Artificial Intelligence/Machine Learning to Improve Supply Chain Management – Phase I

Final Report

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Acronyms and Abbreviations

Term	Definition
AI/ML	Artificial Intelligence/Machine Learning
ASPs	Afloat Spares Packages
CAC	Common Access Card
CTMA	Commercial Technologies for Maintenance Activities
DOD	Department of Defense
DSPs	Deployed Spares Packages
GFE	Government Furnished Equipment
GBM	Gradient Boosting Model
LCN	Load Classification Number
NCMS	National Center for Manufacturing Sciences
NDA	Non-Disclosure Agreement
NMC	Non-Mission Capable
ODASD-MR	Office of the Deputy Assistant Secretary of Defense, Materiel Readiness
PMC	Partially Mission Capable
RF	Random Forest
SAAR	System Authorization Access Request
U.S.	United States

1. Executive Summary

The commercial Supply Chain Management industry must maintain, sustain, and logistically support aircraft, ships, and vehicles all over the world, while navigating the numerous supply chain challenges that must be addressed for organizations to successfully sustain their fleets. Downtime due to spare parts delays result in schedule delays, service interruptions, increased costs, and ultimately dissatisfied customers. Major logistics companies such as UPS and FedEx are required to efficiently and effectively maintain disparate fleets of air, land and sea assets around the globe, and supply chain disruptions can significantly affect these businesses' bottom line. Similarly, the U.S. Marine Corps deploys the F-35B/C in a distributed manner throughout the globe and logistically support those units with Afloat Spares Packages (ASPs) and Deployed Spares Packages (DSPs). The current baseline performance has provided limited effectiveness in attaining a fully mission-capable deployed aircraft. Specifically, the Marine Corps must increase efficiencies and effectiveness by influencing the type, range, and depth of the parts within these spare packages to forecast a more accurate mix of high-demand parts per aircraft, optimizing the efficiencies of those supply packages. Failure to do so decreases the readiness of the fleet and jeopardizes warfighter effectiveness.

The solution to resolve this problem was for SteerBridge to utilize Artificial Intelligence/ Machine Learning (AI/ML) tools to develop a prototype that is accurate at predicting future supply and demand insights for F-35 ASP/ DSPs. The first step in this process was for the team to gather as much historical data as possible from previous F-35 deployments. This, alongside access to subject matter experts, proved to be a significant obstacle in the first several months of the project. The team worked with various Marine Corps stakeholders and traveled to several F-35 squadrons to collect the appropriate data needed to feed the prototype. In conjunction with data collection, the SteerBridge technical team built a comprehensive user interface that allows for tailored recommendations based on input from the user. This required in-depth front-end and back-end development of the prototype so that it was visually appealing, but also provided accurate predictions and analysis. As data was collected, it was inserted into the tool so that all historical data made available was tracked.

The second nine months of this project entailed a detailed analysis of all compiled data. The team was responsible for understanding the historical data to inform predictive analysis. As data became more abundant, the tool became more reliable. This also required SteerBridge data scientists to run a multitude of models to determine which was most trustworthy at predicting which parts would fail most frequently, and which parts would be in highest demand while on deployment. The team also had to account for the understanding that each F-35 is unique and is comprised of different parts that have their own usage history. With all these variables in mind, the team sought to determine what the "optimal" ASP/DSP would be for future F-35 deployments.

Funding was secured for the collaborative initiative through the National Center for Manufacturing Sciences (NCMS) Commercial Technologies for Maintenance Activities (CTMA) Program and the Office of the Deputy Assistant Secretary of Defense, Materiel Readiness (ODASD-MR).

