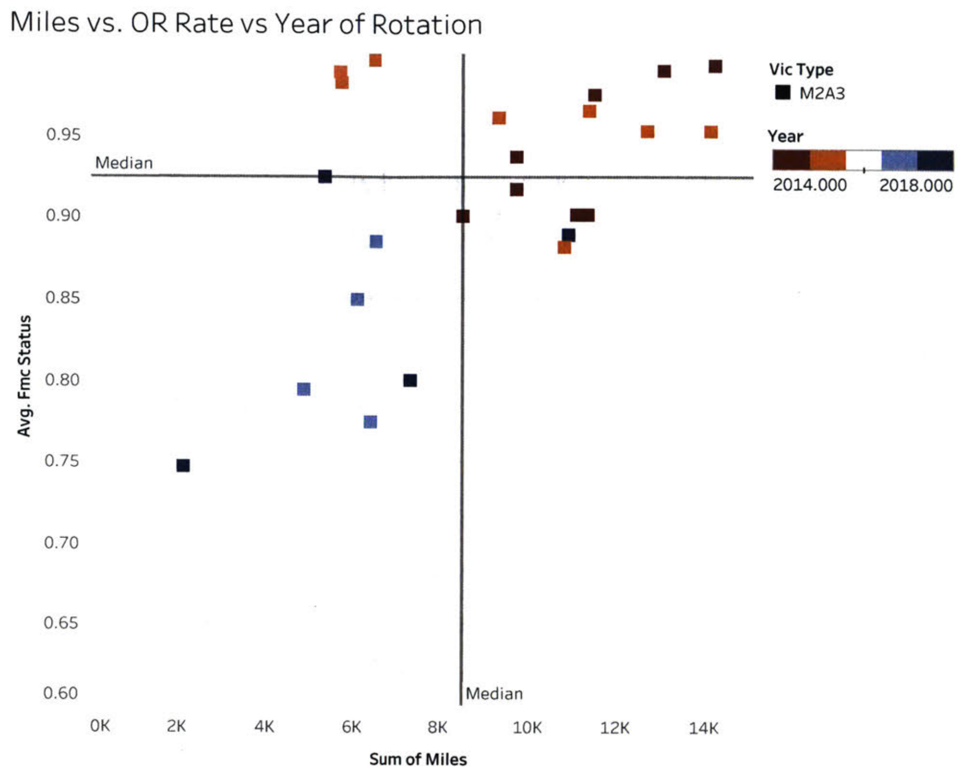

Figure 22: M2 Company OR Rate vs Train-up Mileage vs Rotation Year

Given these results, two questions emerge. First, why are older units driving on average 273 more miles per tank during train up? Second, why does more wear and tear on the tanks not result in more tank break downs?

5.3.3. Additional OR Rate to Mileage Analysis

Although the overall OR rates did not correlate with train-up miles, I also examined a few specific points in a unit's rotation to see if mileage may have an effect on the OR rate at certain points. I examined the first and fifth days of a unit's NTC rotation. By taking a snapshot of those days, I hoped to find that although OR rates throughout NTC may not be affected by train-up mileage, those miles did affect the OR rates on arrival day units or the final day of RSOI. **However, these also had very little correlation between them, producing a .008 and .02 r^2 value respectively. Thus, there is no correlation between those specific days' OR rates and train up miles.**

Next, I analyzed to see if miles driven at NTC itself could contribute to the lowered OR rates. Train-up miles did not affect OR rates, but miles actually driven at NTC may. However, like the previous regressions, this regression also computed a low r^2 of .05. Again, this number is too low to attribute any correlation.

Finally, I compared the total number of miles driven by each tank in its lifetime to its OR rate. Note: for most vehicles, the odometer is set to 0 when it rolls out of the factory. However, when M1s and M2s were upgraded from their previous versions to M1A2s or M2A3s, they received entirely new engines and internal systems, and therefore their odometers were reset to 0 when upgrades were completed. This explains why the odometer readings for these tanks is low when considering each vehicle's hull age. However, this measurement also cannot explain the substandard OR rates, as the r^2 is also .05.

To compare these M1 values to the M2 population, I completed the regression analysis for each test for the M2s. Results were very similar to the M1 results. Day 1 and Day 5 values came to .008 and .12 respectively, while overall odometer r^2 value came to .22.

After reviewing all of the data, there is significant evidence showing the OPTEMPO requirements placed on M1s and M2s in the course of their train-up to NTC, at NTC, and in the course of each vehicle's lifetime does not correlate to the OR performance metric at NTC. As it stands today, increasing or reducing the mileage driven by each vehicle does not seem to have a demonstrable effect on the OR rates at NTC, and thus will not solve the sub-standard OR rate problem.

5.4. Research Question 3: Does part stockage breadth on the NTC ASL effect OR Rate?

The second major explanation brigade internal personnel posited for the causes of sub-standard OR rates was the wait time for replacement parts. If a part is not on the ASL or in shop stock, there is often a multi-day wait for delivery from an outside warehouse. Therefore, I examined the current NTC ASL, compared it to the parts failures in this study's rotations, and make a recommendation and analysis as to possible changes in parts included in the NTC ASL.

The current NTC ASL has over 9000 parts that cover the requirements of all three brigade types the Army currently fields. As NTC is the premier training event for every Army unit, its ASL receives the highest priority for parts, short of those required for overseas units and combat deployments. However, even the importance of an NTC rotation is subordinate to cost savings measures caused by budget constraints. Therefore, the ASL does not contain all of the possible parts an M1 may need during a rotation.

The first analysis step is to understand the performance of the ASL as compared to the requirements collected from the 8 rotations in this study. During the course of the study, the Army had 9822 total tank training days at NTC. In that time, 506 faults caused 1238 NMC tank days. This number counts multiple faults on the same tank at the same time as one NMC tank day. When multiple faults on the same tank are separated into their own tank days NMC, the number rises to 1664 days NMC. For this analysis, only M1 parts are analyzed, as some parts (such as a radio mount) can be installed on multiple vehicles, and thus could skew the stockage analysis. Using M1 specific parts, the total faults decrease to 425, 1547 NMC tank days, and 179 different NIINs.

When the ASL is compared against this fault list, the first step is to establish which parts were or were not on the ASL. **Fifty of the 179 (28%) of the failed NIINs were on the ASL. For those parts, the average number of days NMC is 4.2. For the 129 NIINs not on the ASL, the average number of days NMC is 5.7.** Additionally, parts on the ASL were 56% of the faults at NTC, but only 41% of the overall days NMC. A complete table is below:

	ON ASL	NOT ON ASL	TOTAL
NIINS	50	129	179
%	28%	72%	
FAULTS	239	186	425
%	56%	44%	
DAYS NMC	638	909	1547
%	41%	59%	

Figure 23: ASL vs Non-ASL Fault Data

Obviously the ASL has identified the commonly broken parts, keeping them on hand, and thus keeping the days NMC lower than otherwise would have occurred. Had they not, the number of NMC days would have been higher (presumably to 56% of the days NMC), and thus dropped the OR rate. Additionally, the ASL has done an excellent job analyzing and identifying Maintenance Significant Parts to include on the ASL. There are 312 MSPs NIINs for the M1 Abrams, of which 81 are found on the NTC ASL. Of the 179 NIINs that failed during this study, 41 of them were MSPs and all 41 were on the ASL. This shows the analysis of the ASL has effectively raised the overall OR rate at NTC.

Even with this success, examination of the effects of adding some of the more common faults not stocked to the ASL, and how they could affect OR rate, revealed possible OR gains. The issue is determining which parts should be placed on the ASL. To analyze this, 3 different courses of action each with a different part requirement, budget cost, and OR Rate were analyzed.

The three courses of action differ by the number of times each part failed during this study. These consisted of any fault which occurred more than twice, three times, or four or more times. This provided the following information:

Total # Faults	Total NIINs	Total Faults	Total Days NMC
2	28	85	272
3	11	50	125
4	6	36	83

Figure 24: COA Fault Breakdown

As seen above, up to 272 NMC-tank-days are lost to repetitive faults caused by parts not on the ASL. Using the cost of an NMC tank day of $5729, the dollar values of the lost tank days are:

Total # Faults	Total NIINs	Total Faults	Total Days NMC	Cost of Lost Tank Days
2	28	85	272	$ 1,558,288.00
3	11	50	125	$ 716,125.00
4	6	36	83	$ 475,507.00

Figure 25: Cost of Lost Tank Days

Obviously, a significant amount of opportunity cost is lost on tank crews waiting on parts to arrive.

However, it can be confidently assumed by adding these parts to the ASL, there will be an increased OR rate, and a resulting cost savings, when looking beyond just the cost of the part. As analyzed above, the difference in days NMC is 1.5 days less per fault for faults on the ASL vs those not (5.7 vs 4.2). This makes sense overall, as ASL parts are more likely at Ft. Irwin and thus have less delivery time than parts which must be ordered from distant depots or SSAs. Additionally, though the data shows a 27% difference in NMC time, the actual difference after removing systematic limitations is much more striking. For both ASL and non-ASL parts, there are ordering, transportation, and installation times which cannot be decreased due to the maintenance system structure. As explained in Chapter 3.4, this structural time requirement is on average 24 hours. Therefore, assuming a 24-hour system structural part diagnosis, delivery, and installation time, ASL parts wait on parts for 3.2 days, while non-ASL parts wait 4.7 days, a difference of 32%.

Therefore, using the average of 1.5 days saved if a part is on the ASL, the assumed number of days saved can be calculated for all three courses of action, seen below:

Total # Faults	Total NIINs	Total Faults	Total Days NMC	Cost of Lost Tank Days	Days Saved	% OR Rate Recovered
2	28	85	272	$ 1,558,288.00	127.00	1.3%
3	11	50	125	$ 716,125.00	75.00	0.8%
4	6	36	83	$ 475,507.00	54.00	0.5%

Figure 26: Possible OR Rate to be Recovered

The number of days saved can then be used to calculate what the difference in Army OR rate would have been had these parts been on the ASL. Though these amounts are not major changes, the Army is initially trying to raise the OR rate from 87.4% to 90%. These proposed changes would have accomplished 50%, 31%, and 19% of the required OR improvement of 2.6%.

