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# THESIS

**ENGINE MAINTENANCE MANHOURS: AN ANALYSIS OF THE ACCURACY OF CORRECTIVE MAINTENANCE STANDARD RATIOS USED IN DETERMINING MANPOWER REQUIREMENTS**


by

Margaret A. Dori


March 2022


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Previous research found the Navy’s preventative maintenance to corrective maintenance (PM:CM) ratio standard underestimated the amount of CM performed on guided missile destroyers (DDG). This study expands on these findings by comparing the actual PM:CM ratio on the 501-K34 engine onboard Flight I DDGs to the current standard to understand the Navy’s accuracy in predicting Surface manpower requirements. The T-56 onboard the P3 aircraft is the aeronautical equivalent to the 501-K34 engine. This research evaluates the maintenance manhours performed on each engine type to understand the maintenance requirement to maintain operational availability on similar engines in different environments. This study concluded Flight I DDGs are not manned appropriately regarding 501-K34 engine maintenance. Actual PM:CM ratios were largely inaccurate compared to the Navy ratio standards and suggest more CM was performed than predicted. This paper recommends a study be conducted of all Flight I DDG equipment to establish new ratio standards. Maintenance manhours were substantially different between Surface and Aviation engines. The different operational concepts, maintenance documentation, and cultures between the Surface and Aviation communities would explain the difference in maintenance manhours. This paper recommends studying each engine’s operational availability to determine if one maintenance system better supports the availability of the engine within that system.

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# ABSTRACT

Previous research found the Navy's preventative maintenance to corrective maintenance (PM:CM) ratio standard underestimated the amount of CM performed on guided missile destroyers (DDG). This study expands on these findings by comparing the actual PM:CM ratio on the 501-K34 engine onboard Flight I DDGs to the current standard to understand the Navy's accuracy in predicting Surface manpower requirements. The T-56 onboard the P3 aircraft is the aeronautical equivalent to the 501-K34 engine. This research evaluates the maintenance manhours performed on each engine type to understand the maintenance requirement to maintain operational availability on similar engines in different environments. This study concluded Flight I DDGs are not manned appropriately regarding 501-K34 engine maintenance. Actual PM:CM ratios were largely inaccurate compared to the Navy ratio standards and suggest more CM was performed than predicted. This paper recommends a study be conducted of all Flight I DDG equipment to establish new ratio standards. Maintenance manhours were substantially different between Surface and Aviation engines. The different operational concepts, maintenance documentation, and cultures between the Surface and Aviation communities would explain the difference in maintenance manhours. This paper recommends studying each engine's operational availability to determine if one maintenance system better supports the availability of the engine within that system.

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# LIST OF ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| 3M | Maintenance and Material Management |
| CASREP | Casualty Report |
| CM | Corrective Maintenance |
| CNSP | Naval Surface Forces Pacific Command |
| DON | Department of the Navy |
| GAO | Government Accountability Office |
| JCN | Job Control Number |
| NALCOMIS | Naval Aviation Logistics Command Management Information System |
| NAVMAC | Navy Manpower Analysis Center |
| NAVSEA | Naval Sea Systems Command |
| NSWC | Naval Surface Warfare Center |
| PM | Preventative Maintenance |
| RFI | Request for Information |
| ROC/POE | Required Operational Capabilities and Projected Operational Environments |
| SMD | Ship Manpower Document |
| SQMD | Squadron Manpower Document |

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# EXECUTIVE SUMMARY

Prior to 2001, shipboard manpower requirements were based on wartime watchstanding and workload, which were derived from required operational capabilities and projected operational environments (ROC/POE), maintenance, and own unit support. In 2001, the Navy implemented an initiative known as "optimum manning" that decreased shipboard billets to the number that was just right to perform all ROC/POE requirements. It did not consider maintenance requirements. A Fleet Review Panel conducted in 2010 found a decline in Surface Force readiness due, in part, to manning initiatives that did not factor shipboard maintenance into the manpower requirements (Balisle 2010). Among other recommendations, the panel called for a review of actual shipboard manpower requirements based on maintaining the ship.

One aspect of the workload that feeds into manpower requirements based on maintaining the ship is the number of manhours required to perform corrective maintenance (CM). The Navy uses a preventative maintenance (PM) to CM (PM:CM) ratio standard to predict CM manhours in the Surface community. This thesis examines the accuracy of the PM:CM ratio in predicting CM manhours. Specifically, it compares actual PM:CM ratio on the Flight I DDG gas turbine generator engine, the 501-K34, to the current Navy PM:CM ratio standard in an effort to answer the question, "*How accurately is the Navy predicting Surface manpower requirements based on manhours spent on engine maintenance?*"

The aeronautical equivalent to the 501-K34 is the T-56 used on the P3 aircraft. Being a similar engine that is maintained and utilized differently, review of the T-56 offers an interesting comparison to the 501-K34 in the number of maintenance manhours required to maintain current operational availability. Specifically, this thesis evaluates the difference in number of maintenance manhours between the 501-K34 and T-56 engines in an effort to answer the question, "*How does the amount of maintenance manhours compare on similar engines in different operational concepts—Surface and Aviation?*"

This thesis uses an analytic method to address the accuracy of the PM:CM ratio standard in predicting Surface manpower requirements for 501-K34 engine maintenance. First, historical manhour data was collected and cleaned and used to calculate actual PM:CM ratios. Next, quantitative characteristics of the PM:CM data set as well as percent error between actual and current Navy standard ratios were analyzed to establish accuracy of the past data set. This thesis then evaluated what the accuracy (or inaccuracy) of the past data set implies for future data sets. Simply, it calculated the likelihood of observing certain inaccurate manpower requirement predictions. As a requirement to probability calculations, the data sets were first confirmed to be normally distributed.

A second analytic method was used to compare the maintenance manhours seen on similar engines but used in different operational concepts. Again, quantitative characteristics of the manhour data set as well as percent difference between the 501-K34 (Surface) and T-56 (Aviation) engines was analyzed to establish the difference. A student's t-test was performed to determine if the observed difference was statistically significant or if it came about simply by chance. This thesis finally discussed potential factors that would explain the difference in maintenance manhours between the two engines.

Based on the first analytic method, the following results are summarized for maintenance pertaining to the 501-K34 onboard Flight I DDGs. Actual PM:CM ratios of 1.32 for mechanical and 0.56 for electrical tended to be smaller than the current Navy ratio standards of 2.0 and 1.0. Assuming PM is consistent, the smaller ratios suggest more CM was performed than predicted. Mechanical ratios were significantly inaccurate with an average of 60.0% error. Electrical ratios were even more inaccurate with an average of 165.1% error. Additionally, it is 70.6% and 66.6% likely the Flight I DDG will observe less mechanical CM and more electrical CM on the 501-K34 engine than predicted by the Navy PM:CM ratio standards.

Based on the second analytic method, the following results are summarized for maintenance pertaining to the 501-K34 (Surface) and T-56 (Aviation) engines onboard Flight I DDGs and P3s, respectively. The PM and CM maintenance manhours both differed between the 501-K34 and the T-56 engines; however, there was more of a percent difference observed with PM than CM. In fact, evidence supported the statement that PM manhours were significantly different between the 501-K34 and T-56 engines, and the difference did not happen by chance. There was not sufficient evidence to support stating CM manhours were significantly different between 501-K34 and T-56 engines. Possible factors that would explain the observed difference in maintenance manhours is the differences in operational concepts, maintenance documentation, and community cultures between Surface and Aviation.

This study concluded Flight I DDGs are not manned appropriately regarding 501-K34 engine maintenance. Actual PM:CM ratios tended to be smaller than the Navy ratios standards which, assuming consistent PM, indicates there was more CM than predicted. The actual PM:CM ratios averaged 60.0% and 165.1% error from the Navy ratio standards. These tendencies away from and in large percent error from the Navy ratios standards illustrate the high degree to which the determination of manpower requirements for this sample of ships was inaccurate. Additionally, probability analysis indicates the Navy will more often observe less mechanical CM and more electrical CM than predicted in future observations. In either case, mechanical or electrical, it is likely the current ratio standard will inaccurately predict Flight I DDG 501-K34 engine maintenance manpower requirements. According to the Fleet Review Panel, the inaccurate ratio standard could contribute to poor material condition of readiness of the Surface Fleet (Balisle 2010). While this paper gathered actual PM:CM ratios, those ratios were based on maintenance on one piece of equipment, the 501-K34 engine. The Navy PM:CM ratio standards are based on all workcenter equipment maintenance. As such, the actual PM:CM ratios found in this study should not replace the current Navy PM:CM ratio standards. Instead, this study provides one of many data points in the last decade that suggest the Navy did not either accurately determine the requirement or improperly fund the requirements for the Surface Fleet. This paper recommends the Navy Manpower Analysis Center conduct a study of all Flight I DDG workcenters to validate actual PM:CM ratios and update ratio standards to better reflect actual fleet CM requirements.