1.1 Results

Overall, SteerBridge was successful with gathering large amounts of data that the Marine Corps had not yet analyzed. With this data, the team will be able to produce user stories, parts forecasting, better understand critical failures,

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and provide tailored recommendations for future deployments. On a granular level, SteerBridge employed several models to predict future ASP/DSP performance and compare it to the actual performance of previous ASP/DSPs. Models were trained on two years of data, and then forecasted for a two-month window (November 10, 2022 to January 9, 2023). The team utilized both the Gradient Boosting Model (GBM) as well as the Random Forest (RF) model. SteerBridge's data scientists were successful with both models as each resulted in fewer missing parts and provided a significant improvement. Table 1 and Table 2 depict these results.

These tables are a snapshot of the improvement that can be made when utilizing SteerBridge's models for attempting to predict ASP/DSP performance. The team was also able to correctly predict 84% of the parts that will fail based on the type of jet being assessed or flown. This was done utilizing historical data and comparing actual results to a model developed by the SteerBridge team. Given the effectiveness and accuracy of the model, there is high confidence that this model can be used to predict failure for future deployments as well.

Table 1. GBM vs ASP
(Displays ASP Performance vs GBM Forecast performance)

	Shared Parts	Parts Missing
ASP	57.57%	42.42%
GBM Forecast	72.72%	34.84%
Improvement	26.31%	17.87%

Table 2. RF vs ASP
(Displays ASP performance vs RF Forecast performance)

	Shared Parts	Parts Missing
ASP	57.57%	42.42%
RF Forecast	90.90%	9.09 %
Improvement	57.89%	78.57%

1.2 Benefits

Given the widespread applicability of both AI/ML and Supply Chain Management, there may be potential benefits for both the Department of Defense (DOD) and the public sector. As this tool continues to be refined, it has the potential to reduce customer wait time, predict the future likelihood of part failure, increase cost-effectiveness, and enhance overall mission planning. With accurate modeling, not only will the Marine Corps have the appropriate number of parts packed for deployment, but it will save additional space that has previously been used by storing redundant parts. This allows for other supplies to be packed that may have otherwise been left behind. Increasing fleet readiness enables the warfighter to do their job effectively and ensure national security is maintained.

1.3 Recommendations

SteerBridge recommends continued communication between industry and government participants. These conversations are invaluable to SteerBridge's team as insight is gained into the voice of the user. This communication also aids with data discovery as the team seeks access to vital data that resides in secure systems. With the help of government stakeholders, the co-aligned industry team can utilize this data within the tool so that it provides accurate outputs that reflect historic data.

Additional recommendations include:

- Further test and validate the prototype developed in this phase of the project.
- Gather more data so that the algorithm is more robust and comprehensive.
- Develop an automated approach to detect alternate part numbers in stock to improve the supply's gross issue effectiveness.
- Gather additional data regarding configuration change history.

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Frequently, the configuration change history will not show top-level parent information, so it can be difficult to determine when a part was first and last installed into an aircraft and what happened in between.

1.4 Invention Disclosure

☒ Yes Inventions ☐ No Inventions
DD882 Invention Report sent to NCMS ☒

1.5 Project Partners

- U.S. Marine Corps
- Joint Strike Fighter Program Office
- SteerBridge Strategies
- National Center for Manufacturing Sciences (NCMS)
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2. Introduction

2.1 Background

In 2021 and 2022 the Marine Corps conducted a market survey to understand the current commercial best practices, the potential for enhancing those best practices with advancements in analytics-based modeling and predictive algorithms, and the viability of prototyping an improved Supply Chain Management strategy using those advancements. The market survey confirmed the viability and provided a best-in-class industry participant to close the Marine Corps' current Supply Chain Management need and actual performance gap. Phase I of this effort focused on the investigation of feasible spare parts supply chain strategies within the dynamic global environment in which the Marine Corps currently operates, by demonstrating the potential of various executable solutions. Figure 1 illustrates the detailed process often required to order a critical part for the aircraft that the Marine Corps hopes to resolve.