However, if these improvements are too expensive, the benefit to the taxpayer is lost. Therefore, I computed the total cost of adding the additional parts onto the ASL. In doing that I determined whether any of the parts failed at the same time for the same unit. If so, then the ASL should store more than just one NIIN item. Only 2 NIIN parts occurred more than once at the same time and both were in the top 6 most common part faults. Therefore, the part costs to the Army, should they order all new parts to fill this ASL requirement would be:

Total # Faults	Total NIINs	Total Faults	Total Days NMC	Cost of Lost Tank Days	Days Saved	% OR Rate Recovered	Total Cost to Add	Cost Saved
2	28	85	272	$ 1,558,288.00	127.00	1.3%	$ 90,231.46	$ 727,583.00
3	11	50	125	$ 716,125.00	75.00	0.8%	$ 37,006.46	$ 429,675.00
4	6	36	83	$ 475,507.00	54.00	0.5%	$ 18,057.44	$ 309,366.00

Figure 27: Cost Savings

When the parts analysis is complete, it is obvious OR rates can be improved through the addition of parts to the ASL. Though the ASL and its NIIN list has done an excellent job of decreasing NMC time by targeted part breadth, there is still room for improvement, which could improve the overall Army NTC OR rate. With the results of the sample analyzed, making changes to the recommended NIIN stockage would have improved every brigade's OR rate. Every brigade had at least a few of these selected NIINs fail. Therefore, it is safe to assume, although it cannot solve the entire problem, that expansion of the ASL would have positive effects on the OR rates at NTC.

5.5. Research Question 4: Do Individual Unit Maintenance Programs Effect OR Rate?

The third reason for the sub-standard OR rate was mentioned by members of organizations/commands outside of rotational units. From their experience, some units completed NTC above the 90% standard because of their robust maintenance programs. Others failed because their programs were not strong or capable enough to handle the stress of NTC requirements. Therefore, I looked for ways to analyze each unit's maintenance program to observe indicators of the more capable programs.

For this study, it is almost impossible to analyze the relative quality of each unit's maintenance program. To be done properly, researchers would have had to be present for each unit's train-up and rotation to judge and compare the units' SOPs, maintenance systems, recovery timelines, reporting, and decision making. To make up for the lack of this level of data collection would be to study accurate company, battalion, and brigade level records for training, maintenance, and performance AARs, used in conjunction with interviews of unit personnel for reference. However, multiple issues prevent this program review from occurring for this study. First, most units have experienced a 100% personnel turnover since their rotation, many having left the Army itself. It would be very difficult to track down dozens of soldiers per unit to get their individual unit's explanation and frame of reference. Additionally, only two of the eight Brigades were able to provide training schedules that showed the train-up period. Without either of these resources, it is impossible to judge a unit's maintenance program quality. However, for the purposes of this study, I created a system of comparison of each unit against the others.

This desired data, which cannot be collected at present, are measures which are described as the actions on the "front end" of a maintenance program. These could be judged, weighed, and used to correlate to maintenance performance later at NTC. For instance, I could use measures like percentage of maintenance days to training days in train up to compare the unit's emphasis on maintenance; I could examine the unit's ability to report NMC vehicles properly to its performance once it arrives at NTC, where maintenance issues are quickly identified by independent OCs. However, as these measures are not available, other solutions must be found. To compare unit maintenance programs against each other, I have taken multiple performance measure results to create a scorecard of performance results. This scorecard uses multiple different data measures which act as indicators of a unit's maintenance program from the "back end." A unit may be unlucky in one area, but if indicators are poor in multiple areas, it strongly supports the unit's maintenance program is sub-standard compared to other units and/or the Army Standard.

The scorecards are made up of four different indicators for an overall maintenance program score. These indicators are:

1. Unit performance in executing controlled substitutions
2. Unit performance in entering mileage data into GCSS-A/SAMS-E systems
3. OR rate change from train-up to NTC
4. NMC Batteries on arrival to NTC

5.5.1. Unit Maintenance Program Indicator Explanation

5.5.1.1. Controlled Substitution

Controlled Substitution, also called Controlled Exchange, is the removal of serviceable parts, components, and assemblies from unserviceable, but economically repairable, equipment and their immediate reuse in restoring a like item of equipment to a mission capable condition. (DA PAM 750-1 Commander's Maintenance Handbook, 2013) This differs from the term cannibalization in that cannibalization occurs to vehicles that will not become FMC again in the future, while controlled substitution plans on returning both vehicles to FMC status. Units use controlled substitution to efficiently harvest combat power in situations where immediate combat power is imperative for mission success. By moving FMC parts from one broken tank to another, commanders minimize maintenance losses to ensure unit success. Although substitution is rarely used at home station, its use during FTXs, Gunnery, and NTC can make the difference between success and failure.

Controlled substitution is governed in accordance with Army Regulation 750-1. Commanders must follow certain rules to approve and order substitutions. For example, the replacement of NMC parts must not damage a vehicle any further, components must be unavailable within the supply system at that time, the part must be on a valid requisition, and others. The main goal of these requirements is to ensure no further damage to vehicles occur, and the proper Army supply system needs are not circumvented or ignored.

However, other than unit internal records or a close search of unit maintenance records, the Army does not track controlled substitutions, at NTC or otherwise. Thus, for this study, I closely examined the maintenance records in AMSAA or the O26 to identify vehicles used for controlled substitution. The first method to do this was the easiest, as some units noted in the comments section of their AMSAA files of completed controlled substitutions. For those without comments, I identified the most likely situations where a controlled substitution occurred. First, if an M1 was NMC, and subsequently gained an additional fault, the additional fault is assumed to be a controlled substitution. It is impossible for a tank to have a blown engine, and then four days later lose a track section, as the tank cannot move. Additionally, for the M1, it is exceedingly rare for a tank to have two parts fail from different tank internal systems on the same day at the same time. Thus, a failure of the fire control computer at the same time as a transmission is very rare. Therefore, anytime a tank went NMC on the same day for multiple parts failures, it was assumed to be a controlled substitution.

Slightly easier than finding completed controlled substitutions is identifying controlled substitutions which units did not make but could or should have in order to maintain combat power and the 90% OR rate. However, it is not as easy as merely identifying any two tanks with faults at the same time. Units have a variety of reasons for not substituting parts, nevertheless, some guidelines are used to remove those reasons. First, a fault must last more than four days; if the part is going to arrive quickly, there is no need to conduct the substitution. Second, the parts must be multiple use parts. Some parts, such as O-rings, can only be used once and after being installed on one tank cannot be removed and placed on another vehicle. Third, the vehicles must be in the same company. For a variety of reasons units will rarely perform controlled substitute across companies. Fourth, the faults must not occur on training day 17 or later, as units are about to leave the training area and prepare to move back to home station. Finally, each NMC tank is limited to only 2 controlled substitutions. This prevents a single tank from never being repaired, as it is always waiting on a part that has been substituted off.

Using these rules, I analyzed unit performance for both the controlled substitutions units did complete, and how many substitutions they missed, which if executed, would have improved their OR rate. These results can be seen in Figure 28, where "NO CS OR RATE" is the OR rate had the unit not conducted any controlled substitutions, "ACTUAL OR RATE" is the unit's actual rotational OR Rate, "MAX CS OR RATE" is the unit's OR rate had they conducted all controlled substitutions identified as possible, and "MAX CS DIFF" is the difference lost between the actual OR Rate, and the maximum OR rate that could have been possible for the unit.

BRIGADE	NO CS OR RATE	ACTUAL OR RATE	MAX CS OR RATE	MAX CS DIFF
A	91.6%	**91.6%**	94.9%	3.4%
A1	86.4%	86.4%	91.6%	5.2%
A2	96.7%	96.7%	98.3%	1.5%
B	91.1%	**91.1%**	94.0%	2.9%
B1	85.6%	85.6%	90.0%	4.4%
B2	96.6%	96.6%	97.9%	1.3%
C	84.7%	**89.1%**	90.0%	0.9%
C1	82.9%	85.3%	88.9%	3.6%
C2	72.8%	85.1%	86.0%	1.0%
C3	88.9%	88.9%	88.9%	0.0%
C4	95.0%	95.0%	95.0%	0.0%
D	75.9%	**83.2%**	86.6%	3.4%
D1	81.0%	88.9%	91.7%	2.8%
D2	86.8%	86.8%	91.0%	4.2%
D3	59.5%	71.4%	74.2%	2.8%
D4	64.7%	81.7%	84.9%	3.2%
E	90.6%	**91.2%**	91.9%	0.7%
E1	93.7%	93.7%	93.7%	0.0%
E2	87.5%	88.7%	90.0%	1.3%
F	75.4%	**76.4%**	78.8%	2.4%
F1	88.4%	88.4%	88.4%	0.0%
F2	69.2%	71.4%	74.6%	3.2%
F3	67.9%	67.9%	70.4%	2.6%
F4	69.0%	71.0%	76.2%	5.2%
G	90.4%	**91.4%**	91.6%	0.3%
G1	92.5%	93.3%	93.3%	0.0%
G2	90.4%	90.4%	90.4%	0.0%
G3	89.5%	91.6%	91.6%	0.0%
G4	88.1%	88.1%	89.7%	1.6%
H	87.2%	**87.9%**	90.8%	2.9%
H1	82.2%	83.7%	86.0%	2.3%
H2	92.1%	92.1%	95.6%	3.4%
ARMY AVERAGE:	85.03%	87.4%	89.82%	
OR DIFFERENCE:	-2.37%		2.42%	

Figure 28: Controlled Substitution Breakdown

The data shows some units did an excellent job at controlled substitutions, while others lagged behind, causing their OR rates to suffer. Overall, the Army added 2.37% to its NTC OR rate through the controlled substitutions executed, while it could have added an additional 2.42% had it executed all identified possible controlled substitutions.