This study also concluded that the maintenance manhours are different between similar engines, the 501-K34 (Surface) and the T-56 (Aviation). Mechanical PM was significantly different between the 501-K34 and T-56, and the difference is not due to chance. While mechanical CM proved to be relatively different between the two engines, there was not sufficient evidence to support stating the CM manhours were *significantly* different or that the difference was not due to chance. In conclusion, to maintain the current operational availability the Surface 501-K34 engine requires more maintenance manhours than the Aviation T-56 engine. While the systemic differences in operational concepts, maintenance documentation, and culture could plausibly explain the difference in manhours on the similar engines, this paper did not prove correlation or causation. This study simply shows that, although the engines are similar, there is a clear difference in the maintenance. This is the first step in determining if one maintenance system better supports equipment availability, and therefore fleet readiness, within that system. Figure 1 illustrates this concept.

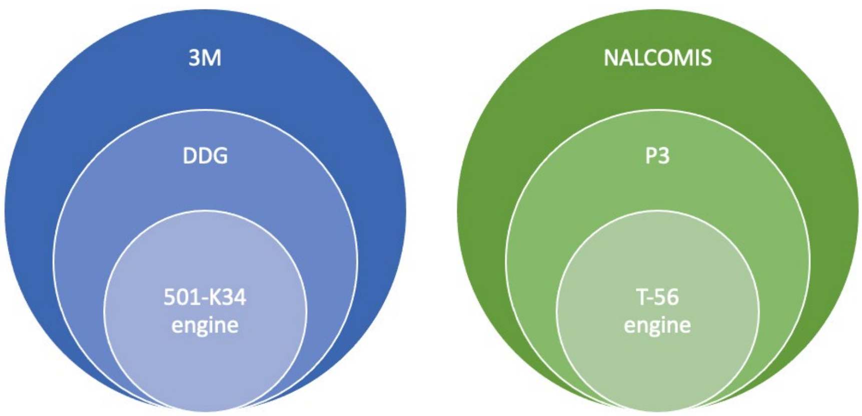


Figure 1. Maintenance Systems Involving the 501-K34 and T-56 Engines

This paper recommends Naval Sea Systems Command and Naval Air Systems Command conduct a study to determine the operational availability of each engine to determine if one maintenance system better supports the availability of the engine within that system. Specifically, are 501-K34 or T-56 engines more operationally available when supported by the 3M or NALCOMIS maintenance systems.

## References

Balisle, Phillip M. 2010. *Fleet Review Panel of Surface Force Readiness.* Norfolk, VA: Fleet Forces Command.

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Most of all, I thank my husband, Matthew, for his endless support and enthusiastic encouragement. You are the inspiration for this research and for me striving to be the best version of myself. I love you.

I dedicate this research to our beautiful daughter, Madelyn. I pray this gives you an example of the result of hard work. You are strong enough to persevere through anything you face. Mommy is so proud of you and loves you very much.

—Margaret "Maggie" Dori

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# I. INTRODUCTION

This chapter introduces the research in that it lays the groundwork for an understanding and background of the research area topic. The research questions and objectives are presented with scope and limitations and organization of study explained.

## A. BACKGROUND

Prior to 2001, shipboard manpower requirements were based on wartime watchstanding and workload, which were derived from required operational capabilities and projected operational environments (ROC/POE), maintenance, and own unit support. In 2001, the Navy implemented an initiative known as "optimum manning" that decreased shipboard billets to the number that was just right to perform all ROC/POE requirements. It did not consider maintenance requirements. A Fleet Review Panel conducted in 2010 found a decline in Surface Force readiness due, in part, to manning initiatives that did not factor shipboard maintenance into the manpower requirements. Among other recommendations, the panel called for a review of actual shipboard manpower requirements based on maintaining the ship.

One aspect of the workload that feeds into manpower requirements based on maintaining the ship is the number of manhours required to perform corrective maintenance (CM). The Navy uses a preventative maintenance (PM) to CM (PM:CM) ratio standard to predict CM manhours in the Surface community. There are fundamentally two different ratio standards, one for mechanical equipment (2.0) and one for electrical equipment (1.0) maintenance. These are stated in the PM:CM Ratio Table which is maintained by Navy Manpower Analysis Center (NAVMAC) and provided in Appendix A. In 2011, Naval Postgraduate School students Martin Fajardo and Luz Ortiz answered this call by reviewing the PM:CM ratio standards in two workcenters onboard DDG ships. They found the Navy ratio standards underestimated the number of CM manhours. They called for studies to be conducted on other DDG workcenters to validate their findings across the DDG platform. This thesis will expand on the Fajardo/Ortiz findings by examining the accuracy of the PM:CM ratio standards in predicting CM manhours.

Specifically, it will compare actual PM:CM ratios on the Flight I DDG gas turbine generator engine, the 501-K34, to the current Navy PM:CM ratio standards.

The aeronautical equivalent to the 501-K34 is the T-56 used on the P3 aircraft. The Surface and Aviation Navies use different systems to document maintenance. The Surface Navy uses the maintenance and material management (3M) system and organizational maintenance management system to document PM and CM, respectively. Naval Aviation uses the Naval Aviation Logistics Command Management Information System (NALCOMIS) to document PM and CM. Being a similar engine but maintained and utilized differently, the T-56 offers an interesting comparison to the 501-K34 in reviewing the number of maintenance manhours required to maintain current operational availability. Specifically, this thesis will also evaluate the difference in number of maintenance manhours between the 501-K34 and T-56 engines.

This analysis will further validate the Fajardo and Ortiz findings as well as help to answer the question, "*How accurately is the Navy predicting Surface manpower requirements based on maintaining the ship?*" It also supports efforts to update the PM:CM ratio standards, opening an opportunity for the Navy and Department of Defense to improve fleet readiness and the nation's defense posture.

## B. OBJECTIVES

The goal of this research was to evaluate the accuracy of the Navy in predicting shipboard manpower requirements needed for maintaining the ship. Another objective of this research was to evaluate the difference in engine maintenance manhours performed on similar engines, the 501-K34 and the T-56, used in different operational concepts.

## C. THE RESEARCH QUESTION

### 1. Primary Research Question

How accurately is the Navy predicting Surface manpower requirements based on manhours spent on engine maintenance?

### 2. Secondary Research Question

How does the amount of maintenance manhours compare on similar engines in different operational concepts—Surface and Aviation?

What factors would explain differences (if any) in the amount of maintenance performed on similar engines in different operational concepts?

## D. SCOPE AND LIMITATIONS

The scope of this thesis focused on similar engines, the 501-K34 and the T-56, onboard the Flight I DDG ship and the P3 aircraft, respectively. The analysis reviewed PM:CM ratio standards and the number of PM and CM manhours performed over a four-year time range, from December 1, 2015, to December 31, 2019. Manhours performed on the 501-K34 engines were collected from Commander Naval Surface Forces Pacific command (CNSP) on Flight I DDGs stationed in San Diego, CA, and Norfolk, VA. The list of ships can be found in Appendix B. Manhours performed on the T-56 engines were collected from Patrol Squadron 30 (VP-30) on P3s stationed in Jacksonville, FL.

Initially, this thesis sought to analyze a possible correlation between the maintenance documentation system and material readiness of each system using CASREPs as the material readiness unit of measure. The Aviation community does not report engine casualties in a similar fashion to the Surface community, however, and so the analysis was limited in comparing material readiness of the two platforms.

While some data was provided for individual engines, another limiting factor was the granularity of the data. The CM manhours of 501-K34 engines were available not per engine, but per ship (or system). The T-56 manhours were provided by engine serial number and aircraft bureau number—the difference being that, in general, either an engine was installed in an aircraft (in which case the aircraft bureau number was listed) or an engine was not installed in an aircraft (in which case the engine serial number was listed). This created uncertainty in whether engine data was repeated in aircraft data. The lack of granularity in the Surface and Aviation data limited this thesis to analysis of the larger systems (DDG and P3 platforms) vice subsystems (501-K34 and T-56 engines).

