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Strategic Roadmap for Corrosion Control within the Department of Defense

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Abstract: Corrosion is a plague on weapons systems and infrastructure within the Department of Defense (DoD). The purpose of this project is to develop a Science and Technology (S&T) Roadmap for the DoD a vision for addressing corrosion. Utilization of the Systems Decision Process guided understanding of the problem and development of recommendations. This analysis focused on Army Blackhawk Helicopters as a case study, but its process can be applied to other DoD systems. The scope of the roadmap spans from present day to FY2029. The end state for the roadmap is a balance between qualitative and quantitative goals for the DoD with regards to corrosion prevention and control.

Keywords: Corrosion, Maintenance, Prevention, Correction, Roadmap, Department of Defense

1. Introduction

Corrosion impacts all systems as the environment degrades their structural integrity. It negatively impacts the infrastructure, weapons, and technology used by the United States military. Corrosion prevention is necessary for force readiness and mission execution. The existing goals addressing corrosion are contained in the 2018 National Defense Strategy outlined by former Secretary of Defense James Mattis. The defense strategy emphasizes there can be no complacency; that the Army must make difficult choices and prioritize what will field a lethal, resilient, and rapidly adapting Joint Force (National Defense Strategy, 2018). Prioritizing corrosion is something that must be done to field that Joint Force. The priority is evident by increasing cost related to corrosion maintenance, lack of standardized reporting of corrosion related issues, and a reluctance to determine the actual impact of corrosion within the Department of Defense (DoD). The only solution to maintain our current military advantage is organizational change, achieved by sustained investments to modernize our military (National Defense Strategy, 2018).

An estimate from J. Edwards (2010) put the annual cost of corrosion at $20.1 billion. One of the reasons for this high cost is that many steps taken to fix corrosion are corrective, not preventive. As reported by E. Herzburg (2014), field level maintenance (FLM) preventive costs exceeded corrective costs at a 6:1 ratio. Many of these preventive costs relate to inspections on vehicles and weapons systems (Herzburg, 2014). The current goal for a corrective-preventive cost ratio is 1:1. However, the study states that while this ratio is desirable, more research is required to see if this ratio will achieve the goal of reducing the cost of FLM. Another reason the problem of corrosion persists is that the process for reporting is not standardized within the DoD. The lack of standards for corrosion reporting, investigating, and publicizing contributes to the lack of actions taken to diminish corrosion in any significant way. The Federal Aviation Administration (FAA) is currently considered a benchmark for these processes. During all inspections when a corrosion issue is identified, the investigator sends the report to both the FAA and the manufacturer to ensure that the mistake will be corrected (AC 43-4B, 2018). For this reason, the military's maintenance processes should mirror those outlined by the FAA.

1.1. Problem Definition

Many corrosion related issues affect the DoD. This project researched the effects of corrosion on a wide range of military vehicles, weapon systems, and infrastructure, with a specific focus on Army Aviation. According to FM 3-04 Army

Aviation, the process of sustaining Army Aviation is a complex problem that requires a systems-based approach to fix corrosion (2015). Whether the aviation assets are being used in an operational manner or sitting in hangars, "aviation commanders and staff must adhere to the sustainment principles- responsiveness, simplicity, flexibility, attainability, sustainability, survivability, economy, and integration." (FM 3-04, 2015) The focus for aviation commanders is on the availability of the operational aircraft to support ground movements from any commander's requirements. In an operational context, the Mission Essential Task List, or METL, categorically outlines the specific, minimum warfighting functions a unit must be able to perform. Ideally, a maintenance program should maximize the amount of available for support of METL tasks, such as corrosion prevention, while minimizing total cost.

Further exploration is a hard choice, one which promises to make members of the organization uncomfortable as problems are identified and confronted. Research into causes of corrosion and implementation of informational and organizational tools support the outlined Defensive Objectives. Furthermore, they encompass two of the three lines of effort established in the National Defense Strategy: rebuilding military readiness as a more lethal force and reforming the Department's business practices for greater efficiency. At the urging of former Secretary Mattis, the organization seeks to pursue urgent change at significant scale utilizing creative approaches and being disciplined in execution to field a Joint Force fit for the present day (National Defense Strategy, 2018). The minimization of corrosion issues is a crucial part of meeting these objectives, and necessary for force readiness and mission execution.