Independent of the scorecard analysis, controlled substitutions are an integral part of a unit's ability to husband combat power ensuring success at NTC and in actual combat. Though controlled substitution is at best a stop-gap system used to temporarily fix maintenance problems, it is a part of the Army maintenance system that has a direct effect on whether a unit is above or below the Army OR standard. This analysis shows almost all units could improve their controlled substitution policies. Units should be examining those policies to ensure they are aggressively identifying faults in order to harvest combat power.

As the difference between the maximum and actual OR rate show, different units have different maintenance program competencies, resulting in differing amounts of tank FMC days saved. Some of these results could be a function of luck, sometimes there are no faults that allow for controlled substitutions. Therefore, units that did not conduct actual controlled substitutions cannot be punished for their lack of execution. However, comparison can be made from the amount of controlled substitutions that were not made. One source of error is a "bad" unit randomly not having the situation in which a controlled substitution should be done, and thus getting a higher grade than they otherwise should have. This is a possibility, but the other scorecard measurements should minimize this random error in the overall score.

For the regression, each unit's percent of OR lost due to controlled substitutions not being completed is used as a data point for each individual battalion. This will be combined with the other four measures for analysis.

5.5.1.2. Miles Data Reporting

The second measure on the scorecards is unit reporting of each vehicle's monthly mileage into the GSCC-A system. Sometimes, units do not properly report this usage, or enter obviously incorrect mileage (through either negligence or laziness). Normally, this information submission is supervised by leaders in the unit's Forward Support Company. Therefore, sub-standard mileage reporting indicates a sub-standard maintenance program. Good maintenance programs understand the importance of mileage reporting, and thus closely supervise or establish systems to ensure accurate and timely reporting.

Though it seems this missing data may be an issue, the lack of some months of data for individual units did not prevent mileage data from being used in the OPTEMPO analysis section. The data reported to GCSS-A and collected by OSMIS provides both the monthly data, and the final odometer reading for each month. By subtracting the last two odometer readings from each other, the total mileage for the two-month span can be calculated.

For the regression, the number of months not reported correctly is summed, and the sum is a data point score for each battalion.

5.5.1.3. Train-up versus NTC OR Rate Change

The third scorecard category examines the difference in performance for units between their reported OR rates during train-up, and their OR rate at NTC. For some units, their OR performance at home station and at NTC differ greatly. For some, their OR rates improve with NTC's higher priority ASL stockage. Others however, have OR rates that drop precipitously at NTC. This could be for a variety of reasons, but a common observation from both NTC OCs, PM Abrams Observers, and NTC support personnel is units arrive at NTC with unidentified NMC faults, a lack of understanding of what a deadlining fault is, or systematic failures in their reporting standards. No matter the reason, a unit whose OR rate drops precipitously, especially during the first few days of NTC, demonstrates a sub-standard train-up maintenance program.

To establish a score for the difference between train-up and NTC, the NTC OR rate was divided by train-up OR rate. Thus, any score above 1 means the unit was better at NTC than during train-up, or vice versa. This was completed for both overall NTC OR rates and Day 4 OR rates.

5.5.1.4. NTC Arrival Battery Faults

The final scorecard indicator examines the number of faulty batteries units arrive with at NTC. When an M1 will not be turned on for a significant amount of time, its batteries should be disconnected from the tank to prevent the batteries from being drained. If they are not, the batteries may be ruined, and unable to build a charge, and therefore have to be replaced. One indicator of a unit without an engaged and disciplined maintenance program is if its tanks arrive at NTC requiring multiple battery replacements. The score for this measure in the regression is the number of batteries NMC on Training Day 1.

5.5.2. Indicator Scorecard Analysis

The first regression completed included all of the 4 measures outlined above. After computation, the r^2 for this model is .580, suggesting correlation between these factors. However, the p-values for the NMC battery score were very high (.564), signifying there is little effect from this measure to the model overall. Therefore, I removed the NMC Battery score from the analysis to examine if this changed the regression values. This new 3-factor model returned almost the same r^2 value of .570 with the following equation values:

$$NTC\ OR\ Rate = .698 - 1.70(Controlled\ Substitution\ Difference) - .017(Data\ Quality) + .268\left(\frac{NTC\ OR\ Rate}{Train\ up\ OR\ Rate}\right)$$

With both regressions, the Controlled Substitution Difference and the Data Quality returned p-values under .08; while going from regression 1 to 2 caused the OR difference p-value to decrease from .23 to .15. These aspects all point to individual unit maintenance program quality as a major driver in the OR rate performance of a unit at NTC. Therefore, though there are some Army-wide systematic issues that could be used to raise OR Rates (such as a larger ASL breadth), the r^2 values from this analysis show individual units also effect OR rates. Additionally, the largest takeaway from the scorecards is the huge effect that controlled substitutions have on OR rates, and how much it correlates to OR rates finishing above or below the set Army standard.

6. Conclusions, Recommendations, and Future Research

"If the tanks succeed, then victory follows"

-General Heinz Guderein, Father of Modern Combined Arms Warfare

6.1. Conclusions

Since their first battlefield success at the Battle of Cambrai in 1917, the tank has been the most decisive weapon in ground combat. The ability to rapidly bring mobile, protected, and lethal firepower to the battlefield gives US Army commanders an unparalleled advantage over adversaries in every form of combat. Successful armored formations allow commanders to gain, retain, and exploit the initiative on the battlefield, which is the foundation of freedom of maneuver. However, as the Russian Army learned during their invasion of South Ossetia in 2008, mechanical issues can rapidly deplete a once powerful armored force, thereby limiting a commander's combat power, freedom of maneuver, and eventually their mission accomplishment (Cornell & Starr, 2009). Thus, it is of the utmost importance the US Army maintain an armored force capable of preventing, identifying, and fixing mechanical issues.

This study has been tasked with identifying issues in M1A2 Abrams OR rates, and if any, possible causes. Once the sub-standard OR rate was identified, three possible drivers of that shortage were identified: unit mileage OPTEMPO, NTC ASL breadth, and individual unit maintenance programs. These three drivers were identified by multiple different members of the Army Maintenance System during early discussions of the problem. In almost all discussions, one driver was singled out as the reason for sub-standard OR rates. However, the principle driver identified by anyone interviewed was almost always outside of their own organization. Rotational units blamed OPTEMPO requirements placed by higher headquarters, as well as a parts shortage at NTC for declining OR rates. AMC and NTC support personnel blamed the rotational units of not properly maintaining their vehicles, and using Army Systems designed to assist unit maintenance programs improperly. However, in reality, no one driver caused all of the overall issue. In fact, sub-standard OR rates were proven to be caused by a variety of problems, both inside and outside the rotational unit.

M1 OR rates over the past 5 years are below the Army standard of 90% with the sample average coming to 87.4% overall. The analysis for this study identified whether a problem existed at all. Data was available for eight of the 19 ABCTs who conducted an NTC rotation over the past 5 years. Additionally, it showed that M2 OR rates have stayed above the standard during the same period. The OR rate data also revealed interesting trends during an NTC rotation. Overall, units saw a significant drop in OR rates in the first two days of the rotation, as tanks arrive off the rail transportation and are inspected for the first time in a month. The average unit then saw an increase over the next three days of RSOI before another large drop caused by the first battle period. Finally, units saw a steady rise in OR rate for the rest of the rotation, excluding the few drops corresponding to additional battle periods (which were quickly overcome). This indicates units are learning at NTC, as they should be, and thus improving their maintenance support, even as they move a progressively further distance from the SSA at NTC. M2 data for the same periods supported these same trends.

Mileage as currently evaluated has no effect on a unit's OR rate. The analysis of the first possible driver for OR rate decrease was the most surprising of all the analysis. I started with a hypothesis of: the more mileage placed on these tanks, the lower the corresponding OR rate. I hypothesized this negative correlation would hold true for miles in a unit's train up, at NTC and for the lifecycle mileage of the tank. This was an intuitive hypothesis, a belief that equipment used more often sustains a higher level of wear and tear, and thus a more frequent occurrence of faults and days NMC. However, analysis of each mileage measure shows almost no correlation with OR rates. For each regression analysis, the r^2 value was significantly below the minimum levels which allow a statistic to make even minimal correlation assumptions.

There could be a variety of reasons for this. The first, and most likely, is the M1A2s are so relatively new (average total odometer reading of 2724 miles). The tanks may be new enough that usage wear and tear has not reached a level to affect the tanks. Thus, if usage faults happen to start occurring around 20,000 miles, most tanks are not close to that, and will not suffer from the mileage driven during this study. There may be a mileage point where OR rates do begin to decrease at a more correlated rate, but the Army has not reached that point yet.

However, there was some correlation between the year a unit went to NTC and its subsequent mileage and performance. When the median line for both OR rate and Mileage is added to the data set separated by year, Figure 21 the superiority of older rotations emerges. Why did older rotations drive on average 273 miles more per tank?