Additionally, sufficient data was not available to perform analysis on *electrical* T-56 maintenance, and so the Surface and Aviation comparison focused on *mechanical* maintenance.

## E. ORGANIZATION OF STUDY

This thesis is organized into four additional chapters. Chapter II provides a literature review of references that helped to frame the area of research and provide a background. Chapter III presents the methodology used to collect, clean, and analyze the data. Chapter IV presents the analyzed and interpreted data as well as discusses the quality of the data. A summary, conclusions and recommendations follow in Chapter V. Appendices, a list of references, and an initial distribution list are provided as additional information.

# II. LITERATURE REVIEW AND THEORETICAL FRAMEWORK

This chapter provides a literature review of references that helped to frame the area of research. It provides a more in-depth background to the area of research and methodology for this research paper.

## A. BACKGROUND

A brief understanding of manpower and manning is helpful in understanding the history in this area of research. Manpower refers to the measured workload required to accomplish ROC/POE (Fajardo and Ortiz 2011). This is commonly explained as the "spaces" or workload required to be filled or accomplished on a ship during wartime operations. Congress authorizes a certain percentage of this requirement in the budget which is referred to as the billets authorized. Manning, or personnel, is "the specific inventory of personnel at an activity" (Department of the Navy [DON] 2015, p. C-7). Similarly, this is commonly referred to as the "faces" on the muster report available to fill the requirement. The Navy fills the authorized billets with personnel, but due to detailing timing and complications the personnel assigned can be less than billets authorized. Finally, due to leave, temporary additional duty, and other duties external to the ship even less personnel make up the current muster on hand. This inherent readiness gap between wartime requirement and current on hand averaged 8.4% of the requirement (Balisle 2010). This concept is illustrated in Figure 1:

In 2001, the Navy implemented an initiative known as "optimum manning" that decreased shipboard billets to the number that was just right to perform all ROC/POE requirements. It did not consider maintenance requirements nor the inherent 8.4% gap in readiness.

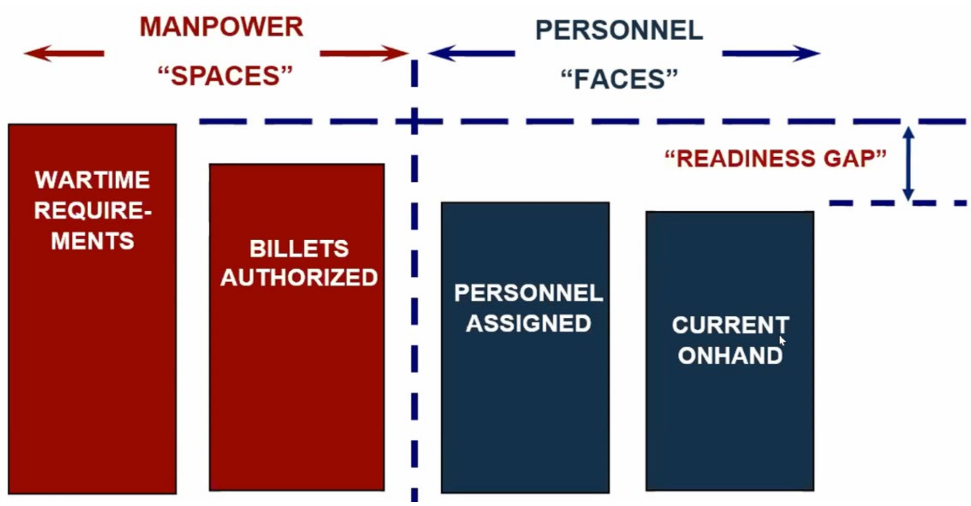


Figure 1. Manpower vs. Manning (Personnel). Source: Hernandez (2020).

After nearly a decade of implemented optimum manning, the Fleet Review Panel chaired by Vice Admiral Phillip Balisle, USN-Ret., in February 2010 revealed that Surface Force readiness had degraded over the previous 10 years. One factor causing the decline was the optimum manning initiative that did not assess shipboard manning requirements against shipboard maintenance requirements. Specific manpower recommendations of the Fleet Review Panel were (1) to increase manpower of optimum manned ships to 110% of their current authorized to account for the 8.4% gap in required versus actual bodies onboard; (2) immediately study actual shipboard manning requirements based on not only maintaining the ship but also watch standing and operational requirements; and (3) review Top Six Roll-Down (an initiative to move 25,000 billets down one pay grade) criteria (Balisle 2010).

In response to the Balisle report and by direction of NAVMAC, in 2011, Naval Postgraduate students Martin Fajardo and Luz Ortiz analyzed the PM:CM ratio standard for DDG class ships, which is used to predict the number of manhours required for CM based on the number of hours performed on preventative maintenance. Fajardo and Ortiz found the current ratio standards of 2:1 (mechanical) and 1:1 (electrical) significantly underestimated the amount of CM performed by analyzing the Open Architectural Retrieval System through Naval Sea Systems Command (NAVSEA). Their findings showed actual ratios of 1:1.64 (mechanical) and 1:10.9 (electrical). Their research concluded with a recommendation for NAVMAC and NAVSEA to conduct a study of actual shipboard maintenance performed and their newly determined ratios (Fajardo and Ortiz 2011).

In 2013, NAVMAC issued a revision to their Fleet Manpower Document instruction. While the instruction was a top-level view of the manpower requirements determination process and did not specify the PM:CM ratio standard, it did speak to the culture of the Surface Navy still being geared toward optimum manning. That is, manning for efficiency to the exclusion of maintenance. Compared to the Squadron Manpower Document (SQMD) which is based on "a comprehensive maintenance manhour per flight hour model" (DON 2013, p. 2), the afloat Ship Manpower Document (SMD) is based on identifying "the most efficient organization to support watch/workload" (DON 2013, p. 2)—in so many words, optimum manning. This is important to note as it seems that even in the three years following the Fleet Review Panel, the mindset of manning the Surface Navy had not changed.

In 2016, the National Defense Authorization Act authorized the Government Accountability Office (GAO) to conduct a "review of the Navy's reduced manning initiatives in the surface fleet" (Pendleton 2017, under "GAO Highlights"). They noted the Surface "maintenance backlogs increased during the optimal manning period (2003–2012) and continued to increase" through 2015. Navy officials also acknowledged the decrease in material condition and readiness of the ships due to the optimum manning. The GAO noted the Navy does not require reassessing of manpower determination factors or measuring workload while ships are in port. The GAO recommended the Navy "reassess the standard workweek, require examination of in-port workload, require reassessment of the factors used to develop manpower requirements, and identify personnel costs needed to man a larger fleet" (Pendleton 2017, under "GAO Highlights").

This thesis will expand on the Fajardo/Ortiz findings by examining the accuracy of the PM:CM ratio standard in predicting CM manhours. It also aims to answer a portion of the GAO call to reassess the factors used in developing manpower requirements and the Fleet Review Panel call to review actual shipboard manning requirements based on maintaining the ship.

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# III. METHODOLOGY

This chapter describes the process taken to address the research questions. It outlines the data collection and cleaning method. It also explains the analysis method used to produce the results outlined in Chapter IV.

## A. DATA COLLECTION

The first step in achieving the research objectives was collecting the data. This involved formulating an initial request for information (RFI), determining from whom to request that information, and scoping the request based on feedback.

Based on the research objectives in Chapter I, the initial RFI in Appendix C was generated. Surface engine maintenance occurs based on calendar- and engine-hour periodicity. Aviation engine maintenance is performed based on engine-hour periodicity with minimal "as-required" checks outside of that. The first PM check on the T-56 engine occurs at 200 hours. With this knowledge, the initial RFI scoped the data request at 200 engine hours, providing at least one Aviation PM check and multiple Surface checks of data. Within that periodicity, the following information was requested in the initial RFI:

1. What maintenance checks were completed.
2. Number of PM manhours per engine
3. Number of CM manhours per engine
4. Number of CASREPs per engine

Simultaneously, commands were identified for data requests. CNSP, through Antech Systems contractor, provided manhours of PM conducted on 501-K34 engines onboard Flight I DDGs based in San Diego, CA. Naval Surface Warfare Center (NSWC) Corona Division provided the Surface CM and CASREP data for Flight I DDGs. As the single P-3 fleet replacement squadron, VP-30 in Jacksonville, FL, was selected to obtain the largest pool of T-56 data from a single squadron. VP-30 provided manhours of PM and CM conducted on T-56 engines onboard P3 aircraft based out of Jacksonville, FL.