1.2. Establishing a Vision

Since 2013, the US Armed Services have not set collaborative goals nor made progress for corrosion prevention and control. In a conference with representatives from Logistics Management Institute (LMI), the development of a Science and Technology (S&T) Roadmap outlining specific, quantitative measures of progress towards corrosion reduction was emphasized. The representatives strongly agreed that there is a lack of vision for this issue and once this is addressed, it will become a catalyst for change in the corrosion community. In an article from the American Institutes for Research, V. Boyd (1992) reflects that to begin the process of change, one of the elements that need to be present is a "widely shared sense of purpose or vision." Vision provides guidance to an organization by presenting what it wishes to attain.

1.3. Methodology

The Systems Engineering Department at West Point uses a problem-solving framework called the Systems Design Process (SDP). It is an iterative process where the stakeholder is involved throughout the design process to optimize utility of the final product. The first phase of the SDP is the problem definition phase. The main goal of this phase is to gain the best understanding of the stakeholder's problem, and creation of a problem statement to ensure that the solution meets their needs. In order to create a problem statement, each group member completed a literature review on how corrosion effects four different areas within the DoD. In order to manage the scope, Army Aviation proved to be the most cost-effective focus area for the project. Each group member then completed further research into how corrosion effects Army Aviation. Background research and multiple interactions with stakeholders from LMI created a Findings, Conclusions, Recommendations matrix (FCR) that resulted in recommendations for future work. From there the team broke down the problem through functional analysis. Functional analysis allows the problem to be decomposed by goals which allows for an understanding of how minor functions effect the overall goal of the project. One way to visualize this is through a functional hierarchy as seen in Figure 1. After development of these problem definition products, an updated problem statement provides a launching point for the rest of the process.

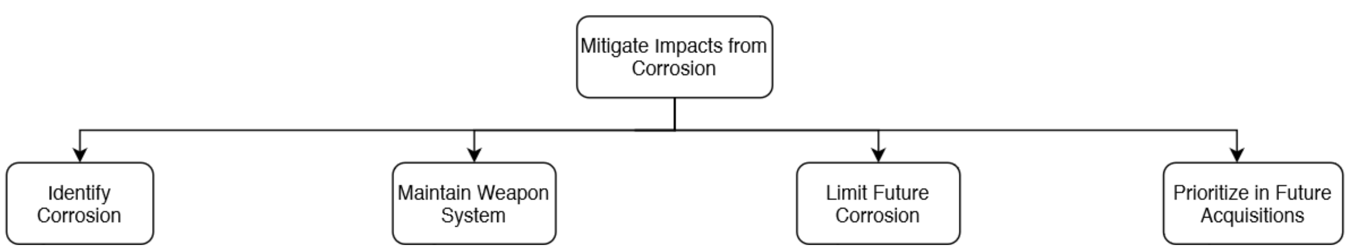

Figure 1. Top Level Cutout of Functional Hierarchy

1.4. Functional Hierarchy

The two recommendations generated from the problem definition phase and FCR matrix were (1) corrosion control should be more proactive rather than reactive to minimize future costs, and (2) complete standardization of prevention and control methods to minimize corrosion related costs. The resulting functional hierarchy can be seen in Figure 1 with the overall goal is at the top, and subfunctions below. In a similar hierarchy metrics were applied to each objective to gauge how well the final product meets the stakeholder's requirements. The final problem statement became corrosion creates significant costs for aviation assets due to a lack of standardized prevention and reporting procedures within the Department of Defense.

2. Solution Design

2.1. DOTMLPF

DOTMLPF is a lens used throughout the military to make sure standards are being met. It is a DoD acronym "that pertains to the eight possible non-materiel elements involved in solving warfighting capability gaps" (Defense Acquisition University). The acronym uses eight different lenses: Doctrine, Organization, Training, Materiel, Leadership, Personnel, and Facilities. Doctrine focuses on the "way the military fights, emphasizing maneuver warfare and combined air-ground campaigns." Organization focuses on "how the fight is organized by divisions, air wings, Marine-Air Ground Task Forces, etc." Training "prepares to fight tactically." Materiel is "all the stuff necessary to equip the forces that does not require a new development effort." Leadership's lens makes sure "leaders are prepared to lead the fight." Personnel is the "availability of qualified people for peacetime, wartime, and various contingency operations." Facilities includes "real property, installations, and industrial facilities" (Defense Acquisition University). This framework provides greater understanding of the maintenance process and the effects of corrosion. DOTMLPF is a tool that will provide an avenue for understanding the foundational problem of corrosion and provide a scale where change can be applied at each level.