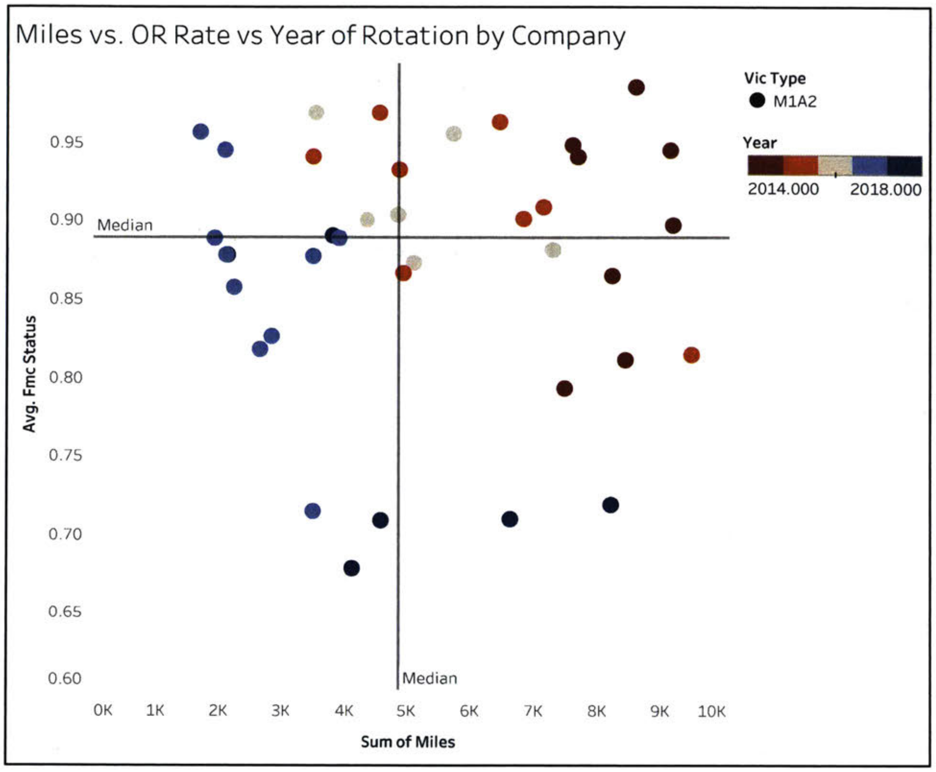

Figure 29: M1 Company OR Rate vs Train-up Mileage vs Rotation Year

To answer this question, I looked at the state of the Army in the years 2013-2014. Before I began to analyze the effect that the year's rotation took, I hypothesized the War on Terror requirements (little armor use in Iraq and Afghanistan) caused a loss of institutional knowledge which caused lower OR rates in 2013-2014. During the height of the wars in 2001-2011, the Army focused on counterinsurgency and other low-intensity conflict training. As a result, few units conducted large heavy armor training. Thus, a generation of tankers could, and did, lose knowledge of the fieldcraft, tricks of the trade, and the experience of major force-on-force training events. In 2013, many junior NCOs, the primary trainers of a unit, had never fired a Tank Gunnery Table VI. This drove the initial hypothesis that older rotations would be relearning those lessons the hard way, and thus drive down their OR rates. However, the data obviously refutes that idea. The increase in mileage could be due to leaders identifying this lack of training, and prioritizing additional field training to counteract the loss of expertise as much as possible. As units rebuilt the junior NCO experience, they may not have felt it necessary to conduct as much field training.

The second aspect which may have changed the number of miles driven is the changing requirements at NTC which occurred during the course of the study. As mentioned in the

Background section, older units were only required to complete pre-requisite live fires up to and including platoon live fire (GT XII). In 2015 units were required to complete a company live fire as well (GT XVIII). GT XVIII is normally a personnel, time, and range heavy requirement, but does not put significant mileage on the tanks themselves. Requiring units to spend 7-10 days completing GT XVIII may prevent units from doing additional maneuver training, which is normally mileage intensive.

A third hypothesis which may have driven increased miles, was the individual posts each unit is stationed. Since units must drive to the training areas and ranges before and after training, bases with training areas close to the unit motor pools may have significantly less miles. However, analysis showed no correlation.

One unknown aspect that may influence these numbers is the use of Heavy Equipment Transport (HET) trucks to move tanks from motor pools to training areas. As a result of the M1's low fuel efficiency, it is sometimes cheaper for a unit to transport tanks on HETs. The M2s have much better gas mileage and there is not a significant amount of savings to HET transport to the training areas. This may explain both the increased mileage during train-up for M2s versus M1s, and the reason lower mileage occurred for M1s later in the study, as budget cuts caused a decrease in training budgets.

When all of these results were posed to members of the Army maintenance system, a few explanations for the lack of correlation were posited. First, from unit maintenance team and tank NCO sources: tanks break while just sitting in the motorpool, but if you continually use them, they breakdown less. This is due to the better lubrication and issue prevention like hose dry rot when used consistently in training, as opposed to tanks sitting for a weeks between engine starts and movement while in the motor pool. Units with more mileage are likely using their tanks on a more consistent basis, doing daily as opposed to weekly maintenance, and thus keeping their tanks in a readier state. Additionally, units conducting more field training may often have more refined, robust, and competent field maintenance systems. Units that understand and perform UMCP operations well are more likely to verify, order, and fix tanks at a faster rate, thus increasing their OR Rate. A way to create a competent unit maintenance system is to exercise those units in the field as much as possible.

When asked this question, AMC personnel concluded another contributing factor is the mileage usage on the robustness of a unit's shop stock, ASLs, and parts ordering process. From their explanation, units that conduct more training may break parts at a higher rate, but, their shop stock and ASLs have more parts meeting the usage per year requirements. For both shop stock and ASL, a part must break and be ordered a certain number of times in a year to be added to the ASL. Once on the list, it must be ordered a certain number of times to stay on the list. Therefore, units which train more have more mature ASLs and shop stocks, which they then can utilize at NTC. Parts on hand in Shop Stock or at the SSA take less time to deliver to the mechanics, thus vehicles are returned to FMC status faster.

These three aspects suggest a positive correlation between miles and OR rate, which is not seen in the regression. Thus, there may be a trade-off in OR rate between mileage, where some faults are prevented by usage, while others are exacerbated by it.

Finally, the analysis may just be indicating the truth: mileage may have no effect on OR rates.

ASL breadth is a driver of the lowered OR rates at NTC based on the difference in NMC times for parts stocked or excluded from the NTC ASL. The second possible driver of OR rates is the parts availability on the ASL in the SSA at NTC. Parts must be on-hand to replace broken equipment; if they are not, the unit must wait, which drives down OR rates. Since current Army systems are unable to analyze NIIN fill statuses at the NTC SSA during the study months, I could only analyze what is on the ASL, what parts broke during these NTC rotations, and conduct analysis based on those factors. The data indicated NMC time difference of 1.5 days between listed parts (4.2 days) and those not (5.7 days). As expected, parts normally stocked on the NTC SSA get to the unit faster than if procured from a neighboring SSA or depot. Analysis did show however, the ASL is currently accomplishing its mission of stocking the most commonly broken parts for the best "bang for the buck." NTC's ASL covered 56% of the faults seen at NTC, but those faults only accounted for 41% of the NMC tank days at NTC. Additionally, 100% of the MSP failures which occurred at NTC were found on the ASL despite only stocking 26% of possible M1 MSPs on the ASL itself. These two measures show how well the ASL team and AMC are providing the right parts at the right place. Even with their excellent performance, improvements can still be made. Adding between 6-28 NIINs could have increased OR rates at NTC between .5-1.3%, a significant amount of the 2.6% shortage currently seen at NTC.

Altering the ASL is not a simple solution to be carried out immediately. There are a significant number of other factors which render the ASL decision-making process more complex.

First, the Army is currently moving toward a standard Brigade ASL which will travel with the unit from home station to NTC, simulating the parts and systems used for combat maintenance operations. This idea forces units to better simulate their requirements for combat operations; however, it does have weaknesses which could be mitigated with an exception for NTC. At home station, units with weak ASL and SSA systems will suffer lower OR rates as parts scarcity harms their ability to train. In the overall training scheme, this is a good learning opportunity, as the missed training opportunity cost is significantly lower at home station than at NTC. Missed training due to NMC tanks can be identified and fixed. Units should then travel to NTC with their organic ASL, but should also be augmented by an NTC ASL. The waste of essential NTC training days on NMC tanks because of an insufficient organic ASL is a dangerous situation. NTC is the hardest, and most beneficial training a unit does short of combat. If units are evaluated on their poor organic ASL performance then tracking the parts used from the NTC ASL is an easier method. Having an on-site back-up parts source ensures maximum training value for the lethality of ABCT formations.

For the NTC ASL though, additional complexities contribute to the difficulty of adding 28 NIINs to the ASL. First, ASLs are limited by the warehouse space a unit has at their post. Thus, part size also plays into storage and transport of all ASL. Additionally, though the parts are normally already inside the Army System, there are additional costs in storage, upkeep, and holding each part. Thus, with each SSA getting a certain amount of money, it may be outside the budget to carry these additional parts at NTC. Finally, the M1 is not the only pacer in the ASL for NTC; M109 Paladin Artillery, AH-64 Helicopters, and Stryker IFVs all make up portions of the NTC ASL. SSA and 916th BDE Support Personnel must decide how to split the available resources amongst the different unit requirements. In all reality, it is a commander's decision on what and where to spend ASL funds. If other pacer OR rates are performing better (and at least the M2 is), NTC personnel should relook at the M1 ASL breadth and add those NIINs which could best improve M1 OR rates.

The relative quality of individual unit maintenance programs has a demonstrable effect on the OR rates of M1s at NTC. Finally, the last OR rate driver is the units' individual maintenance programs. Given that all units have had significant personnel turnover in the years after their NTC rotation, with some units studied having had 100% personnel turnover, it is almost impossible to study the exact SOPs and policies of each unit's maintenance program. Additionally, units have purged their training schedules and records, preventing analysis of where time was spent during their train up. However, I analyzed different data sources to understand the quality of each unit's maintenance program before or in the early stages of their arrival at NTC. Using these measures, I identified, relative to the other units that trained at NTC, the quality of each unit's maintenance program. If, as some within the rotational brigades suggest, the parts scarcity was the only reason for lowered OR rates, the r^2 of these scorecards to OR rates would have been extremely small. However, this is not the case.

A major insight gained in this portion of the research was the relative performance of each unit's controlled substitution policy. The Army as a whole could have gained approximately 2.4% of OR rate by maximizing the controlled substitutions completed during the rotation. The variability in this measure indicates some units do not understand the possible combat power savings involved in controlled substitutions. In the future, units must aggressively search for controlled substitution possibilities. Training for this could be done during Captains Career Course, Staff College, or at NTC RSOI itself.