From the initial RFI, feedback was provided that required further scoping of the data request. PM was conducted on the T-56 engines every 200-, 600-, etc., hours and not calendar periodicities like daily, weekly, and monthly the way Surface ships do with 501-K34 engines. This meant there would be substantially fewer T-56 checks in the data request. Knowing this and to gain a large enough sample size, the data request periodicity was expanded to include all PM, CM, and CASREPs between December 2015 and December 2019. December 2015 was selected as the initial date because that was the last date of the 2017 GAO report observations. The closing date of December 2019 was selected to avoid abnormalities in the data due to the COVID-19 Pandemic. Additionally, the RFI resulted in only three San Diego ships populating data in the Antech Systems database. For this reason, the RFI was expanded to include an additional port. Norfolk, VA was selected due to the large sample size of Flight I DDGs that could be achieved. Finally, this thesis initially sought to use CASREP data to analyze a possible correlation between maintenance documentation systems and material readiness. A final discovery from the initial RFI was that there was not a CASREP-equivalent for Aviation engines. As such, CASREP-equivalent data was not available for the T-56 and correlation analysis was not conducted.

Final data collection included the following. The Surface data included 53,174 manhours of maintenance across 11 Flight I DDGs. The Aviation data included 17,673 manhours of maintenance across eight engines and five P3s.

## B. DATA CLEANING

### 1. SURFACE

As alluded to in the previous section, the Surface data came from two entities, PM from Antech Systems and CM from NSWC Corona. The cleaning of raw PM and CM data will be presented separately as the process was slightly different for the different data sets.

PM data was cleaned in the following fashion. Of the 5,081 PM checks, 696 were not noted as "Completed" in the check status column. These checks were removed from the data as they were considered unaccomplished. Mechanical and electrical maintenance on the 501-K34 is separated by workcenters in the Surface Navy. Workcenters EM01 and

EM02 are responsible for mechanical PM checks, whereas workcenter EM04 is responsible for electrical PM checks. Checks were annotated as mechanical or electrical based on the workcenter that accomplished the check.

CM data was cleaned in the following fashion. Of the 591 CM jobs, 226 were outside the periodicity for which this study was conducted. As such, those jobs were removed from the data. To partition the jobs into mechanical or electrical work, the job control number (JCN) was used as the workcenter was embedded within the JCN. 22 jobs did not contain either EM01, EM02, or EM04 workcenters and were removed from the data as they could not be distinguished as mechanical or electrical work.

Both PM and CM manhours were then summarized by ship. DDG-51 and DDG-67 were removed from the data set as they did not report CM and this analysis required a comparison of *both* PM and CM manhours. Actual PM:CM ratios were calculated by dividing the number of PM manhours by the number of CM manhours as seen in the following equation.

$$\frac{PM\ manhours}{CM\ manhours} = PM\!:\!CM\ ratio$$

Surface CASREP data was provided as consolidated number of 501-K34 engine CASREPs per ship and did not require cleaning.

After cleaning the data, the Surface data included 35,424.8 manhours of maintenance across nine Flight I DDGs that were available for analysis.

### 2. AVIATION

Aviation data was cleaned in the following fashion. As alluded to in Chapter I, T-56 manhours were provided by both engine serial number and aircraft bureau number. This made it unclear if manhours listed for an engine were also accounted for by the aircraft manhours. Simply, it was unclear if data was duplicated. This uncertainty required removal of the data assigned to the eight *engines* and instead only use data assigned to the five *aircraft*.

The data was then partitioned by PM or CM and mechanical or electrical maintenance. PM or CM was differentiated utilizing the work unit code where a number beginning with zero indicated PM and all other numbers indicated CM. Mechanical or electrical was differentiated by manually reviewing the "description narrative" and "corrective action" for an explanation of the work and assigning an "M" or "E" for mechanical or electrical maintenance, respectively.

Manhours were then summarized by aircraft. Electrical PM was not provided for any of the aircraft. Of note, the manhours spent on electrical CM accounted for only 2% of Aviation manhour data (whereas electrical CM accounted for 30% of Surface manhour data). This small portion of the data was removed as it was considered incomplete, and its removal would not impact results. This research focused only on mechanical checks for Aviation. PM:CM ratios were calculated using the same method as with the Surface data.

After cleaning the data, the Aviation data included 7,811.3 manhours of maintenance across five P3s.

## C. ANALYSIS METHOD

### 1. PRIMARY RESEARCH QUESTION

The primary research question was, "*How accurately is the Navy predicting Surface manpower requirements based on manhours spent on engine maintenance?"* The Navy uses ratio standards to predict Surface manpower requirements for CM. The primary research question was answered first by evaluating the range, average and median of actual PM:CM ratios since inaccurate ratios would prove an inaccurate prediction of manpower requirements. To better answer *how* accurate, percent error was calculated; this offered a comparison of actual ratios to what was in use. This research question was also answered by predicting what past ratio accuracy implies for future ratio accuracies. Normalcy was determined before conducting likelihood calculations.

The range, average, and median of actual PM:CM ratios were determined using Microsoft Excel formulas. The median is a robust indicator of where the data is centered, whereas the average is more sensitive to outliers. Similar average and median indicate a symmetric data set where the average is a good indicator of the center of the data. A wider range and relatively large difference between the median and average indicate there are outliers and the median should be used to indicate the center of the data. Based on the reliability of the average, the average or median were used to compare the actual ratios to the Navy ratio standards. Assuming consistent PM, a smaller ratio suggested there was more CM than predicted. Conversely, a larger ratio suggested there was less CM than predicted.

The nature of any prediction is an understanding that it will never be 100% accurate. To better answer *how* accurate, percent error was calculated for each hull using the following formula. An absolute value was used because the magnitude of the delta was needed to calculate percent error.

$$\frac{|actual\ ratio - Navy\ ratio|}{Navy\ ratio} = percent\ error$$

The previous analysis evaluated the accuracy of past predictions. While this was interesting, it was further interesting to evaluate what the accuracy (or inaccuracy) of the past data set indicated for future data sets. Simply, *did past inaccurate predictions indicate future inaccurate predictions?* To evaluate the likelihood of observing certain inaccurate predictions, it was first determined if the data was normally distributed. Normalcy and probabilities were determined based on the delta between the Navy and the actual PM:CM ratios as seen in the following equation. The ratio delta was chosen for this part of the analysis because it was an indicator of the accuracy of predicting CM: A positive delta indicated the actual ratio was smaller than the Navy ratio standard, and, assuming consistent PM, a smaller ratio indicated the ship experienced more CM than predicted. Conversely, a negative delta indicated a larger actual ratio and that a ship experienced less CM than predicted. This concept is illustrated in Figure 2.

$$Navy\ ratio - actual\ ratio = ratio\ delta$$

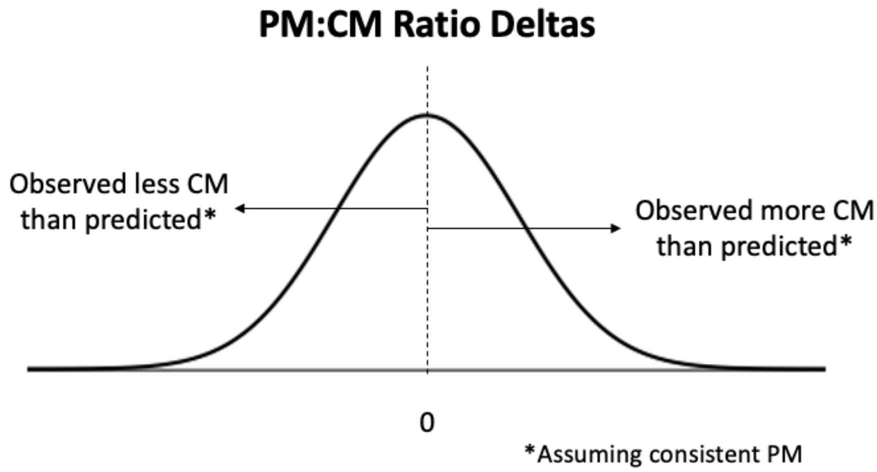

Figure 2. Inference of PM:CM Ratio Delta

Histograms were used to visualize the distribution of the deltas in actual versus Navy ratio standards where a bell-shaped curve indicated a normal distribution. Additionally, normal probability plots were used to confirm normalcy. Normal probability plots are a plot of standard normal values against the standardized actual values. Ratio deltas were standardized using the following formula with mean and standard deviation for each mechanical and electrical calculated using Microsoft Excel formulas. If the data sets were normal, the data points made a general straight diagonal line through the center.

$$\frac{ratio\ delta - mean}{standard\ deviation} = standardized\ ratio\ delta$$

If the data sets were normally distributed, probability analysis was performed. Because the ship sample size was less than 30, the student t-distribution was used in Microsoft Excel to calculate these probabilities. The ratio delta is considered a continuous number because it can take on an infinite number of possible values. Being a continuous number with infinite possibilities, the likelihood of observing a ratio delta of a certain value, say, zero, was essentially zero. For this reason, the probability density function could not be used to determine the likelihood of the next observation being an *exact* value. Instead, the cumulative distribution function was used to determine the probability of the next ratio delta to be a *range* of values. Likelihood of a ship experiencing a ratio delta greater than zero was calculated for both mechanical and electrical data.