Airlines, ships, and the vehicle industry are faced with global logistics challenges that involve a complex operating environment that includes numerous suppliers and stove-piped Supply Chain Management approaches that have varied configurations/processes for their respective fleets. These complexities challenge the effectiveness of supply at the point of need reducing the availability and reliability of the commercial fleets. Phase I was centered on the testing and evaluation of the prototype capability developed within the Marine Corps operating logistics environment that demonstrates AI/ML through advanced mathematical algorithms in Supply Chain Management that will increase parts availability, maximize efficient parts usage, and reduce customer wait times. By using a combination of predictive maintenance, supply chain optimization and customer-enhanced decision making, the challenges and complexities will be reduced, and the overall logistics supply effectiveness will increase. The increased effectiveness of the Marine Corps ASPs/DSPs will demonstrate greater availability during operational scenarios. Cost efficiencies will improve by providing recommendations and a roadmap for algorithms using transactional data to forecast a more accurate mix of high and low-demand parts per aircraft, leading to a more resilient Supply Chain Management strategy that has significant cost savings and improved fleet readiness. These principles can be applied across a wide variety of public and private organizations facing similar spare part challenges.

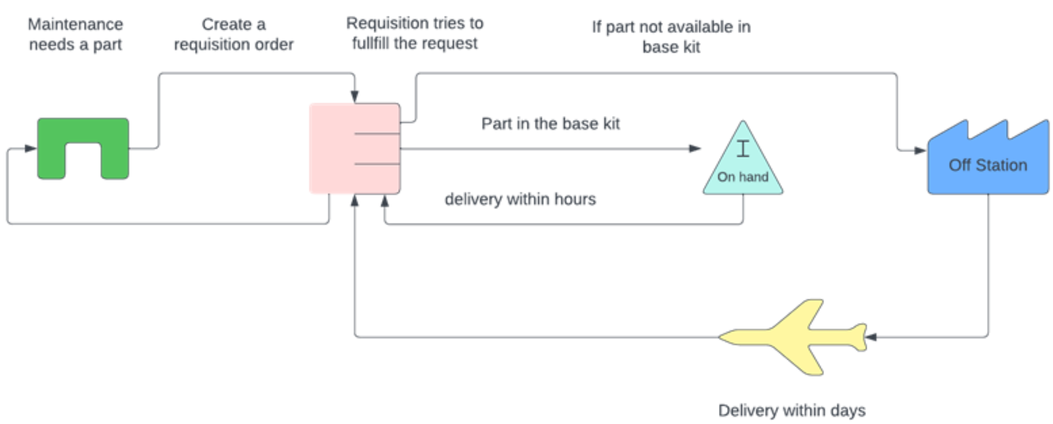

Figure 1. Illustration of Inventory Problems Presenting Logistics Challenges

2.2 Purpose

The purpose and objective of this phase was to develop and test the prototype software for a maintenance organization's use of AI/ML, with advanced mathematical algorithms in Supply Chain Management to increase parts availability and reduce customer wait time. Specific purposes included:

- Increase gross issue effectiveness.
- Decrease customer wait time.
- Increase full mission capable availability rates.
- Optimize supply chain endpoints.

2.3 Scope/Approach

A collaborative effort was used to establish a government and industry co-aligned team that was focused across functional areas. Industry leveraged pre-existing software development and demonstrated advanced mathematical algorithms to enable the prototyping of AI/ML techniques to address the current maintenance and sustainment shortfalls with an integrated verification and validation team. The project leadership team adopted an agile approach progressing through data discovery to prototype development to ensure interoperability of all pilot projects and developmental cross-team collaboration between the functional areas. Project leadership was also responsible for continuous communication with the sponsoring agency to ensure all feedback provided was incorporated into the prototype.

The overarching goal was to aid the Marine Corps with illustrating the improvements that can be made for the F-35 ASP/DSPs. Utilizing the prototype, the project team was able to demonstrate current performance of ASP/DSPs based on historical data. This data helped inform predictive models which were presented through the following deliverables:

- Completed user stores.
- Data source analysis documentation.
- Data integration documentation.
- Results analysis documentation.
- Roadmap to scale model.
- UI/UX wireframe.
- Supply and demand insights.
- Optimal quantity of MSIs from user stories.
- Visualization of supply chain management.
- Visualization of parts availability.
- Model prediction vs actual performance.
- Standard ASP/DSP recommendation and the "tailored" ASP/DSP.
- Supply side usage forecast.
- Demand side usage forecast.