2.2. Cost Savings Model

A diagnostic tool to address the corrosive threat facing Department of Defense is a cost savings model. It is important to note that cost must be minimized while still meeting the METL tasks of the unit and maintaining mission readiness. The cost savings model leverages the preventive to corrective maintenance ratio against total cost of corrosion in FY16. The model is more concerned with optimization of resources rather than traditional minimization, which is the pursuit of absolute lowest costs above all other factors. Exploration to develop the model began with total cost from all types of corrosion-based actions compared to the ratio between preventative versus corrective actions. The FY2016 dataset of all Army airframes provided by LMI was filtered to include only active duty, HH-60M, MH-60M, and UH-60M helicopters. This ensured the data was comparable between aircraft with consistent traits. The population of 1,809 aircraft was reduced to 373 when these filters were applied and the top and bottom 1% were removed as outliers. The scatterplot in Figure 2 with linear (green), quadratic (blue), and mean value (orange) functions below.

Much of the data characterized in this work is inconsistent due to unreliable reporting. This results in correlations difficult to determine. The attempted linear, polynomial, exponential, and logarithmic fits all failed to provide a model of statistical strength, with more elaborate fits equally poor and at greater risk of over-fitting the data. The best fits of models considered were the linear with an R-squared value of 0.22 (in green) and the polynomial with an R-squared of 0.36 (in blue). While neither of these are good fits, the polynomial indicates more investigation should be done around the 4:1 ratio because the vertex falls between 4 and 4.5. The data does not seem to have any sort of pattern possibly due to the inconsistency of reporting corrosion issues. In the reporting process of aviation mishaps, the Army has a cause of failure column that can be searched to determine cause, but some of the descriptions do not provide enough information to see whether corrosion played a role. T. Chan (2015) concluded that 16.5% of army reports lack sufficient details to determine the cause of failure. Additionally, Chan (2015) explained that safety investigators of the mishaps didn't have the proper knowledge on the government definition of corrosion which only further allows for variability within the data.

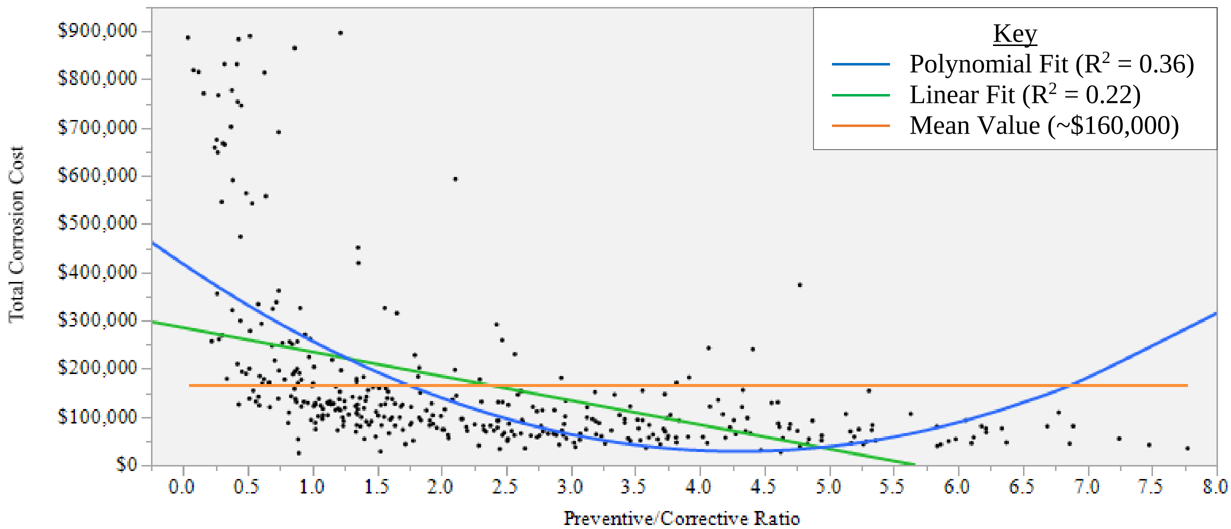

Figure 2. Preventative/Corrective Action Ratio VS Total Cost due to corrosion for FY16