### 2. SECONDARY RESEARCH QUESTION

The first of two secondary research questions was, "*How does the amount of manhours compare on similar engines in different operational concepts—Surface and Aviation?*" This research question was addressed first by evaluating the manhours per engine on the 501-K34 versus the T-56. Percent difference was calculated to provide more granularity in the difference relative to each other. Additionally, a t-test was performed to determine if a difference (if any) was statistically significant or simply due to chance.

A reminder that the data received was in the form of manhours per *platform*, not per *engine*. To compare the number of maintenance manhours on engines, manhours per platform was first converted to manhours per engine in the following fashion. The Flight I DDG has three 501-K34 engines and the P3 has four T-56 engines. As such, the manhours per ship were divided by three and manhours per aircraft were divided by four. While these manhour-per-engine values may not reflect actual numbers, they provided approximate estimates for the purposes of comparing Surface to Aviation. Again, sufficient data was not available to perform analysis on *electrical* T-56 maintenance, and so the Surface and Aviation comparison focused on *mechanical* maintenance.

To provide more granularity of the difference in maintenance performed on the two engines relative to each other, the percent difference was calculated using the following formula:

$$\frac{|Surface\ manhours - Aviation\ manhours|}{average\ of\ Surface\ and\ Aviation\ manhours} = percent\ difference$$

A t-test provided greater granularity as to whether the difference in Surface and Aviation manhours was statistically significant or simply due to chance. The t-test was performed using the Microsoft Excel Data Analysis tool assuming unequal variances of the two samples (Surface and Aviation). The t-test assumed the null hypothesis that there was no statistically significant difference between the samples, meaning the samples were from the same population (ratios are considered the same for both Surface and Aviation). The test outputted several variables that indicated the status of the null hypothesis. A t-statistic greater than the critical value indicated the test rejected the null hypothesis. A t-statistic less than the critical value indicated the test failed to reject the null hypothesis.

The second part of the secondary research questions was, "*What factors would explain differences (if any) in the amount of maintenance performed on similar engines in different operational concepts?*" This question was addressed by discussing the different operational concepts, different maintenance documentation systems, and different community cultures.

# IV. DATA ANALYSIS AND INTERPRETATION

This chapter presents analysis results and interpretation after following the methodology in Chapter III. A warranted discussion about quality of data is also provided.

## A. PRIMARY RESEARCH QUESTION

The primary research question was *How accurately is the Navy predicting Surface manpower requirements based on manhours spent on engine maintenance?*

The actual mechanical ratios ranged from 0.29 to 3.53, averaged 1.32, and had a median of 1.13. The mechanical average was relatively similar to the median, and so the average was used to compare the actual ratios to the Navy ratio standard. The average mechanical ratio tended moderately closer to 1.0 than the Navy 2.0 ratio standard. Assuming consistent PM, the smaller mechanical ratio suggested there was more CM than predicted. The electrical ratios observed a wider range from 0.04 to 5.32, averaged 1.96, and had a median of 0.56. The difference between the electrical ratio average and median was substantial (27% of the range). As such, the median is used to compare the actual ratios to the Navy ratio standard. The electrical ratios tended relatively close to the Navy 1.0 ratio standard, with the smaller electrical ratio suggesting there was more electrical CM than predicted. These tendencies away from what the Navy used indicated the Navy's Surface manpower requirement predictions were inaccurate. To investigate the magnitude of inaccuracy, percent error was calculated.

Percent error calculations confirmed that the actual ratios were inaccurate compared to what the Navy used. In four cases, the difference was by as much as hundreds of percentage points. Mechanical ratios were significantly inaccurate with an average of 60.0% error. Electrical ratios were even more inaccurate with an average of 165.1% error. The large percent error in both mechanical and electrical ratios illustrated the high degree to which the determination of manpower requirements for this sample of ships was inaccurate.

Histograms were developed to visualize the distribution of the deltas in hopes of determining likelihood of observing certain inaccurate predictions. The histograms do not appear to exhibit the typical bell-shaped curve of a normal distribution as shown in figures 3 and 4. Because the histograms were inconclusive, normal probability plots were used to further evaluate normalcy.

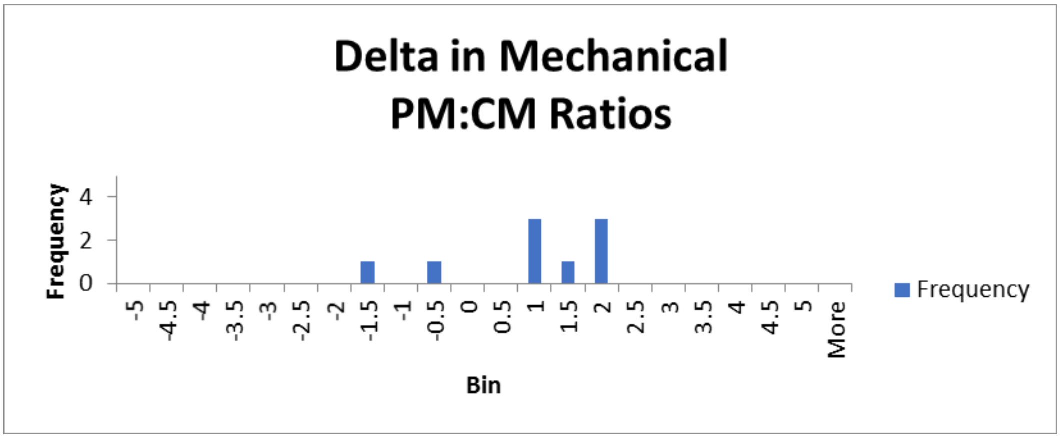


Figure 3. Histogram of Deltas in Mechanical PM:CM Ratios

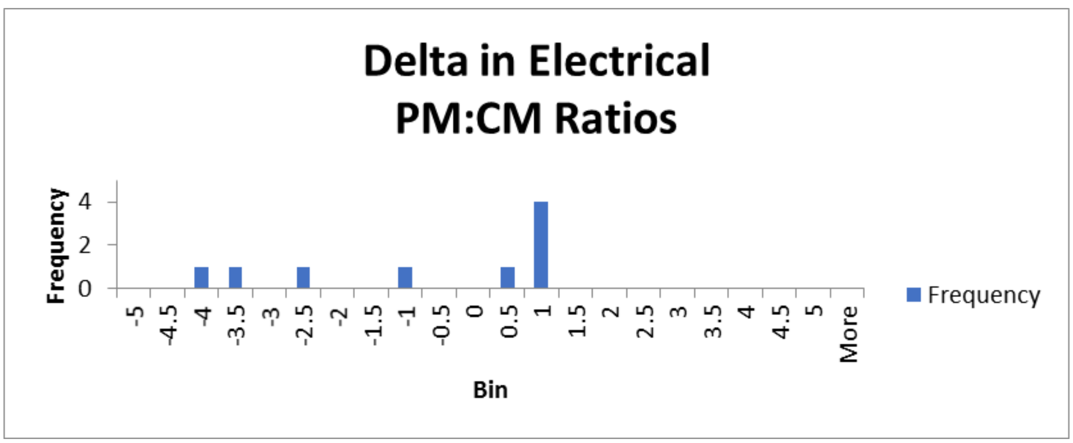


Figure 4. Histogram of Deltas in Electrical PM:CM Ratios

If the data sets exhibited a normal distribution, the large, blue data points would make a general diagonal line like the dashed, orange ideal line in Figure 5. As seen with the linear, blue trendline, this was the case in both mechanical and electrical instances. The probability plots provide a reasonable basis to treat the existing data as following a normal distribution. Because the data follows a normal distribution, probability analysis was used to evaluate the likelihood of observing certain inaccurate predictions.