Each deliverable was presented and briefed to the sponsoring government agency. This allowed for continued feedback to ensure that the project team was executing tasks in line with the desire of the sponsor.

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3. Project Narrative

In August of 2022, SteerBridge, in conjunction with NCMS, began this project with the Marine Corps to develop a prototype that can analyze and predict the effectiveness of F-35 ASP/DSPs using AI/ML. The project was separated into two increments, each with a unique purpose to ensure that all goals were achievable by the end of the period of performance.

The first increment focused heavily on data discovery and gaining the required access for members of the SteerBridge team. Data discovery entailed many discussions with members of the sponsoring agency to determine where SteerBridge should look for the necessary F-35 deployment history data. This took several months to determine and required a great deal of effort from our team. Concurrently, the team began developing the prototype itself, so that the data would have a place to be analyzed. SteerBridge's software engineers and data architects worked to build a prototype that had both front- and back-end functionality. The front-end required detailed visualizations, while the back-end required a reliable algorithm that digests large amounts of data and provides meaningful recommendations.

Once the team understood the data requirements, they knew specific permissions were required to access that data. Access obstacles included Common Access Cards (CACs), System Authorization Access Request (SAAR) Forms, Security clearances, Government Furnished Equipment (GFE) materials, and Non-Disclosure Agreements (NDAs). Given the nature of this project, it took several months for these issues to be resolved for all personnel on the team. As the first increment ended, the team was able to retrieve extensive amounts of data that would feed the algorithm.

With many of the access requirements and data collections completed during the first increment, the team was able to access, gather and determine the nuances of the data during the initial phase of the second increment. Utilizing the compiled data, the project team developed standard ASP/DSP recommendations, supply-demand forecasts, and demand-side usage forecasts as it relates to F-35 deployments. The team used the methodology described in Figure 2 to plan their supply chain management modeling.

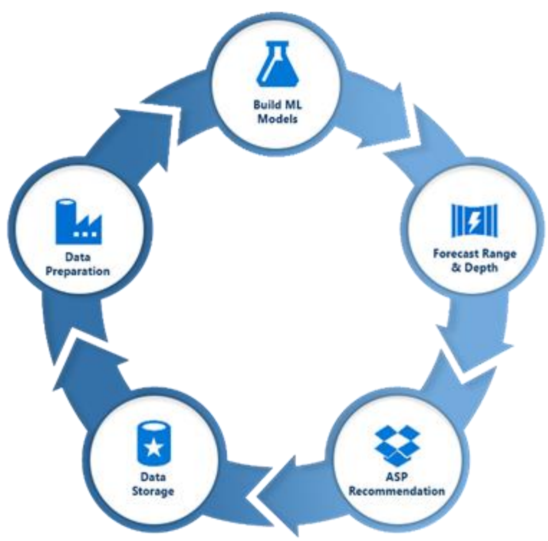

Figure 2. Procedures Required to Build ML Models to Provide Effective Recommendations

A key deliverable in the second increment of the project was to determine the failure rate of specific parts while on deployment. This is significant to the Marine Corps so that they are able to better understand which parts are more or less likely to fail, which will enable them to pack accordingly prior to deployment and limit the wait time when a part is required. Using historical data from each F-35, SteerBridge developed tailored predictions of which parts are most likely to fail in the future. They discovered that if a part fails within the last month, it is more likely to fail in the next two months. Additionally, as depicted in Figure 3, increased flight hours often coincided with increased critical failures.

