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DoD Aircraft Maintenance Rating Analysis

Matthew Beigh, Jonathan Grinsell, David Jeong, Aliyah Murray, and Daniel Voecks

Department of Systems Engineering
United States Military Academy
West Point, NY 10996

Corresponding author's Email: Matthew.Beigh@usma.edu, Jonathan.Grinsell@usma.edu, David.Jeong@usma.edu, Aliyah.Murray@usma.edu, Daniel.Voecks@usma.edu

Author Note: Cadets Grinsell, Jeong, Murray, and Voecks are seniors at the United States Military Academy studying in the Department of Systems Engineering. Upon graduation, they will commission as Second Lieutenants in the United States Army. Major Matthew Beigh, instructor in the Department of Systems Engineering, served as advisor for our research. His guidance and instruction has helped us throughout the course of this project. We are sincerely thankful for all of the time and effort he invested in us and his determination to push us to succeed.

Abstract: The Department of Defense recognizes the importance of corrosion prevention in the military and its impact on the military equipment, infrastructure, and the associated high annual cost. The Corrosion Policy and Oversight office seeks to determine whether corrosion related maintenance is addressed effectively frugally on DoD assets in order to meet the availability targets. West Point administration provided a capstone group the opportunity to analyze "big data" with the final goal of establishing a method of scoring the relationship between CPO's two superordinate goals: achieved availability compared to target and cost per day of availability. The group created a model that provided a score of how well certain units and locations controlled maintenance. The group then used this information to identify parts that play significant roles in cost and maintenance performance.

Keywords: Maintenance, Availability, Corrosion, Performance Scoring, Big Data

1. Introduction

The United States Congress and the Department of Defense (DoD) have recognized the importance of corrosion prevention and control in the military not only for the safety and availability of military equipment and infrastructure, but because it costs taxpayers approximately $23 billion dollars annually, 25% of every maintenance dollar (U.S. GAO, 1). To address this issue, the DoD established the Corrosion Policy and Oversight (CPO) office, the client for this project in conjunction with Logistics Management Institute (LMI), a non-profit consulting firm. While methods to combat corrosion exist, a definite solution on how to solve the problems surrounding corrosion in the long term does not exist. Rather, corrosion is still a prevalent risk to aircraft and their capabilities requiring continuous modern research to find better and improved solutions. Specifically within aircraft, corrosion impacts the metal parts and is usually identified by a whitish grey color as opposed to the common red rust (Aircraft Corrosion).

The CPO partnered with LMI to create the Maintenance and Availability Data Warehouse (MADW) for the better understanding of the effects of corrosion through the analysis of historical records. This effort, led by LMI senior fellow Eric Herzberg, resulted to the construction of a massive repository of maintenance records across the DoD. This database could allow for a bottom up analysis of aircraft performance and availability that was previously not possible. In meetings with the primary stakeholders, Eric Herzberg at LMI and Dan Dunmire at CPO, it was made clear that the mission of our work for the DoD Corrosion Policy and Oversight Office is to create a model in order to assess aircraft and determine "how well the DoD is doing" with regards to spending tax payer dollars to meet mission availability standards. This model will consequently allow the CPO office to enact policy across all branches of the military in order to more efficiently address corrosion maintenance, resulting in increased availability and fewer tax dollars spent. This success is determined through two superordinate goals: achieved availability compared to target and cost per day of availability. The cost per day of availability is a helpful "gauge of how effectively and efficiently each maintenance dollar is spent", in short, it is "the amount of available time for each weapon system… [calculated from] the possible time a system can be available during a specific time frame minus the time it is not available during the same time frame" (Watson, 2017).

Cost per Day of Availability	Conclusion	Action	Grade
↓	Winning	Celebrate	A
–	Almost Winning	Stay Focused	B
↑	Potential Problem	Reduce Cost	C
	Availability		
↓	Potential Problem	Buy Availability	D
–	Potential Problem	Allocate Money Efficiently	E
↑	Worst Problem	Allocate Money Efficiently	F

