Advanced Tools and Methods to Improve Material Handling Equipment Overhaul

Final Report

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Commercial Technologies for Maintenance Activities (CTMA) Program

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Acronyms and Abbreviations

Term	Definition
3D	Three-Dimensional
AM	Additive Manufacturing
APL	Approved Parts List
BOM	Bill of Materials
CTMA	Commercial Technologies for Maintenance Activities
DOD	Department of Defense
EOL	End of Lifecycle
MHE	Material Handling Equipment
MRO	Maintenance, Repair, and Overhaul
NCMS	National Center for Manufacturing Sciences
ODASD-MR	Office of the Deputy Assistant Secretary of Defense, Materiel Readiness
OEMs	Original Equipment Manufacturers
R&T	Reach and Tier
RDI	Ricardo Defense Incorporated
RRAD	Red River Army Depot
SLEP	Service Life Extension Program
SOW	Statement of Work
U.S.	United States

1. Executive Summary

Leveraging new advanced analytical tools and advanced manufacturing processes has ushered in a transformative era for the government and industry which enables them to proactively address a myriad of challenges. These innovative technologies not only anticipate obsolescence, but they empower organizations to stay ahead of the curve when it comes to adopting new technologies and handling intricate supply chain issues. This foresight is paramount in establishing a diverse and resilient supply system that remains unwavering in delivering critical components for maintenance and sustainment activities. While most of the Maintenance, Repair, and Overhaul (MRO) services are traditionally linked to aviation and aerospace, the scope has broadened. Products or equipment with high costs and extensive lifecycles, such as Material Handling Equipment (MHE), are now prime candidates for these streamlined MRO processes.

MRO activities encompass an array of functions that ensure the continuous upkeep of military equipment throughout its lifespan, including periodic maintenance, unscheduled repairs, retrofits, and even complete rebuilds. However, it’s no secret that many organizations have faced challenges when attempting to carry out MRO operations efficiently and effectively. Siloed processes, disparate systems, and the constant deluge of data, from scheduling and forecasting to inventory management and parts replenishment have hindered the seamless execution of these critical tasks. That’s where Ricardo Defense Incorporated (RDI) continuous improvement strategies, digital engineering tools, and advanced manufacturing techniques have proven to be invaluable.

RDI’s contributions to this field have not only accelerated processes but have also set the standard for maintaining high-quality standards while mitigating risks. Their ability to provide viable alternatives for obsolete parts ensures that MRO activities stay on schedule and experience no cost escalation. This revolution in military maintenance operations exemplifies the power of cutting-edge technologies and methodologies in enhancing the readiness and reliability of our Armed forces, ultimately contributing to the national defense infrastructure.

This project was undertaken with the primary objective of addressing the pressing challenges faced by both commercial and military sectors in the realm of MRO activities. The ever-present issues of obsolescence, supply chain erosion, and the rapid emergence of advanced technologies have significantly impacted vehicle and MHE components across various industries. These challenges have resulted in decreased system efficiency and increased downtime due to maintenance requirements. To combat these issues effectively, a collaborative effort between the government and industry involved a thorough analysis of damaged or defective parts.

This analysis utilized advanced modeling and simulation techniques to identify optimal alternative solutions, preventing structural degradation and enabling safer operation and maintenance of equipment. In response, the project initiated the procurement of corrosion-resistant coatings, which proved to be a valuable strategy for extending the lifespans of critical components, thereby preventing premature End of Lifecycle (EOL) scenarios.

Furthermore, this project introduced innovative repair and refurbishment options that have significantly enhanced the agility and functionality of repairable solutions. This, in turn, has not only mitigated further damage but has also generated substantial cost savings in maintenance, while simultaneously bolstering the longevity of supply chains and crucial parts. In summary, this project represents a substantial leap forward in the pursuit of unique, adaptable, and cost-effective solutions to the complex challenges faced in MRO activities within the commercial and military sectors.

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

At the initiation of the project, RDI's personnel traveled to Red River Army Depot (RRAD) to engage and assess the requirements of the Service Life Extension Program (SLEP) for the Navy shipboard 4.5K Reach and Tier (R&T) Forklift Truck. The team played a pivotal role in the disassembly of the vehicle, inspecting and labeling components in strict accordance with the Statement of Work (SOW) and the Parts Breakdown Technical Manual 0532-LP-000-4206. This comprehensive approach enabled RDI to pinpoint critical elements, identify obsolete parts, and mitigate potential risks to the project.