Utilizing historical F-35 data, the team was also able to determine the average customer wait time while on deployment. Being able to predict part failures with an awareness of wait time will enable the supply chain to move or stage parts before failure, greatly reducing Non-Mission Capable/Partially Mission Capable (NMC/PMC) time. Figure 4 shows the average wait time based on deployment data gathered during this phase.

Finally, demand forecasting was required to help understand potential part vulnerabilities in the future. While past failures can indicate a future failure at Load Classification Number (LCN) level, other additional features are required to have a full picture. To do so, the project team ran over 150 models using data from four Marine Corps squadrons to determine which were most viable. The model blueprint is shown in Figure 5.

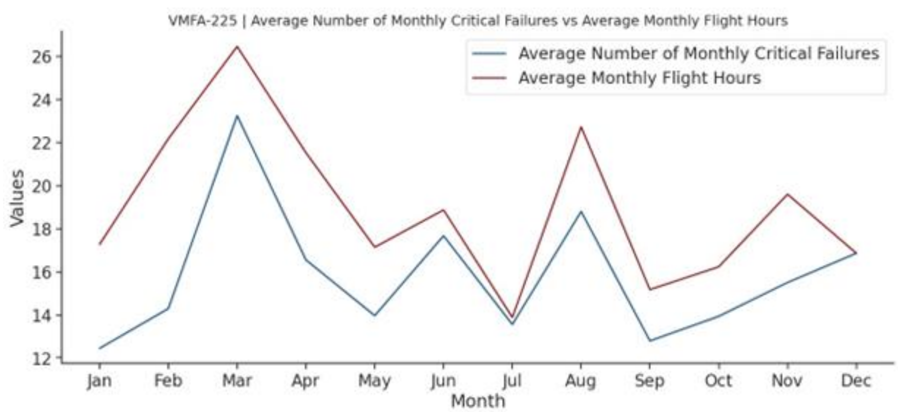

Figure 3. Average Monthly Critical Failures vs Average Flight Hours

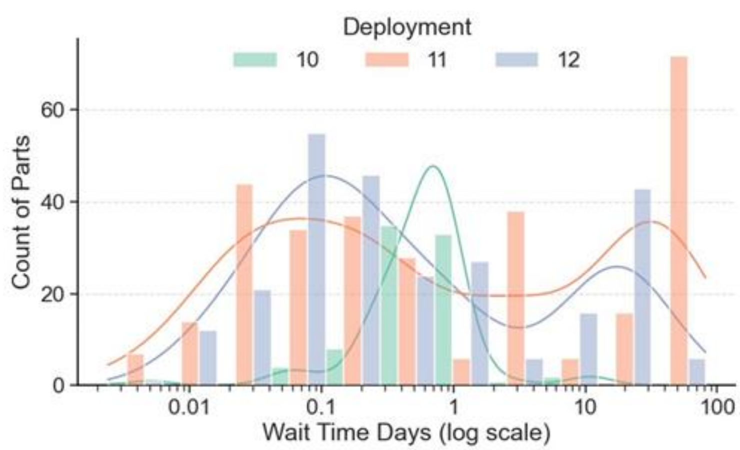

Figure 4. Average Wait Time for Parts While on Deployment

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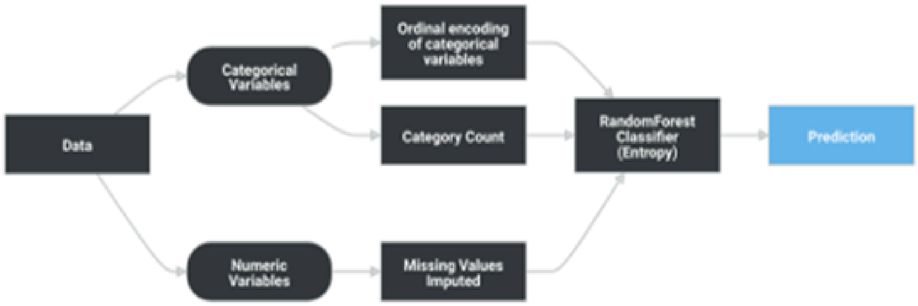

Figure 5. Model Blueprint to Determine Demand Forecasting

The results of the model were encouraging as it was able to predict approximately 84% of all critical part failures, therefore greatly assisting in demand forecasting.