Figure 1: Proposed Scale for Equipment Availability

As seen in Figure 1, a proposed grading scale by LMI, maintenance should strive to decrease how much it costs to keep the system working over extended periods of time as well as meet a predetermined threshold for availability. In the figure, the up arrow represents increasing cost per day of availability and decreasing for the down arrow; the hash represents no change. According to these superordinate goals, the "successful" aircraft would be those that are at or above the availability target with a low, or decreasing, cost per day of availability. The worst aircraft would be below the availability target with an increasing cost per day of availability, meaning that the system is non-mission capable more that it should be. Subsequently, it also means that more money is being spent to for less usable time. This combination means that the DoD is spending large sums of money on an aircraft only for the aircraft to fall short of the availability target. Once this process has been completed for the all aircraft of a specific model (for example the HH-60G), it would be applied to all variations of the model (all UH-60s). Then, the model would be applied to all aviation platforms across the Air Force and across the DoD. After determining the successful aircraft population, the next step for the team is to determine what makes them successful by investigating the preventative versus corrective corrosion maintenance history as well as the environmental severity index. The environmental severity index, ESI, is an environmental assessment scheme based on atmospheric parameters to measure how susceptible assets are to corrosion. This is a factor of interest to CPO because of its potential as a predictor of the corrosiveness of a particular location.

2. Methodology

The dataset LMI provided was a record of the Air Force's H-60 variant, the HH-60G "Pave Hawk", from FY 2008 through 2016. The information included in these files were individual records pertaining to a series of air frame tail numbers recorded by different units throughout the Air Force. The dataset was divided into two files ranging from years 2008-2012 and 2013-2016. Despite there being a large amount of data encompassed in these files, roughly 1,500,000 lines, some records were appended or incomplete and therefore unusable. For each accessible record, data such as which part was worked on, various categorized maintenance costs, and whether or not it was due to corrosion were recorded. The Air Force data offered the most manageable dataset to begin analysis with and the team believed that an effective model could then be developed to better study larger sets such as the Army or Navy. To begin organizing the data, a pivot table allowed quick changes between data for different years. The data was further sorted by Unit Identifier Codes (UIC), a unique alpha-numeric identifier assigned to each company equivalent level unit. These codes were then cross referenced with locations to determine where these units were stationed. Two very important columns in the data were the maintenance turnaround time and the total cost. These refer to the total amount of time that a specific maintenance action removed the aircraft from being mission capable and the total cost induced by doing so respectively. The data was sorted through and extraneous information not deemed directly related to the study was removed. This made the data much more manageable and simpler to work with.

Analyzing the data, the team applied the Systems Decision Process (SDP) to develop a model based upon the clients' superordinate goals. Under problem definition, it was decided that two variables must be included in the formula to account for the client's expectations. These were "maintenance turnaround time" and "total calculated cost". Formula (1) is the completed formula that was used in the analysis of the data.

$$Score = \left[\frac{\sum_{n}^{2016} \frac{x_n}{x_{n-1}} * w_i}{\sum w_i}\right] * b\ ;\ (a - 0.85) \quad (1)$$

$x_n = Cost\ per\ Day\ of\ Availability$
$w_i = relative\ weight$
$b = positive\ or\ negative\ value\ based\ upon\ difference\ in\ (a - 0.85)$
$a = availability\ of\ the\ aircraft$

The formula represents the product of a weighted average of the cost per day of availability and a negative look up table to determine whether the availability criteria had been satisfied. Formula (1) involves an availability threshold of 85%. This is a lower bound on the amount of time that a system must be working and mission capable. Thus, a value of 0.85 would dictate that any air craft that is not fully mission capable at least 85% of the year is failing in this maintenance area. This availability threshold is an assumption on part of the researchers to get a more accurate representation of the effectiveness of airframe maintenance. This value was chosen to allow for a wider range of which units failed to meet this level of performance. The Air Force owns fewer air frames and vehicles than other service branches. Because of this, it was expected that a greater amount of detail and time would be spent on upkeep for these systems. The 0.75 threshold held in the army would not work since majority of records would be above this from the start. Therefore, a threshold of 0.85 might allow greater variability by imposing a stricter requirement on what it takes to be considered passable (U.S. Department of the Army, 2004).

$$Cost\ per\ Day\ of\ Availability \sim x_n = \frac{c}{a*365} \quad (2)$$

$c = Total\ Calculated\ Cost\ (per\ tail\ number)$

Formula (2), the calculation for cost per day of availability, is the quotient of the total cost for an air frame from the entire year and the product of percent availability times 365 days a year. This value represents how much it costs to have a specific aircraft operational per day.