Unit maintenance programs do, as expected, have an effect on OR rates. This means that the problem of OR rates in the Army is not completely systematic on an Army-wide level. Individual units can affect and ensure whether their OR rates are above the standard. While there is no available data on why some unit's programs are failing, this study has demonstrated that they are failing. In the next section, I will discuss future research on how to analyze why these units may be failing.

Though not as expected, the results of this study have shown a multitude of different drivers are affecting the OR rates at NTC. Though it is surprising that mileage OPTEMPO has no effect, the other two possible drivers have proven to cause declines in the OR rates of M1s at NTC. Next, I will use this information and an understanding of the next steps possible for this study to discuss how the Army Maintenance System and future research can be used to further improve the understanding of NTC performance.

6.2. Recommendations

Given the above analysis, I have 4 major areas of recommendations: automation of the Army's vehicle mileage reporting systems, future unit OPTEMPO research, NTC ASL stockage breadth adjustment, and individual unit maintenance program issues. These recommendations vary in difficulty from the simple (reviewing a unit's controlled substitution policy upon arrival at NTC), to the more resource intensive, (the design of a new automated mileage reporting system). As discussed in the beginning of this thesis, there is no one silver bullet that will solve all of the Abram's NTC OR rate problems, but initiating any of these recommendations will serve to either help solve a portion of the problem, or at least deepen our research understanding of the problem.

6.2.1. Automated Mileage Reporting Systems

The first recommendation considers an issue tangential to NTC OR rates, but would affect the Army as a whole: mileage reporting. Throughout this study, I assumed mileage reporting was correct, except in a few instances where I eliminated obviously false data. However, this mileage information is important for Army-wide analysis and must be as accurate as possible; specifically, for its future use in predictive analysis.

The Army is currently exploring predictive analytics to provide parts to units before faults even occur. This type of "big data" analysis could greatly assist units to ensure parts failures can be quickly fixed through predictive parts ordering, and tanks returned to FMC status; thus, raising OR rates both at home station and at NTC. This data would use Army-wide mileage usage reports to analyze how often parts fail on tanks and then provide support personnel, maintainers, and commanders information on their expected faults. However, this information must have a solid foundation of mileage reporting. Mistakes made by overworked, tired, or inattentive maintenance clerks could both hamstring unit efforts at predicting failures, as well as cost the Army a significant amount of money in needless purchases.

I recommend the Army develop an automatic or automated reporting system for the hours and mileage to be reported the Army's central systems independent of soldier reporting systems. Instead of mistakes being made by the crew reading the odometer or the clerk entering the information, an automated system could ensure accurate reporting from the tank to the Army. Additionally, this system could offer a significant understanding of that information, from daily or hourly usage, to the driving type (terrain versus roads). This system could operate in a number of ways, with the tank's internal computers storing the information until queried by a system that transmits the information to the Army's records. This system could take a number of different forms: a hand held/USB based equipment and operated by the company mechanics, a wireless or Bluetooth report submitted from the tank to a centrally connected system (like GCSS-A), or an addition to the tank's internal satellite communication systems. This system removes human error, missed reporting, or other issues that prevent rapid and accurate reporting of tank use.

6.2.3. NTC OR Policy and Research Recommendations

The following recommendations are based on the OR drivers researched in order to identify either systematic improvements to operations, or to suggest future additional research which would provide further insights on the problem, its causes, and possible solutions.

6.2.3.1. OPTEMPO

This study shows that mileage currently driven by M1s before, during, and at NTC has not been affecting the OR rates. **Therefore, I have no recommended changes to the mileage units are driving during training.** Mileage however, is only one measure of OPTEMPO; while there are other OPTEMPO measures which may affect OR rates. These are the number of days scheduled by units for maintenance and recovery before, during, or after training events at home station, and the number of soldiers tasked to non-training or maintenance related duties over the course of a train-up. **I would recommend the Army study training schedule and extra duty OPTEMPO to better understand their effects on OR rates.**

To study maintenance days, future research must have access to the daily training schedules of each unit for the entirety of their train up. Future researchers could then analyze the number of days units planned and performed maintenance and recovery operations, as compared with training requirements. In discussions with battalion and company internal maintenance leaders, a common statement was the unit's planned recovery periods were too short from the beginning, or were whittled down as additional requirements took time and resources. This meant tanks were not properly reset after training in preparation for the next requirement, and thus were more likely to break in the future. This research needs to be done in conjunction with the unit's training, as to ensure up-to-date information, and gather the information before it is purged. This study attempted to gather that information, but all older rotations had deleted their training schedules, and there were no personnel assigned with institutional knowledge to discuss it.

The second OPTEMPO measure, extra-duty taskings, was an additional measure which came up in discussions, specifically from the company leadership. Units are often tasked to extra duties, such as gate guards, clean-up assignments, etc. Future research should examine these requirements to see, specifically during maintenance days, what percentage of soldiers are actually at maintenance versus those assigned to extra duties. This again will require close contact with the units themselves, concurrent with their training.

Similar to the mileage analysis, this data could shed insight into the correlations between unit time OPTEMPO requirements and OR rates, both during training and at NTC.

6.2.3.2. Parts Stockage

Many rotational units blamed the lack of parts for the OR problems experienced at NTC. As the analysis shows, the ASL overall is doing a good job minimizing the NMC time for the most common parts, while assuming risk in those rarer parts faults. However, the next step, and my recommended future research in this area, is to better understand the second level effects of the NTC parts situation. This can be approached in two ways. The first would look at the ASL fulfillment data at NTC and home station, while the other examines parts failures on an Army-wide level.

I recommend the Army study and record the monthly fill rates for parts usage long term to analyze performance when ABCTs rotate into NTC. This study analyzed all of the faults that have occurred at NTC and their relationship to the ASL. However, there is no historical data for the NTC ASL and its parts fill status and listings for most of the study. Thus, there is no way to look into the past to analyze whether parts, either ASL or non-ASL, were actually stocked when the faults occurred both at NTC and home station. In future research, a researcher can collect this data on a monthly basis to better understand the performance of the parts system and possible improvements.

Second, I recommend the Army study parts demand across the force during major training events to better understand which M1 parts fail during high intensity training. Specifically, to best inform the NTC ASL, the Army should examine those parts which fail during major training periods, where the use most closely resembles that of NTC. As it stands, usage does not consider the unit's specific training densities, and thus has one steady state demand requirements. In reality, units tend to require more parts during the train-up period, specifically in months with the densest training (M-6 to M-2). By examining parts requirements during high OPTEMPO home station training, it may reveal insights as to parts that break more often in those situations. This could then feed future predictive algorithms which utilize a unit's train-up schedule to dynamically restructure the ASL listings both at home and at NTC.

6.2.3.3. Unit Maintenance Programs

A unit's maintenance program is a multi-faceted entity which has a significant number of variables to make it successful. As with prior drivers, this study could not access past records of study units, and was not able to identify the specific aspects of unit maintenance programs beyond their controlled substitutions, and their performance in a number of program quality indicators. However, a few recommendations can be made to better serve both the Army and future researchers.

First, NTC should better record unit maintenance operation AARs and OC/T reporting. This gives better reference point for the unit itself, fellow units preparing for NTC or combat, evaluators, and other possible researchers. This could include aspects such as reported unit OR rates, the OR rates in the maintenance system, recorded controlled substitutions, and other OC/T comments for the unit overall.

Second, NTC should ensure units examine their own internal SOP controlled substitution policy and ensure units are evaluated on their execution of the policy. This study showed the Army as a whole could have boosted the OR rate by 2.4% from controlled substitutions alone, raising it to the 90% standard. Units may be hesitant to conduct controlled substitutions at home station, and thus carry the reluctance into NTC, but they miss out on significant combat power and training by doing so. NTC could accomplish this "training" early in the RSOI period, by prompting OC/T to rotational unit leader discussions on their policy and outlook during the training.

Third, as the Army emphasizes, ensuring engaged maintenance leadership is critical to success, and must be re-emphasized during any maintenance event. Indicators of leadership shortcomings is very obvious when examining the mileage data input into the Army system. Problems such as negative mileage reports, clerical errors, or a lack of reporting shows unit maintenance leaders are not ensuring the quality control of their clerk's performance. If simple tasks such as monthly mileage reporting are not done to standard, what else could be missed or shortchanged?

Future research in this area must again focus on continuous contact with the unit during their train up and at NTC. Real time analysis would be able to examine and record actual maintenance program inputs for comparison to the eventual NTC OR rates. This could include observation of proper semi-annual services, reporting, or general program emphasis overall.

6.3. Final Thoughts

The Army plans on using the M1 Abrams well into the middle of the next century. As battlefields change and adversaries adapt, there will still be a need for mobile-protected firepower to allow the US Army to successfully seize, hold, and secure ground. As the Abrams goes through its periodic updates, so too must the maintenance system supporting it. This study has shown a surprising insight into current mileage not impacting OR rates. Though this should be tested continuously as vehicles increase their lifetime mileage, it allows units and leaders to trust their tanks and train without worrying about overextending their vehicle capability. ASL listings and their consistent monitoring have also proven successful; however, given NTC's importance, they should also be examined for even further optimization. Finally, the individual maintenance program regressions show the current OR rate problems are not the same throughout the Army, and individual units can and must ensure their systems are robust and effective.

As the Army moves towards additional data collection and analysis, it must utilize the informational treasure trove allowed by big data analysis. Leaders must endeavor to improve systems with new insights as to cause and effect of OR rate changes. New systems like predictive fault and parts forecasting will undoubtedly be part of that upgrade. However, these systems rely on accurate and timely reporting by soldiers, leaders, and sub-systems within rotational units to assure success both at NTC and on any future battlefield.