Another statistical approach is the examination of subpopulations within the dataset. Sub-set bins provide an additional perspective which focuses on relational patterns on a smaller scale. The general lack of independence within the subpopulations when plotted as histograms, as well as quantile-quantile plot inconsistencies, further reflect the complexity of the issue. Due to these failures of independence tests comparison of averages alone would be inconclusive (in yellow) and therefore medians are also considered. As seen in the tables below, a reduction from the current 6:1 ratio to 4:1 has roughly equivalent value, roughly stabilizing in the $70,000s (in orange). This reduces the disparity between prevention and corrosion in line with the current aims of CPO. However, reduction lower than 4:1 towards 1:1 sees binned medians, and means, steadily increase upwards as the ration meets the point of equality. A similar trend is observed at other bin sizes, including intervals of 2. It must be acknowledged the smaller sample sizes >10% of the population (in red) are weaker indicators from lack of enough datapoints. These numerical indications, which provide a better, worst model, and a heuristic understanding of industrial maintenance, lead to the logical conclusion more emphasis should be placed on prevention than corrosion. According to this explored dataset, CPO's current vision for a 1:1 ratio is not supported and furthermore ill-suited for the broader corrosion vision. From this simplistic cost savings model, a change from the current 1.95 ratio to 4:1 for the UH-60M would yield an annual per capita savings of approximately $28,000 for each airframe. That equates to over $10 million in annual savings for these 373 HH-60M, MH-60M, and UH-60M active Army helicopters. However, investigation of other vehicles and equipment is strongly believed to deliver additional savings orders of magnitude greater than this figure.

Table 1. Binned ratio intervals by whole integers

Bin (Ratio Interval)	(0.01,1)	(1,2)	(2,3)	(3,4)	(4,5)	(5,6)	(6,7)	(7,8)
Sample Size	n = 88	n = 106	n = 68	n = 46	n = 33	n = 17	n = 12	n = 3
Median (in thousands of $)	254	118	81	75	78	59	76	42
Mean (in thousands of $)	354	134	104	84	98	69	72	44

Table 2. Binned ratio intervals by two whole integers

Bin (Ratio Interval)	(1,3)	(3,5)	(5,7)
Sample Size	n = 174	n = 79	n = 29
Median (in thousands of $)	103	76	70
Mean (in thousands of $)	123	90	70

3. Science and Technology Roadmap

The end state for this project, as determined by investigation and application of the SDP, is the creation of a Science and Technology roadmap for improving corrosion management. A roadmap is the implementation of long-term functional goals using intermediate benchmarks to guide progress on a fixed timeline. The International Technology Roadmap for Semiconductors provided an exclusively quantitative projection for progression towards its goals (Revolvy). This roadmap is viewed as the "gold standard" for roadmaps across the science and technology community. The International Technology Roadmap for Semiconductors is very quantitatively accurate but also has relevant and achievable goals listed for future improvement. A different roadmap considered was NASA's Earth Science Vision Roadmap which is qualitative in nature and simply has verbal goals that are not tied to specific measurements (Allen, 2015). Incorporating both methods best suits the Department of Defense's needs in terms of a corrosion control and prevention roadmap because there are both quantitative measurements and qualitative organizational implementations that need to be included.

Corrosion - What is Done to Address: Continued Investigation / Prevention / Correction		Army Corrosion Roadmap											
Management	*FY16 CPO Estimate*	Confirmation			Implementation					Validation			
		2020	2021	Re-evaluate	2022	2023	2024	2025	Re-evaluate	2026	2027	2028	**2029**
Aircraft Unavailability Due to Corrosion (%)	11.40%	11.30%	11.05%		10.70%	10.35%	10.00%	9.70%		9.45%	9.25%	9.10%	**9.00%**
Additional Annual Corrosion Cost [Corrosion/Other Cost]	24.38%	24.10%	23.60%		22.80%	22.05%	21.35%	20.70%		20.10%	19.65%	19.30%	**19.00%**
Estimated Mishaps from Corrosion (%)	2.28%	2.25%	2.20%		2.10%	2.05%	2.00%	1.95%		1.90%	1.85%	1.80%	**1.75%**
Unusable Reports from Lack of Detail (%) from LMI FY16	16.40%	16.35%	16.00%		9.00%	8.00%	7.00%	6.00%		5.00%	4.00%	3.50%	**3.00%**
Corrosion Cost Ratio [Prevention : Correction]	[6 : 1]	Additional Research Required			[5.6 : 1]	[5.2 : 1]	[4.9 : 1]	[4.6 : 1]		[4.4 : 1]	[4.2 : 1]	[4.1 : 1]	**[4 : 1]**
Implementations	*DOTMLPF-P*											**End State**	
Develop a New Reporting Process	D	Evaluate readiness level for equipment & personnel			Publish standards for reporting		Enforce standards of new reporting process			Maintain standards of new reporting process		A new system is effective at reporting, communicates when set thresholds are failed, and roadmaps have been implemented across all appropriate systems.	
Create Minimum Thresholds for Reporting	D T					Determine appropriate thresholds	Ensure thresholds are established throughout the Army			Update thresholds			
Create Additional Roadmaps for Other Platforms	D	Create roadmaps for other Army vehicles, infrastructure, systems			Create roadmaps for other services					Re-evaluate and nest all services roadmaps			
Amend Technical Manuals (TMs)	D (P)olicy	Review manuals			Update manuals					Update manuals		A new system causes changes in the training manuals, making imperative new training for all soldiers, tests for corrosion, and implementation of a widely shared vision to continue maintaining aircraft.	
Proper Knowledge and Instruction for Personnel	L (P)ersonnel T				Train the trainers on new corrosion processes		Implement test to ensure proper knowledge			Retrain soldiers on new processes			
Required Corrosion Analysis and Dedicated Budget in Acquisition Process	(P)ersonnel M	Interview analysis	Establish budget constraints		Update Annual Budgets					10 year budget outlook			
Widely Shared Purpose and Vision	L O	Establish a purpose/vision			Share Army's purpose/ vision	Maintain a unified Army vision				Share vision across services	Maintain a unified service vision		
Deliberate Operational/Environmental Tests	O T F	Develop standards for tests			Publish test standards across Army	On-going				Ensure tests are conducted to standard	On-going	A new system will require reallocation of budget for more efficient corrosion prevention, an increase in standards for accepting reports, and a centralized corrosion control command.	
Reject Inadequate reports; Request Missing or Omitted Information	D (P)olicy	On-going			On-going					Re-evaluate reports & information	On-going		
Centralized Logistics Program	M F (P)olicy	Evaluate program effectiveness	Centralize and standardize		Investigate trends at the macro level for corrosion supplies and resources					Reform logistics program to eliminate wasteful practices			