The value model outputs a single number, positive or negative, that typically has a range of +/- 3. Whether or not the value is negative refers to the 0.85 availability criterion. If it has been met for that aircraft then it will be positive and vice versa. The magnitude of the value describes how effective the maintenance being performed is. For instance, a value of one means it that the cost per day to keep the aircraft in the air was roughly the same over the course of the time recorded. A value of five on the other hand would mean that the cost of maintaining the aircraft would have decreased. This in turn means the actual maintenance is doing more for less money.

The group later conducted a time-based analysis on the data focusing on specific aircraft parts. A Pareto analysis followed to determine the top twenty air frame parts that contributed to the total cost, total labor cost, total corrosion cost, maintenance turnaround time, and were most present overall. Within the top twenty for each case included a baseline that could then be sharpened to contain only those parts present under all four categories. This in turn meant that these items took the longest to repair and are responsible for majority of the maintenance associated costs.

We investigated thirteen parts of the aircraft: body/hull, countermeasure, detector, door, gearbox, gun, landing gear, panel, radio, rotor, seat, stabilator, and wheels/tires. We then conducted another iteration of a cost per day analysis using the described value model individually on each of these parts aggregated across the years 2008-2016. Previously, all the data across every single aircraft was compiled. For this iteration, the only information for an aircraft that was analyzed was that which directly pertained to the specific item in question.

One-way ANOVA, analysis of variance of the means, was conducted on the average scores for each item for which the results are discussed below. Similarly, the quotient of the total cost that item incurred and the number of aircraft that experienced an issue with that part was recorded.

3. Results

The purpose of this study was to provide the CPO office and the DoD with usable and relevant information regarding aircraft data from their database. While initially it began with a more corrosion focused aspect, it eventually turned to one

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regarding the importance of maintenance. The value model created provides an easy to understand score that tells whether or not the maintenance of the aircraft meets the two goals assigned by the client. First, determining what the cost per day of availability is and second, assessing whether or not the target availability of 0.85, the proposed threshold for this analysis, was met. Tables 1 and 2 display the results achieved from the first round of analysis and Table 3 the second round.

Table 1. Average Maintenance Rating Determined by Unit

UIC	Score	UIC	Score	UIC	Score	UIC	Score	UIC	Score
FFGQW	0.509	FFL1G	0.747	FFBLV	1.37	FFC81	1.162	FFC6K	0.541
FFGN8	0.215	FFCZS	-1.094	FFF20	1.023	FFHLV	1.017	FFCYP	-2.445
FFFYP	0.149	FFK3R	-0.01	FFB04	1.819	FFRPN	1.526	FFLJ8	-0.113
FFTLL	0.323	FFQ37	5.472						

Table 2. Average Maintenance Rating Determined by Location

Location	Score	Location	Score
APO	-0.255	Creech AFB	1.897
Washington	0.547	Tyndall AFB	1.017
Tulsa	1.526	Altus	5.472
Pentagon ADM	1.574	Saint Josephs	1.224
Wright Patterson AFB	0.685	Scott AFB	0.897
Edwards AFB*	28.058	Beale AFB*	86.929

* These bases are outliers, but are included in the table for completeness.

As previously mentioned, the initial analysis dealt specifically with looking at the Air Force helicopter data provided by LMI. The scores came from the specified fields of all aircraft and were sorted at the conclusion by Unit Identifier Code, UIC, and Location. Here it is important to identify the low scorers and the high scorers. The 48th Fighter WG, UIC FFB04, had the highest average score amongst the units in the study. Surprisingly, the unit identified by UIC FFCYP had a score of -2.445. This might lead one to believe that they are performing worse than the 48th Fighter WG, but in reality means they are not meeting the 0.85 proposed threshold for this analysis. Despite this, they have a better Cost per Day of Availability meaning that while they might not be up in the air as much as the other unit, they are conducting their maintenance more efficiently. The score that details both a failure to achieve the 0.85 requirement as well as execute cost-efficient maintenance is the 23rd Wing WG, FFK3R. With an overall low score of negative 0.01, this unit is doing very poorly in comparison to its sister units and it might be worth it for the Air Force to investigate further as to why this is.

The most notable score for location is Altus, located in Oklahoma, having a score of 5.472. This is incredible compared to other locations and could mean that this location is, in general, is more resistant to environmental factors and thus easier to maintain the aircraft. It is also important to acknowledge that Edwards AFB and Beale AFB have unusually high scores, both of which are based in California. It should be noted that these bases are outliers in the results most likely due to inaccurate numbers within the original data. There is only one record for each and the values are highly susceptible to bias. Although a relationship might exist between the maintenance performed at these locations and them residing in California, there are too many factors at play to say one way or another.