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Appendices

Appendix A

Systems Architecture Analysis

The OR rates for M1 Abrams at NTC are driven by the NTC/Army Maintenance System. This system includes a significant number of elements, and is considered a medium-to-high complexity system. Goals are defined as the answers to "What is planned to be accomplished" and "What does the producing enterprise hope to achieve." (Crawley, Cameron, & Selva, 2016)The system primary goal is to return broken tanks to Fully Mission Capable (FMC) status. The system secondary goals are to fix the tanks at the smallest possible cost to the taxpayer, as close to the front lines as possible, and to do so in a degraded, wartime environment. Though the Army does not have a defined system problem statement, an applicable one for this NTC Maintenance System is:

"To rapidly return Non-Mission Capable vehicles to Fully Mission Capable Status by quickly assessing, ordering, receiving, and repairing vehicles using operators, on-hand maintainers, support personnel, and parts warehouses on or near NTC."

Stakeholder/Beneficiary Analysis

There are a variety of stakeholders and beneficiaries involved in the NTC Maintenance System. They include personnel at every unit level inside the BDE, across the Army Logistics System, and even to each citizen of the United States. Additionally, these stakeholders, except for taxpayer, are also operators within the system at some point. The individual identification and analysis for each is below:

1. The Tank Crew: Armor soldiers who live, work, and fight on the M1s. They maintain each tank, and thus have major inputs and benefits from the maintenance system. They need to quickly identify faults in the tank and relay information onto their commanders and mechanics. They benefit from the system in their receipt of repaired tanks, whether repaired by themselves or mechanics. An FMC tank allows them to return to training, thus benefiting their abilities in future combat and training requirements for the Army. Their exact duty description within this system is found in ATP 4-33: "Operator[s] are system specialists in those military occupational specialties that receive formal training from their proponent on diagnosing specific system faults. Their primary focus is on a system's performance and integrity. These

personnel troubleshoot the entire system using simplified (or embedded) diagnostic equipment to identify, isolate, and trace problems to a faulty line replaceable unit, line replaceable unit replacement (utilizing on-board spares), and identifying/correcting crew training deficiencies. After operators have exhausted their maintenance capabilities, they rely on Ordnance maintainers in field maintenance organizations or teams to conduct field maintenance on the item of equipment." (ATP 4-33 Maintenance Operations, 2014)

2. Mechanics/Maintainers: These soldiers confirm faults, identify needed parts, and fix vehicles when those parts arrive. They ensure the highest possible OR rate for their unit. They have many inputs into this system at multiple points, such as fault confirmation, parts identification, and the replacement of those broken parts. The system creates benefit for them, because it provides them information about faults, ordering, and repair of the tanks. There are multiple levels of maintainers, but as mentioned above, the system we are studying is focused on field level maintainers only. Thus, we have placed depot level maintainers outside of the boundary of our system. (ATP 4-33 Maintenance Operations, 2014)
3. Commanders: Commanders in this system include those at company, battalion, and brigade level, each of whom has a significant role in the maintenance system. From ATP 4-33: "Commanders at all levels must understand the Army maintenance system, and the role of operators, crews and maintainers, to have the right capabilities in the right place at the right time." (ATP 4-33 Maintenance Operations, 2014) The commander's inputs start well before a unit reaches NTC. They establish unit maintenance culture and training, which directly effects the skills each crew and mechanic brings to NTC. They also decide, after receiving staff input, the location and maintenance plan for their unit's time at NTC. Additionally, and important for this study, the Brigade Commander establishes the level at which controlled substitution of parts can be completed. The Brigade Commander normally places this decision ability at the battalion level, and given the relatively close operations at NTC, it is normally kept there. In operations on a more extensive scale, it can be delegated to company level as well. The commander benefits from this system because it quickly returns their tanks to FMC status, giving the commander more

combat power and thus allowing more freedom of maneuver, a higher chance of mission success, and the probability of lower friendly casualties.

4. Taxpayers/US Citizens: Taxpayers are the only stakeholder in this system which are not also an operator of the system. However, the taxpayer is the primary beneficiary of the NTC Maintenance System. The entire purpose of all NTC training is to ensure the safety and well-being of the citizens of the United States. They, through Congress's budgetary approval, fund the Army in general, who then funds the NTC Maintenance Program. The obvious benefit gained by taxpayers of any standing army's country is safety and a hopefully peaceful way of life.
5. Parts Warehouse Personnel/Army Material Command-Sustainment Command: These stakeholders control and operate the parts flow from their storage location to the BDE maintenance personnel. Their major input is to: "match materiel to mission and assure logistics readiness in the Army force generation process." (ATP 4-33 Maintenance Operations, 2014)They accomplish this by maintaining, accounting, monitoring, and managing all replacement parts for the Army as a whole, through Field Support Brigades, SSAs, national depots, and other logistics centers. They benefit from this system from the rapid and accurate reporting from line units, allowing them to track, predict, and estimate unit parts requirements for the future, both in training and in combat.
6. General Dynamics/Parts Suppliers: The primary parts supplier for the M1 tank is the designer and producer of the tank, General Dynamics. However, they do not provide 100% of the parts required for the tank. Parts suppliers provide the actual maintenance parts to AMC in order to allow those parts to be stored and used in future repairs. Normally, this supply is done well before the parts are needed. They receive benefit from the revenue received from the Army's purchases.

Army Maintenance System Decomposition

Army Maintenance System Form Decomposition

Below is the hierarchical decomposition of the Army Maintenance System showing the command relationship between each entity:

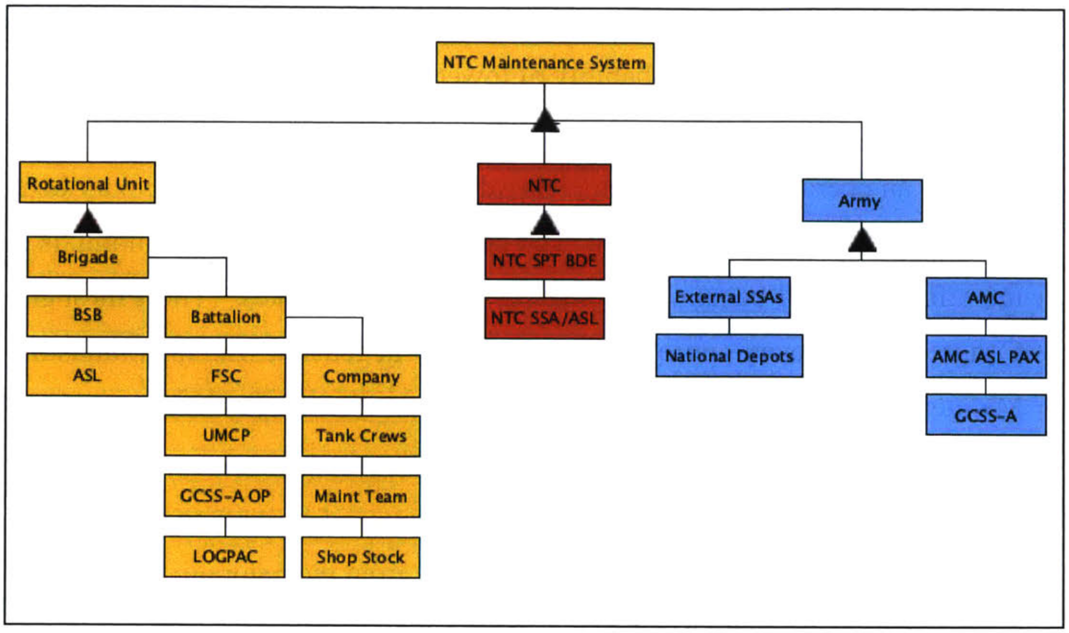

Figure 30: NTC Maintenance System Decomposition

Army Maintenance System Functional OPM Decomposition

Below is the System OPM diagram showing the Army Maintenance System path for an M1 tank from NMC to FMC:

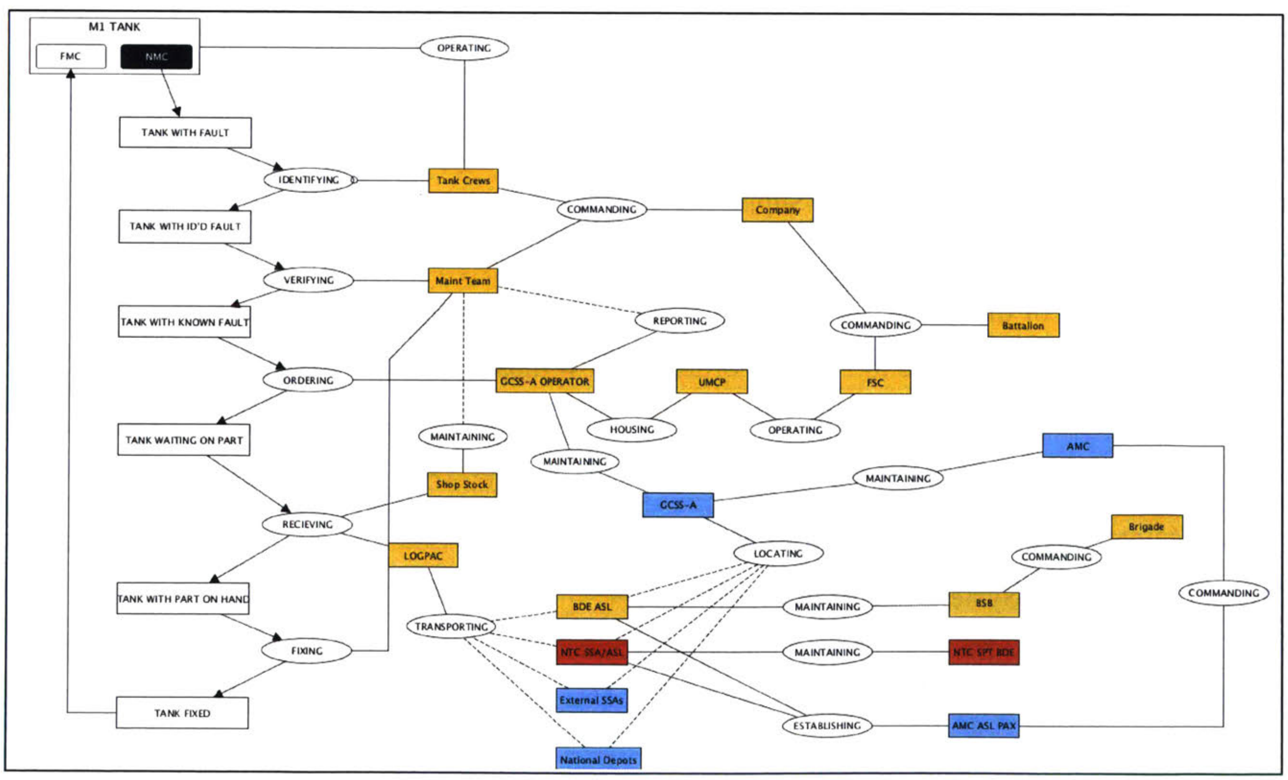

Figure 31: Army NTC Maintenance System OPM Decomposition

Army Maintenance System Stakeholder Value Network

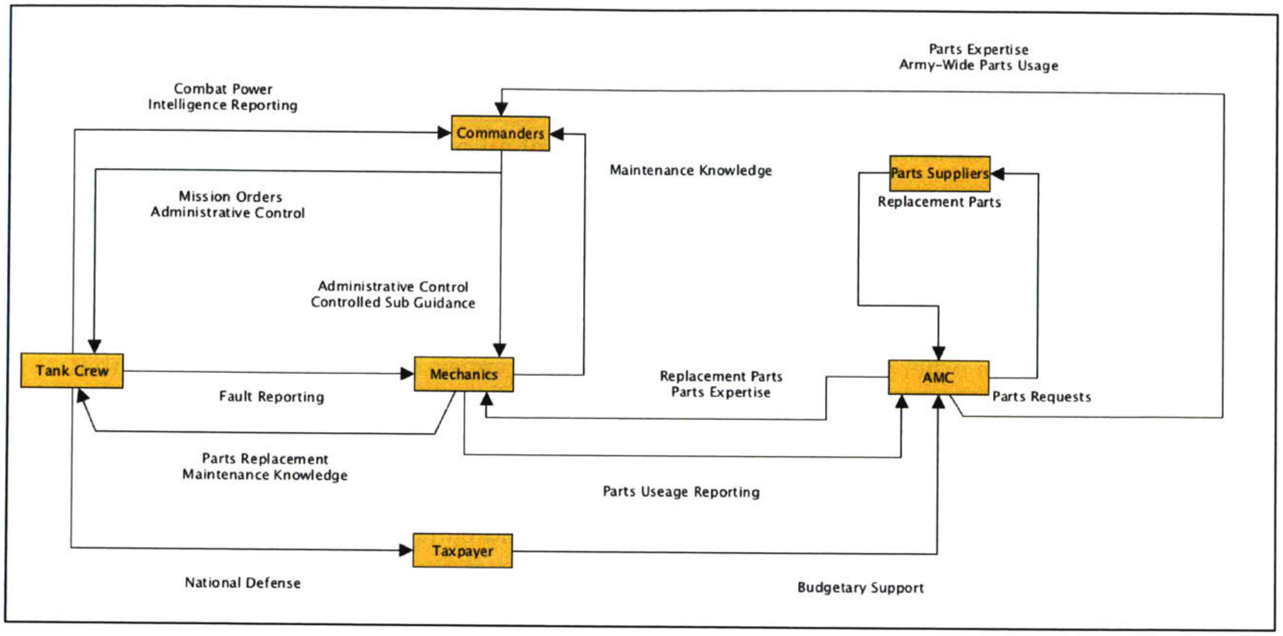

Figure 32: Stakeholder Value Network

Appendix B

ABCT Leadership Personnel involved in Maintenance Operations

Commanders (BDE, BN, CO): Commanders are responsible for everything their unit does and fails to do. They set priorities, plan, supervise and control all operations at their unit level. This includes overall responsibility for maintenance operations, though other members of the unit are more involved in the actual performance. Depending on the responsibility delegated by higher headquarters, commanders' control and authorize the controlled substitution of parts from one vehicle onto another in order to harvest/maximize combat power. (FM 3-96 Brigade Combat Team, 2015)

Executive Officers (XO) (BDE, BN, CO): XOs direct the operational efforts of the brigade/battalion staff (or Company) and sustain brigade and battalion readiness. The XOs are the primary officers in charge of their units' maintenance, and are tasked with reporting, supervising, and organizing all their unit's maintenance efforts. (FM 3-96 Brigade Combat Team, 2015)

Battalion Maintenance Officer/Battalion Maintenance Chief: Supervise the execution of all battalion maintenance operations. They work closely with the Executive Officers, Company Maintenance Sergeants, and SAMS-E clerks to ensure the timely and seamless maintenance operations. They both advise and assist the Commander and Executive Officer in making maintenance and repair decisions. (ATP 4-33 Maintenance Operations, 2014)

Company Maintenance Sergeant: Responsible for the operations of the Company Unit Maintenance Team (UMT). The Maintenance Sergeant oversees all maintenance on company vehicles, advises the company commander and XO on maintenance decisions, and is administratively responsible for the soldiers in the Unit Maintenance Team. (ATP 4-33 Maintenance Operations, 2014)

SAMS-E or GCSS-A Clerk: Orders parts in the Army requisition system for broken vehicles as the UMT requests them. They receive the 5988-E maintenance forms from the tank operators and maintainers and order the parts delineated on the forms from the Army system. Additionally, they are responsible for reporting monthly miles usage from each vehicle. (ATP 4-33 Maintenance Operations, 2014)

Brigade Support Battalion Support Operations (SPO): Responsible for the logistical support of all material in the brigade. The SPO tracks the common operating picture of the unit's maintenance parts status, and plans the logistics support based on unit and mission requirements. (ATP 4-33 Maintenance Operations, 2014)

Appendix C

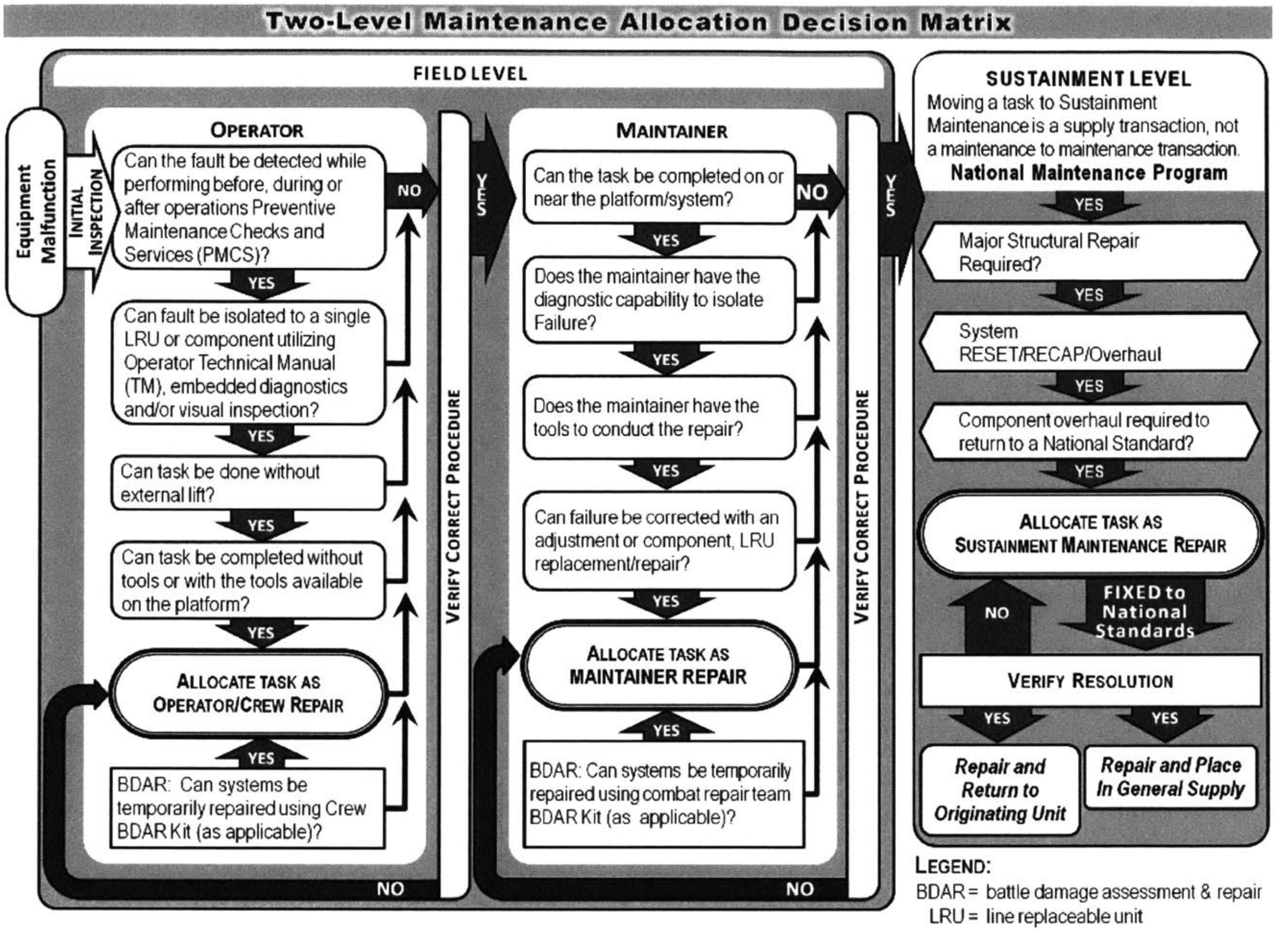

Figure 33: Two-Level Maintenance Allocation Decision Matrix.