Figure 3. Corrosion S&T Roadmap for Army Aviation Systems at Large

As seen in Figure 3 the S&T Roadmap has both quantitative and qualitative sections. The Management portion is the quantitative section that has current estimates by row. The Implementation portion is the qualitative portion where each function is measured by goals created from stakeholder analysis. The roadmap is based upon current research and reports for Army Aviation assets within the DoD. To illustrate the implementation of this roadmap through a more focused scope, an example roadmap for the UH-60M is viewable in Figure 4. For both, the left-hand column is the current state or numbers based upon LMI's research. The right-hand column is the suggested 2029 goal determined through research and stakeholder interaction. These numbers are believed to be strong indicators to optimizing availability and cost. The progression is tapered and designed to be revised upon adoption of the timeline and through annual reviews and cyclic in-depth revaluation.

Corrosion - What is Done to Address: Continued Investigation / Prevention / Correction	*Example* UH60-M Corrosion Roadmap													
		Confirmation			Implementation					Validation				
Management	*FY16 CPO Estimate*	2020	2021	Re-evaluate	2022	2023	2024	2025	Re-evaluate	2026	2027	2028	**2029**
Aircraft Unavailability Due to Corrosion (%)	12.60%	12.50%	12.30%		11.65%	11.25%	10.90%	10.60%		10.35%	10.20%	10.10%	**10.00%**
Additional Annual Corrosion Cost [Corrosion/Other Cost]	20.30%	20.20%	19.85%		19.50%	19.20%	18.90%	18.65%		18.45%	18.25%	18.10%	**18.00%**
Corrosion Cost Ratio [Prevention : Correction]	[1.95:1]	Additional Research Required			[2.1 : 1]	[2.2 : 1]	[2.4 : 1]	[2.6 : 1]		[2.9 : 1]	[3.2 : 1]	[3.6 : 1]	**[4 : 1]**

Figure 4. Science and Technology Roadmap for UH-60M Quantitative Metrics

4. Conclusion

For future work, further research needs to be done into the cost savings model. Although CPO originally stated the desired ratio for preventive costs to corrective costs is 1:1, the findings from the current cost-savings model show that a 4:1 ratio is more achievable. Additionally, the technical manuals need to be changed if any progress is going to be made against corrosion. Although difficult to implement, technical manual changes under the doctrinal domain of DOTMLPF reflect the difficult decisions discussed by Former Secretary Mattis and would help solve the reporting issues of related maintenance. The roadmap highlights avenues of change such as developing minimal thresholds for reporting, standardized instruction for those treating or identifying corrosion, and rejecting poor reports to ensure that mistakes are not repeated. Similar to the FAA, corrosion failures need to be reported to both a centralized corrosion management institution and the manufacturers. The complex changes now could save significant spending and result in the lethal adaptive force the National Defense Strategy described.

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