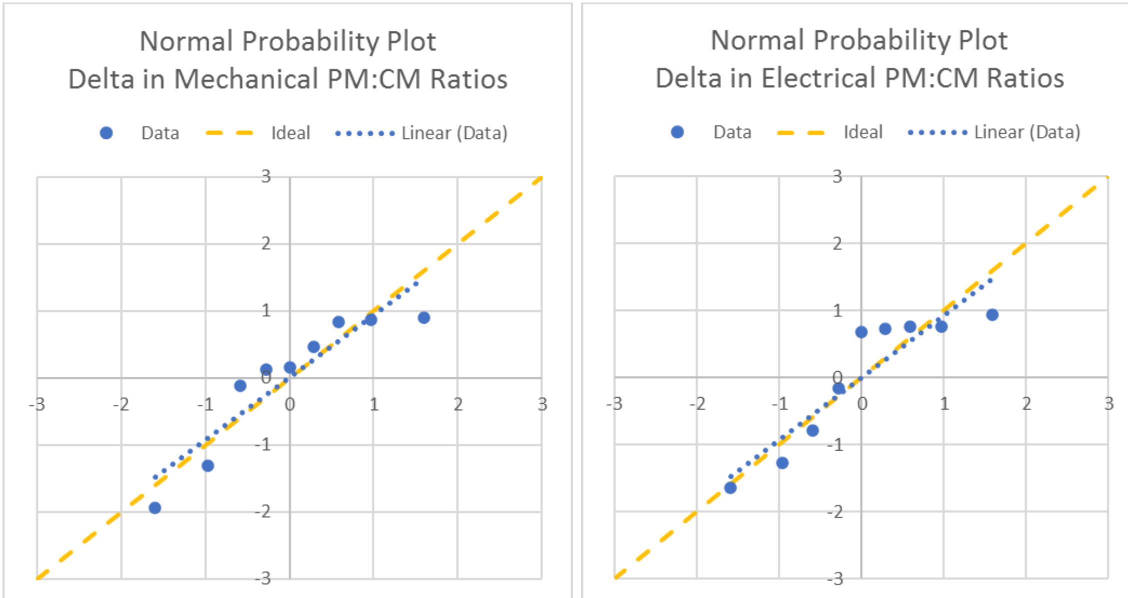


Figure 5. Normal Probability Plots for Mechanical and Electrical Deltas in PM:CM Ratios

Based on mechanical data, it is 29.4% probable that the next Flight I DDG will observe more mechanical CM on the 501-K34 engine than predicted by the Navy PM:CM ratio standard. Similarly, based on electrical data, it is 66.6% probable that the next Flight I DDG will observe more electrical CM on the 501-K34 engine than predicted by the Navy PM:CM ratio standard. These predictions indicate Flight I DDGs will more often observe less mechanical CM and more electrical CM than predicted by the Navy PM:CM ratio standards. In either case, mechanical or electrical, it is likely the determination of manpower requirements for Flight I DDG 501-K34 engine maintenance will be inaccurate.

This analysis validated the Fajardo and Ortiz findings that the Navy PM:CM ratio standards were inaccurate (Fajardo and Ortiz 2011). In the case of mechanical and electrical maintenance, the Navy PM:CM ratio standards were inaccurate by hundreds of percentage points compared to the actual ratios. Additionally, the Navy ratio standards will likely prove inaccurate CM predictions in the future. From multiple perspectives, the actual manpower requirements are not in line with what the Navy predicts and suggests Flight I DDGs are not manned appropriately with regard to 501-K34 engine maintenance.

## B. SECONDARY RESEARCH QUESTION

The first of two secondary research questions was, "*How does the amount of manhours compare on similar engines in different operational concepts—surface and aviation?*" The following paragraphs answer this question by using analysis methods described in Chapter III.

Manhours spent conducting mechanical PM averaged 380.5 on the 501-K34 and 77.1 on the T-56. Manhours spent conducting mechanical CM averaged 533 on the 501-K34 and 313.4 on the T-56. At first glance, the PM manhours was an order of magnitude more on the 501-K34 than on the T-56, whereas CM manhours between the two types of engines was on the same order of magnitude. These figures are displayed in Table 1. To provide more granularity of the difference in maintenance performed on the two engines relative to each other, the percent difference was calculated.

As suspected with the order of magnitude difference, PM manhours were largely different between 501-K34 and T-56 engines, with a 132.6% difference. The 501-K34 and T-56 manhours were more closely related with CM manhours percent difference of 52%. The relatively large percent difference suggests the number of manhours is largely different on similar engines when utilized in different operational environments. These figures are displayed in Table 1. A t-test was performed to determine whether the difference in surface and aviation manhours was statistically significant or simply by chance.

Table 1. Manhours per Engine

| | AVG HOURS PER ENGINE | | % DIFFERENCE | |
|---|---|---|---|---|
| Platform | PM | CM | PM | CM |
| DDG | 380.5 | 533 | 132.6% | 52% |
| P3 | 77.1 | 313.4 | | |

The PM t-test calculated a t-statistic of 5.126, critical t-value of 2.228 and p-value of 0.0004. Because the t-statistic was more than the critical value, the test rejected the null hypothesis. This meant the PM manhours were significantly different between the 501-K34 and T-56 engines. The CM t-test calculated a t-statistic of 1.073, critical t-value of

2.179 and p-value of 0.3044. Because the t-statistic was less than the critical value, the test failed to reject the null hypothesis. This meant there was not sufficient evidence to support the statement that CM manhours were significantly different between 501-K34 and T-56 engines.

From multiple analyses, the mechanical PM was significantly different between 501-K34 and T-56 engines—so much so that they were considered to be from different populations. While mechanical CM data proved to be relatively different between Surface and Aviation, there was not sufficient evidence to support stating the data came from two different populations. Overall, there was some factor that made the number of manhours of mechanical maintenance significantly different between Surface and Aviation engines.

The second part of the secondary research question was, "*What factors would explain differences (if any) in the amount of maintenance performed on similar engines in different operational concepts?*"

The previous part of this research question established there was a significant difference in the number of mechanical PM manhours performed on the 501-K34 versus the T-56. The first, and more obvious, factor that could contribute to the difference in maintenance manhours is that, while the 501-K34 and T-56 are similar engines, they were used in different operational concepts. The 501-K34 engines are run while the ship is underway, but not while the ship operates pierside. Additionally, ships rotate engines such that two are online in parallel while one is offline. While deployed, the engines are used on and off the entire day for sometimes a month long *as well as* used pierside while in port. Conversely, all four T-56 engines run each time the aircraft operates. While deployed, the engines may operate several hours at a time during a 24-hour period. The different run times for the 501-K34 and T-56 would explain different maintenance manhours.

The second factor that could contribute to the difference in maintenance manhours between the 501-K34 and T-56 engines is the way in which the maintenance was documented. When Aviation PM and CM is completed, the workcenter takes credit for the manhours NALCOMIS clocks while Sailors gather and stow support equipment (for example, tools and hazardous material) and conduct the maintenance. When Surface PM is completed, the workcenter takes credit for the number of manhours listed on the maintenance card. This does not include time for support equipment nor is the *actual* time to conduct the maintenance, but instead, an estimate of how long the maintenance *should* take. When Surface CM is performed, the workcenter takes credit for the number of manhours the workcenter estimated it took. This varies between person to person and ship to ship and may or may not include the time for support equipment. The difference in maintenance documentation methods would explain different manhours reported to conduct the same maintenance.

The third factor which would contribute to a difference in maintenance manhours reported for the 501-K34 and T-56 engines is cultural differences. The Aviation community places a high priority on aircraft maintenance. The Squadron Manpower Document (SQMD) allocates maintenance manhours to squadrons based on a "maintenance manhour per flight hour model" (DON 2013) whereas the Surface Manpower Document (SMD) allocates manhours to afloat commands based on "the most efficient organization" (DON 2013). Additionally, the Aviation community develops specialized maintainers by partitioning enlisted rates into two categories: operators and maintainers. Aviation maintainers are responsible solely for the maintenance of the aircraft, whereas Surface engine maintainers are simultaneously charged with operating and damage control efforts for the engines in addition to other shipboard equipment. The Aviation community made an enlisted rate dedicated to documenting maintenance—a final fact that establishes the emphasis placed on maintenance documentation in the Aviation community. The Aviation Maintenance Administrationman rate "performs a variety of clerical, administrative, and managerial duties necessary to keep aircraft maintenance activities running efficiently" (Navy COOL 2020). While the Surface community has a collateral duty to oversee the ships 3M system, it does not have an equivalent rate dedicated to accurate documentation of maintenance. The differing cultures may explain a difference in manhours to conduct maintenance on similar engines.