SteerBridge will continue to better develop and refine this prototype in future phases as the team gathers additional data from various F-35 squadrons worldwide. This phase successfully showed how AI/ML can be used to benefit supply chain management and the potential payoffs of using this modeling. As the team progresses through future phases, they will be able to account for nuances in the historical data and develop an even more detailed and accurate tool to aid the sponsoring organization.

4. Conclusions

Throughout the period of performance, SteerBridge was able to collect information regarding historical F-35 data and the challenges the Marine Corps face as it pertains to Supply Chain Management. Based on data from previous F-35 deployments, the team discovered that the current ASP/DSPs used are not highly efficient. However, using AI/ML, the team was able to use predictive models to generate ASP/DSP loading and crating that are much more cost-effective. Additionally, the team has developed the prototype that will continue to mature and provide a more comprehensive recommendation for future F-35 deployments/ phases. With many of the access obstacles resolved, the team is eager to gather more data to make the algorithm and the analysis even more robust. Based on the success of the initial predictive models, the team is optimistic that further refinement will provide the Marine Corps with a tool that greatly aids the warfighter and all future F-35 deployments.

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5. Project Benefits

Although this project was performed in conjunction with Headquarters Marine Corps to assist the F-35 Joint Program Office, many benefits would be applicable to the public sector as well.

5.1 Benefits for the General Public

By having a system and supporting models in place to address these maintenance and sustainment scenarios before they occur, a company will be able to optimize worldwide sustainment operations across the entire spectrum of the sustainment value chain. This will enable much greater efficiency of operations as each critical node (link) in the chain can be optimized in relation to all other complementary nodes in the chain. This efficiency gain will make tomorrow’s aircraft, ships, and ground vehicle industries more efficient and profitable, and those gains will be realized through less costly airfares or cost to transport material for the public as well as improved safety indices. These industries will have the ability to greatly reduce debilitating equipment downtime and failures that can cause injury or death. They will also avoid the high costs of scrambling to find suppliers and those who have the skills to repair complex equipment, which can lead to a loss of trust from customers. A well-planned maintenance plan could easily become a much safer environment in which to work. Analyzing, producing, and implementing these processes should be considered in lockstep with the manufacturing and production of the equipment.

Other potential benefits include:

- Airline, shipping, and vehicle-based industry, upon adoption of these AI/ML algorithms will greatly reduce equipment downtime, avoid the high costs of scrambling to find suppliers and increase on time performance.
- Provide cost efficiencies by providing recommendations and a roadmap for algorithms using transactional data to forecast a more accurate mix of high and low-demand parts per aircraft.

5.2 Benefits for DOD

U.S. air power provides a significant role in both our national security and economic hegemony. To this end, the F-35 enhances our global military and economic partnerships by protecting critical supply lanes to ensure supply chain integrity; thus, allowing for consistent delivery of products to and from the U.S. Our allies depend upon the uninterrupted flow of these exports and the U.S. requires certain critical imports for both manufacturing and use in rebuilding the country’s infrastructure.

Additional benefits include:

- Increased speed of decision making.
- Decreased customer wait times.
- Increased gross issue effectiveness.
- Enhanced mission planning capabilities that facilitate improved mission success rates.
- Optimized sustainment policies and practices at the Program Office, Field supply activities and Field supporting agencies.
- Improved collaboration between engineering and logistics providers.
- Reduced cost of goods – by increasing speed, optimizing maintenance and sustainment cost.

The tool being developed could yield a wide range of applicability as many branches of the U.S. military are experiencing similar supply chain issues. An effective prototype can be utilized for other aircraft and vessels that are vital to national security efforts.

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