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Table 3. Scores per Aircraft Item Compared to Cost

	FY 2008-2012			FY 2013-2016		
Part	Score	Total Cost	Cost/Item	Score	Total Cost	Cost/Item
Body/Hull	13.56	$9,144,699	**$101,608**	8.72	$11,165,178	**$132,919**
Countermeasure	5.70	$3,845,567	$41,350	2.26	$5,373,585	$61,765
Detector	2.64	$2,180,234	$24,775	2.23	$3,117,073	$37,555
Door	2.68	$2,873,324	$32,285	3.31	$4,796,614	$57,103
Gearbox	2.34	$1,965,607	**$21,840**	3.43	$2,448,418	$29,499
Gun	4.67	$3,000,873	$37,048	4.28	$5,425,987	$64,595
Landing Gear	6.85	$3,023,614	$33,227	2.52	$4,244,807	$51,142
Panel	3.35	$2,084,591	$23,422	2.14	$2,524,879	$30,420
Radio	3.28	$2,357,968	$25,630	2.03	$3,144,148	**$37,430**
Rotor	4.69	$2,259,291	$26,271	3.73	$3,751,960	$46,320
Seat	3.15	$1,625,870	$18,905	3.34	$2,256,870	$26,243
Stabilator	3.38	$2,355,151	$27,385	6.50	$3,092,649	$40,164
Wheel/Tires	2.83	$711,483	**$8,784**	2.37	$2,147,544	**$27,184**

The second portion focused on individual parts of helicopters and the cost it took to maintain them. Table 3 splits up the scores and cost by years, from 2008-2012 and 2013-2016. The thirteen parts identified by the Pareto Analysis as having the greatest impact were: body/hull, countermeasure, detector, door, gearbox, gun, landing gear, panel, radio, rotor, seat, stabilator, and wheels/tires. It is first seen that the consistently most expensive item is the body/hull. Not as surprising, it also claims the largest cost. Focusing on what would provide the most benefit per dollar spent, it is key to identify the parts that have the lower score and the lowest cost. Improving this would then allow an increase in the score and efficiency of maintenance with respect to that part. In this case, allocating more money to improving wheels and tires, seats, and panels would hopefully lead to a better performance overall. Therefore, the potential for units to increase their own maintenance score would improve if they focused on these three parts.

4. Future Work

While we have made tremendous progress on the concept and plan for interpreting the data, we still plan to incorporate environmental factors, as well we develop a system to rank the importance of each of the parts of the aircraft based on cost and other factors. The team was initially provided with the data that are dealing with environmental severity index, however incorporating ESI into the value model in a relevant manner has proven more challenging than initially expected. The current methods of measuring ESI do not distinguish much between areas within a region. This means that while a region might be assigned one ESI value, there could be zones within that that are considerably different. For instance, coastal regions might have a relatively low (less environmentally severe) score, but the beaches and areas directly next to water would inevitably have a much higher score. This inability to assign accurate ESI values on a smaller scale means that it is hard to identify trends and the effects the environment plays on maintenance. Developing a value model that accounts for the environmental factors would be more helpful not just to LMI, but to DoD office of Corrosion Policy and Oversight that is mostly focused in allocation of time and resources that will address problems with corrosion in DoD aircraft. Additionally, it is important to create a method to rank the importance of the parts of the aircraft. Currently, they have succeeded in gathering data to understand what problems are present. This model provides LMI a method of identifying these problems and which they should address first. By creating a system to rank the importance of the parts of the aircraft, LMI will have the tools to visually understand where to direct their time and resources.

5. Conclusion

Both the United States Congress and the DoD have recognized the need for a more efficient and cost effective strategy for corrosion prevention and correction within the military. Efficient and effective maintenance practices can assist in meeting these objectives. Our stakeholders at LMI and CPO made clear the mission to assess "how well DoD is going" in regards to their corrosion policy by assessing aircraft's achieved availability compared to target and cost per day of availability. In order to determine the success of the aircraft, we found it necessary to create a model to score the effectiveness of aircraft maintenance and an additional value model to determine the main areas of interest. Overall, through our interactions and various conversations with Eric Herzberg and the rest of the LMI team, we have been able to clearly identify a problem statement for our project and work hard to adhere to our stakeholder needs and desires. While we have made tremendous progress in our findings, we are still looking to incorporate environmental factors and rank structure for or work to have more of an impact not only with LMI, but DoD as well.

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