The systemic differences of operational concepts, maintenance documentation, and culture together explain the difference in maintenance manhours on similar engines, the 501-K34 and T-56.

## C. DATA QUALITY

An important part of making inferences based on data is understanding the quality of that data. The human effect on the system and the quantitative properties of the data support this understanding.

Humans perform the maintenance, and so there is an element of variance introduced into the data. While maintenance cards dictate how to perform maintenance and how long the maintenance should take, there may be slight differences between each person, ship, and aircraft. The actual ratios exhibited a normal distribution, however, and so the differences introduced by having humans perform the maintenance is as expected and acceptable.

Another human element that could alter the results is the method in which Aviation data was partitioned into mechanical or electrical maintenance. This was accomplished by the author manually reviewing the "description narrative" and "corrective action" for an explanation of the work and assigning an "M" or "E" for mechanical or electrical, respectively. The author's interpretation of the work performed could introduce unintentional bias to the distribution of Aviation maintenance, and, thus, unintentional bias to the results and interpretation.

In addition to understanding the effect of the human element is analyzing the quantitative properties of the data. For both Surface and Aviation, the range of PM:CM ratios was within the expectation as they were on the same order of magnitude of and included the current Navy ratio standards (2.0 and 1.0). This data point, while simplistic, provided confirmation of initial calculations and data organization. The most telling of the ratio data was the standard deviation and its comparison to the average. All standard deviations were large in comparison to their respective averages. This meant there was large variation in the data set, meaning the ratios would not tend to be close to the average. In the case of the electrical Surface ratio and mechanical Aviation ratio, the standard deviations were larger than the averages. This allows for erroneous negative ratios to be present in predicted data sets. This is indicative of a poor sample. Ratio averages and standard deviations are presented in Table 2.

Table 2. Average and Standard Deviation of Surface and Aviation PM:CM Ratios

| | Surface | | Aviation | |
|---|---|---|---|---|
| | Mech | Elec | Mech | Elec |
| Average | 1.32 | 1.96 | 0.99 | N/A |
| StDev | 1.14 | 2.05 | 1.09 | N/A |

A possible reason for the high variance could be that there is not a linear relationship between PM and CM manhours. In this case, a PM:CM ratio should not be used to predict CM manhours as part of manpower requirements. A more likely explanation for the high variance is that the sample size of ships and aircraft was not large enough to produce data that can be used to generalize or make policy.

# V. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This chapter will first summarize the research and findings. It will then present conclusions and recommendations based on the findings. Finally, it will discuss further research that would have broadened the research aperture rather than narrow the focus.

## A. SUMMARY

This research analyzed the accuracy of the Navy's PM:CM ratio standard in predicting shipboard manpower requirements needed specifically for maintaining 501-K34 engines onboard Flight I DDGs. It also evaluated the difference in maintenance manhours performed on similar engines, the 501-K34 and the T-56, used in different operational concepts. Manhours of PM and CM performed on 501-K34 and T-56 engines were collected for San Diego, CA, and Norfolk, VA, based Flight I DDGs and P3s based in Jacksonville, FL.

Based on the assessment of the data collected, the actual PM:CM ratios tended to be smaller than the Navy ratio standards. This suggests more CM was performed than predicted. While both mechanical and electrical ratios proved to have a large percent error compared to the Navy ratio standard, electrical ratios were substantially more inaccurate than mechanical. Probability analysis indicated the Navy will more often observe less mechanical CM and more electrical CM than predicted.

The analysis also showed there was a difference in maintenance manhours between the Surface and Aviation similar engines, the 501-K34 and the T-56; however, there was more of a percent difference observed with PM than CM. In fact, evidence supported the statement that PM manhours were significantly different between the 501-K34 and T-56 engines, and the difference did not happen by chance. There was not sufficient evidence to support stating CM manhours were significantly different between 501-K34 and T-56 engines. Possible factors that would explain the observed difference in maintenance manhours was the differences in operational concepts, maintenance documentation, and community cultures.

## B. CONCLUSIONS AND RECOMMENDATIONS

### 1. Primary Research Question

*How accurately is the Navy predicting Surface manpower requirements based on manhours spent on engine maintenance?*

a. Conclusion: This study concluded that Flight I DDG manpower does not accurately reflect the manpower required to conduct 501-K34 engine maintenance. Actual PM:CM ratios tended to be 1.32 for mechanical and 0.56 for electrical, which were smaller than the Navy ratio standards of 2.0 and 1.0, respectively, and indicated there was more CM than predicted. The Navy ratio standards averaged 60.0% and 165.1% error from the actual PM:CM ratios. These tendencies away from and large percent error from the Navy ratio standards illustrated the high degree to which the current ratio standards used to determine manpower requirements for this sample of ships was inaccurate. Additionally, it is 70.6% and 66.6% likely the Navy will observe less mechanical CM and more electrical CM on the 501-K34 engine than predicted by the Navy PM:CM ratio standards. In either case, mechanical or electrical, it is likely the current ratio standard will inaccurately predict Flight I DDG 501-K34 engine maintenance manpower requirements. According to the Fleet Review Panel, the inaccurate ratio standard could contribute to poor material condition of readiness of the Surface Fleet (Balisle 2010).

While this research examined actual PM:CM ratios, those ratios were based on maintenance on *one* piece of equipment, the 501-K34 engine. The Navy PM:CM ratio standards are based on *all* workcenter equipment maintenance. As such, the actual PM:CM ratios found in this study should not replace the current Navy PM:CM ratio standards. Instead, this study provided one of many data points in the last decade that suggest the Navy did not either accurately determine the requirement or improperly fund the requirements for the Surface Fleet.

b. Recommendation: NAVMAC conduct a study of all Flight I DDG workcenters to validate actual PM:CM ratios and update ratio standards to better reflect actual fleet CM requirements.

### 2. The Secondary Research Questions

*How does the amount of maintenance manhours compare on similar engines in different operational concepts—Surface and Aviation?*

*What factors would explain differences (if any) in the amount of maintenance performed on similar engines in different operational concepts?*

a. Conclusion: This study concluded that, the maintenance manhours were different between similar engines, the 501-K34 (Surface) and the T-56 (Aviation). Mechanical PM was significantly different between the 501-K34 and T-56, and the difference is not by chance. While mechanical CM proved to be relatively different between Surface and Aviation engines, there was not sufficient evidence to support stating the CM manhours were *significantly* different or that the difference was not due to chance. In conclusion, to maintain the current operational availability the Surface 501-K34 engine required more maintenance manhours than the Aviation T-56 engine.

While the systemic differences in operational concepts, maintenance documentation, and culture could plausibly explain the difference in manhours on the similar engines, this paper did not prove correlation or causation. This study simply showed that, although the engines are similar, there was a clear difference in the maintenance. This was the first step in determining if one maintenance system better supports equipment availability and fleet readiness.

b. Recommendation: NAVSEA and Naval Air Systems Command conduct a study to determine the operational availability of each engine to determine if one maintenance system better supports the availability of the engine within that system. Specifically, are 501-K34 or T-56 engines more operationally available when supported by the 3M or NALCOMIS maintenance systems? The concept of this recommendation is illustrated in Figure 6.

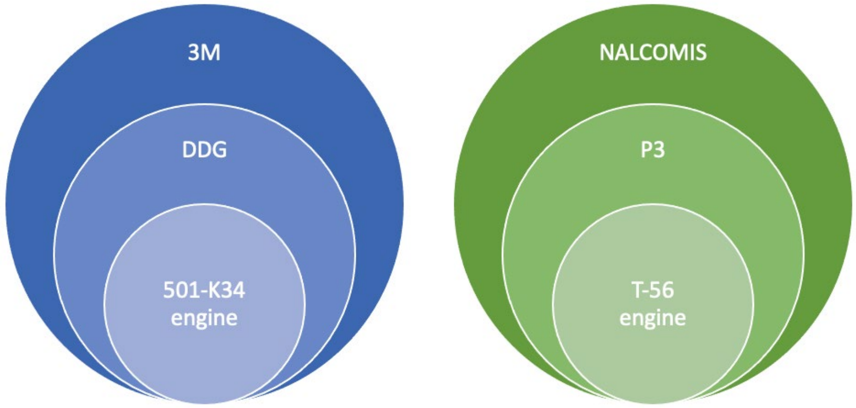


Figure 6. Maintenance Systems Involving the 501-K34 and T-56 Engines

## C. FURTHER RESEARCH

Due to the time constraint of the academic setting, entire workcenters were not analyzed in this research as this would have broadened the scope of research. Additional research that analyzes all workcenter equipment would benefit the establishment of more accurate PM:CM ratio standards.