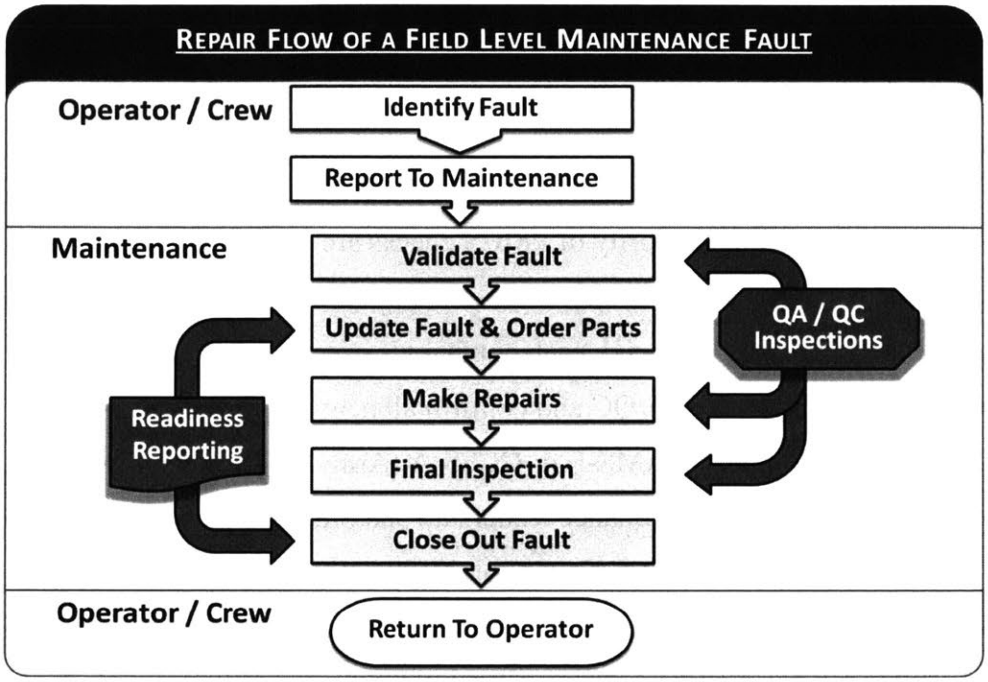

Figure 34: Field Maintenance Flow Chart (ATP 4-33 Maintenance Operations, 2014)

Appendix D

Home Station vs NTC 5988-E Flow

Home Station

As discussed before, the majority of PMCS checks are performed during Command Maintenance Mondays. Faults are identified by the crew, validated by the company mechanics and recorded on the 5988s. At days end, each company's executive officer (XO) collects the 5988s and conducts a meeting to QA/QC and confirm all new and pre-existing faults. By the end of the day Tuesday, the company SAMS-E or GCSS-A (Army Logistics Computer System) clerk coordinates with the Battalion Maintenance leadership and orders required parts. Individual companies carry with them up to 300 different part NIINs (the Army version of an SKU). These parts are called Shop Stock. If a company uses a part routinely, they can place that part on their Shop Stock Listing, and have extras on hand, allowing them to quickly repair routine faults. Parts not in the Shop Stock may also be located in the Supply Support Activity Warehouse (SSA) of each brigade. (FM 4-30 Ordnance Operation, 2014) The SSA stocks parts according to its specific Authorized Stockage List (ASL). The ASL of each unit is unique, as it is based on the type of units organic or assigned to the brigade. Thus, a brigade with only Airborne Infantry will not have any tank parts. Once they receive the order through the Army System, SSA soldiers identify and move the part to each specific unit's pick-up bin, informing the unit the part is ready for pick-up, and maintenance clerks pick up the part. The standard for any NMC tank for most units in the Army is once the part is on hand, work continues on the tank until it is FMC. It normally takes less than 24 hours from part pick up to return to operations. For parts that the SSA does not have on the ASL, or has temporarily run out of, the Army Material Command (AMC) Logistics Support Activity (LSA) identifies a depot or other SSA with the part, and coordinates part shipment to the required SSA. Units are updated on parts status in real time through the AMC computer systems for planning and preparation. (ATP 4-42.2 Supply Support Activity Operations, 2014)

When units are in the field at home station, PMCS is also conducted on a daily basis both during and after operation of the tanks. Similar to the weekly rhythm described above, the 5988 flow is the driving force for parts acquisitions, but daily. However, unlike what is seen at NTC or wartime, where the support units are in the field, support units normally stay in garrison during home station field training. Therefore, the parts ordering processes above the company or battalion training remains the same as other garrison-based repair times.

NTC

Once units move into the training area at NTC, the parts flow process moves into "War" footing and operations. Instead of using a support structure that is garrison based at home station, all support units also deploy to the wargames ongoing at NTC. During this time, the reporting procedures are basically the same, units report using 5988s their malfunctioning equipment, it's sent for approval and ordering, and parts are located.

However, the major difference between garrison based and NTC flow occurs in the acquisition and forward movement of the equipment. Instead of individual companies picking up parts at the SSA, the SSA now acts as a division or corps level support asset (CSSB), and simulates how the parts flow would work in wartime. The Brigade Support Battalion (BSB) executes Logistics Convoys (LOGPACS) to gather the Brigade's required parts 1-2 times per day from the CSSB and moves them to the Brigade Support Area (BSA). These parts are then moved by the BSB to each battalion's logistics command post (primarily the Unit Maintenance Command Post, UMCP). At the UMCP, parts needed for tanks requiring major repairs are left there and repairs made. Parts needed for tanks forward will thus be given to the unit and repairs made. Some tanks will still be forward with the unit are then taken by the battalion, and then company LOGPACs forward to the unit. This entire process can take 12-48 hours for parts to be identified and delivered to the unit. This process is diagramed below.

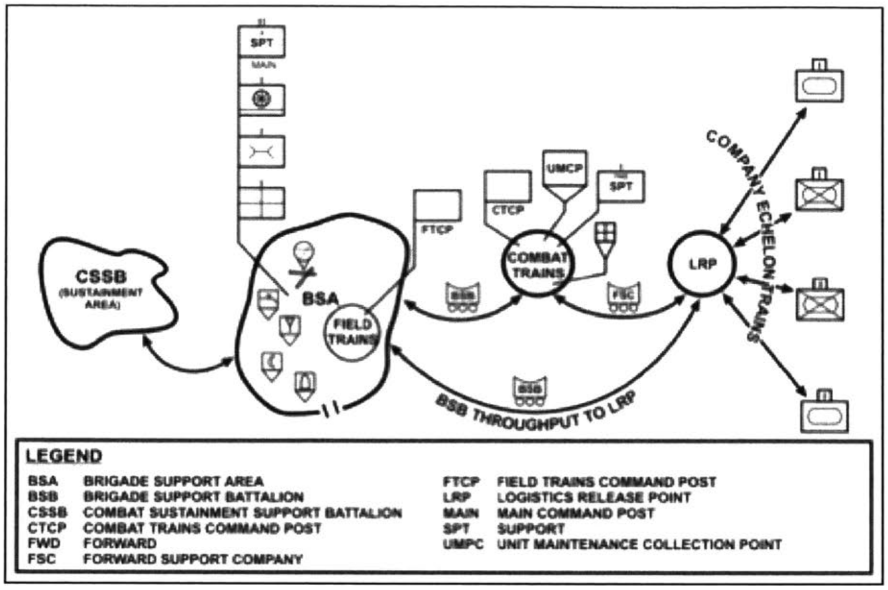

Figure 35: The Field Maintenance Parts Flow (FM 3-96 Brigade Combat Team, 2015)

Appendix E

Rand Corp Dollar Cost Banding Study

In the 1990s, the Army noticed large issues with the duration vehicles were NMC during training throughout the Army's armored units. At that time, the Army operated with an algorithm which calculated the burn rates of parts, and stocked them according to those requirements. However, a system using burn rates does not react well to the cyclical nature of Army training. As mentioned in the Background section, Army training is often cyclical and dependent on the training status of the unit supported. When a unit begins a training cycle, there is little tank usage; however, as the unit increases training complexity, the tanks and other vehicles are used more and more. Thus, though a unit may only use four of a certain NIIN in a year, all four of those failures occur at the same time, not one per quarter. Thus, SSAs were often overwhelmed during periods of heavy training, the exact time when units needed tanks to be FMC. (Rand Corporation, 2001)

Thus, the Army hired RAND Corporation to examine at why this was happening, and what could be done to solve the problem. After studying the issue, RAND devised two solutions which make up Dollar Cost Banding (DCB) which helped improve the state of Army SSA stockage. (Rand Corporation, 2001)

The first solution was to increase the breadth of SSA stockage, namely to determine the different NIINs to be stocked in SSAs. Under the prior standard operation procedure (SOP), a part required 9 requests in a year to be added on the stockage list, or 3 requests to be maintained on the list. This occurred regardless of what the part was, cheap and small, or large and expensive. Dollar Cost Banding identified small, cheap, mission critical items that may have low demand, but would not place an undo burden on the supply system if ordered and stocked anyway. (Rand Corporation, 2001)

The second solution in DCB directly addresses the demand cycle issues caused by training evolutions. It uses the SSA wait time for parts to compute the number of parts on hand that must be stocked. Known as the "Customer Wait Time" (CWT), this solution means that if parts have a long lead time for construction or manufacture, more must be located in the SSA to ensure shorter CWT. By considering the delivery time to the SSAs, the Army was able to increase fill rates, which then of decreased NMC time. (Rand Corporation, 2001)

After establishing the DCB tenets, the Army initiated a pilot program with three brigades to examine the results of this program. In every battalion ASL involved, the fill rates improved, usually on an average of 12-15% per brigade. Most fill rates came from NIINs costing less than $100, but with very low demands. Repair jobs requiring a non-local part decreased by 6% and the average repair time for tanks as a whole decreased from 12.4 days to 8.8 days, a 29% decrease. (Rand Corporation, 2001)

Once the DCB program was proven to the Army, the Army initiated it throughout the entire force, and continues to utilize DCB when examining the requirements for ASLs in the force. (Rand Corporation, 2001)