# APPENDIX A. PM:CM RATIO TABLE

PM/CM RATIO TABLE Updated: 4 Oct 2021

| RATING | PM:CM RATIO | RATING | PM:CM RATIO |
|---|---|---|---|
| AB | 1:1 | FCA | 1:1 |
| ABE | 1:1 | FT | 1:1 |
| ABF | 2:1 | GM | 1:1 |
| ABH | 2:1 | GS | 1:1 |
| AC | 2:1 NEC Only; Non-NEC 1:1 to ET | GSE | 1:1 |
| AD | 2:1 | GSM | 2:1 |
| AE | 1:1 | HM | 2:1 |
| AF | 2:1 | HN | 2:1 |
| AG | 2:1 NEC Only; Non-NEC 1:1 to ET | HT | 2:1 |
| AM | 1:1 | IC | 1:1 |
| AME | 1:1 | IS | 2:1 |
| AO | 1:1 | IT COMMs | 1:1 NEC only; Non-NEC 1:1 to ET |
| AS | 2:1 | IT NETWORK | 3:1 |
| AT | 1:1 | ITS | 3:1 |
| AV | 1:1 | LN | 2:1 |
| AW | 1:1 | LS | 2:1 NEC only; Non-NEC 2:1 to MM |
| AWO | 2:1 | LSS | 2:1 NEC only; Non-NEC 2:1 to MMA |
| AWR | 2:1 | MA | 2:1 |
| AWS | 2:1 | MC | 2:1 |
| AZ | 2:1 | MM | 2:1 |
| BM | 2:1 | MMA | 2:1 |
| BU | 2:1 | MMW | 2:1 |
| CE | 1:1 | MMN | 2:1 |
| CM | 2:1 | MN | 1:1 |
| CMD | 2:1 | MR | 2:1 |
| CS | 2:1 NEC only; Non-NEC 2:1 to MM | MT | 2:1 |
| CSS | 2:1 NEC only; Non-NEC 2:1 to MMA | NC | 2:1 NEC only; Non-NEC 2:1 to MM |
| CTI | 2:1 NEC Only; Non-NEC 1:1 to CTM | ND | 2:1 |
| CTM | 1:1 | OS | 1:1 NEC only; Non-NEC 1:1 to ET |
| CTN | 1:1 NEC Only; Non-NEC 1:1 to CTM | PO | DCPO Maintenance Only – 2:1 *and* Split % credit DC (.3 /Hr), MM (.1 /Hr), EM (.1 /Hr) |
| CTR | 2:1 NEC Only; Non-NEC 1:1 to CTM | PR | 2:1 |
| CTT | 1:1 | PS | 2:1 NEC only; Non-NEC 2:1 to MM |
| CU | 2:1 | QM | 2:1 |
| DC | 2:1 | RP | 2:1 NEC only; Non-NEC 2:1 to MM |
| EA | 2:1 | SB | 2:1 |
| EM | 1:1 | SH | 2:1 NEC only; Non-NEC 2:1 to MM |
| EMN | 1:1 | SO | 2:1 |
| EN | 2:1 | STG | 1:1 |
| EO | 2:1 | STS | 1:1 |
| EOD | 1:1 | SW | 2:1 |
| EQ | 2:1 | UC | 2:1 |
| ET | 1:1 | UT | 2:1 |
| ETV | 1:1 | YN | 2:1 NEC only; Non-NEC 2:1 to MM |
| ETR | 1:1 | YNS | 2:1 NEC only; Non-NEC 2:1 to MMA |
| ETN | 1:1 | | |
| FC | 1:1 | | |
| | | | |

Table 2 *Submarines use MMA(.3/Hr), ETV(.1/Hr), and EMN(.1/Hr). Adapted from Wayne McGovern (email message to author, October 13, 2021).

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# APPENDIX B. LIST OF SHIPS

USS ARLEIGH BURKE (DDG 51)

USS STOUT (DDG 55)

USS MITSCHER (DDG 57)

USS LABOON (DDG 58)

USS RUSSELL (DDG 59)

USS PAUL HAMILTON (DDG 60)

USS RAMAGE (DDG 61)

USS FITZGERALD (DDG 62)

USS GONZALEZ (DDG 66)

USS COLE (DDG 67)

USS ROSS (DDG 71)

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# APPENDIX C. INITIAL RFI

**From:** "Dori, Margaret (LT)" <margaret.dori@nps.edu>
**Date:** Saturday, March 6, 2021 at 10:51 AM
**To:** "Brugger, Jerry L CIV USN COMNAVSURFPAC (USA)" <Jerry.Brugger@navy.mil>, "mark.leary@navy.mil" <mark.leary@navy.mil>, "michael.j.hardin1.ctr@navy.mil" <michael.j.hardin1.ctr@navy.mil>
**Cc:** "Sunvold, Daniel (Dan) (CAPT)" <daniel.sunvold@nps.edu>, "McCabe, Edward (Tick) (CAPT)" <edward.mccabe@nps.edu>, "Hatch, William (Bill) (CIV)" <wdhatch@nps.edu>, "Hernandez, Alejandro (Andy) (CIV)" <ahernand@nps.edu>, "Boensel, Matthew (Matt) (CIV)" <mgboense@nps.edu>
**Subject:** Data request: Comparison of NALCOMIS and 3M

Hello,

My name is LT Maggie Dori and I am an EDO (prior SWO) at Naval Postgraduate School (NPS). I am conducting a comparative analysis of NALCOMINS and Surface ship 3M. Specifically, I am comparing how DDG51 class engine generator and P-3 engine maintenance is attributed by means of engine hours, periodicity of Maintenance checks, and Casualty Reports (CAREPS). I am requesting this data through the Navy Captain's at NPS that hold the Commander Naval Air Forces Pacific and Commander Surface Forces Pacific chairs and Professor Bill Hatch, CDR USN. ret.as my thesis advisor.

BLUF:
Requesting, for 200 engine hours on each T-56/501-K34 engine:
1) What maintenance checks occurred within that engine hour periodicity;
2) Number of preventative maintenance (PM) labor hours spent per T-56/501-K34 engine during that periodicity (via NALCMOIS & 3M systems);
3) Number of corrective maintenance (CM) labor hours spent per T-56/501-K34 engine during that periodicity (via NALCMOIS & 3M systems);
4) Number of CASREPs submitted per T-56/501-K34 engine during that periodicity.

BACKGROUND:

My hypothesis suggests there is a correlation between the accuracy of the maintenance documentation, manpower requirements and fully mission capability of the engines. The main objective of the thesis is to test my hypothesis that NALCOMIS more accurately documents labor hours spent on preventative and corrective engine maintenance compared to the afloat version (3M system). I want to compare the two systems using similar engines on different platforms, the T-56 on the P-3 and 501-K34 (GTG) on Flight I DDGs. Specifically, for a certain engine hour periodicity compare the number of PM/CM labor hours logged per engine. I posture that if the 3M hours are outside the probability distribution of NALCOMIS, this would identify if there is a significant difference in the amount of maintenance the Navy is performing on the same engine on different platforms. Further, T-56/501-K34 engine material readiness will be compared in the form of number of CASREPs per engine. I propose that if 501-K34 engine readiness is outside the probability distribution of the T-56, then there is also a significant difference in engine readiness.

I would suspect the majority of the surface ship maintenance would come out of the MP division within the engineering department and P-3 from the Maintenance department. Aviation has AZs who document this work but unclear if surface ships have a designed person to log engine work, please confirm.

I am not an expert on the engines or maintenance systems. If my terminology or phrasing is incorrect or if what I am saying does not make sense, please provide better context.

I am requesting the data by 26-Mar. I am available by e-mail or phone to answer any questions or clarify. Thank you for offering your assistance in my research.

V/r,
LT Maggie Dori

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