Throughout the project, effective communication and project management were established, and weekly meetings were conducted to create a close-knit relationship between RDI and team partners. These meetings served as a platform to gauge the project's health, measure success, manage expectations, and enhance decision-making processes.

RDI interaction with team partners including the equipment helped develop a robust risk register. This invaluable tool allowed the team to closely monitor significant events and incidents within the pilot project, guiding the team in setting clear priorities to extend the equipment's lifespan.

Simultaneously, RDI took significant strides in enhancing the project's foundation. An updated and meticulously curated Bill of Material (BOM) was developed and finalized, laying the groundwork for a more efficient and streamlined process.

Recognizing the importance of a strong supply chain, RDI actively cultivated new business relationships with suppliers and vendors.
Once the essential parts arrived at their Troy, Michigan facility, the team inspected each component, ensuring they met stringent quality standards and precise government specifications. This quality assurance was followed by efficient packaging and timely delivery, all executed with the precision that the government expected.

Additionally, RDI's personnel played a vital role in establishing key performance indicators for the 4.5K forklifts. This encompassed a comprehensive spectrum, including inventory management, procurement, supplier management, production, warehousing, and cross-functional training. The team then maintained records of all production-related data for future reference, providing a wealth of information to study trends and forecast supply and demand in a rapidly evolving economic landscape.

1.2 Benefits

The project demonstrated the effectiveness and efficiency of vehicle overhaul activities using digital engineering tools and advanced manufacturing techniques. The benefits included improving the reliability of critical parts, maintaining weight, increasing performance, and extending equipment's useful life.

Design flexibility and low material waste can improve production lines and maintenance facilities by aerospace manufacturers and other MRO companies. Digital engineering and additive manufacturing (AM) processes have the potential to save $113-370 billion by 2025. Integrating AM into existing supply chain distributions can produce a more efficient and responsive supply chain, reduce costs and enable economics of scale.

As equipment ages, obtaining repair and spare parts becomes problematic, and AM can provide a robust supply chain for maintenance and sustainment technicians. Efficiency in the maintenance and sustainment workspace will boost job satisfaction, expand skillsets, and improve the bottom line for the American industrial base. Digital engineering tools and advanced manufacturing techniques can significantly improve the ability of the Department of Defense (DOD) to maintain and sustain critical equipment and weapons systems. These technologies can improve core maintenance and supply chain systems, reduce maintenance repairs, and improve reliability. They can be applied at any point in the manufacturing cycle, saving time, money, and material. Digital engineering can accelerate reverse engineering, MRO operations, and three-dimensional (3D) printing applications, increasing mission effectiveness and equipment availability. It also provides data for full-scale engineering, manufacturing, and development, reducing user error and providing unmatched traceability for documentation purposes.

1.3 Recommendations

Ensuring the sustainability and operability of equipment is paramount as it relates to government parts and weapon systems. It is a mission-critical aspect of MRO.

To safeguard the nation's interests, it is imperative to allocate resources toward future initiatives that rapidly modernize equipment, systems, and technologies. RDI's focus lies on enhancing the 4.5K R&T Forklifts.

As of this report, the Navy has taken proactive steps by investing in an additional two to three forklifts. This investment serves as a testament to RDI's commitment to maintaining a high level of readiness and capability in defense operations. These new forklifts are set to be actively supported by RDI, ensuring that their operational efficiency is sustained over time.

The next phase will build upon the invaluable lessons learned from the pilot project. The primary goal of the upcoming phase is to reduce out-of-service downtime to a minimum and enhance the availability of parts and MHE. This proactive approach not only enhances overall operational efficiency but also contributes to cost savings, making the entire system more robust and reliable in the defense sector. It not only secures the present but fortifies the nation's capabilities for the future.

1.4 Invention Disclosure

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

1.5 Project Partners

- Navy Supply Systems Command
- Red River Army Depot (RRAD)
- Ricardo Defense Incorporated (RDI)
- National Center for Manufacturing Sciences (NCMS)

2. Introduction

2.1 Background

MRO activities are essential for the upkeep and sustainability of various types of equipment and transportation assets, including aircraft, trains, and trucks. The MRO tasks cover a wide range of activities that are necessary to keep the fleet assets operational and in safe condition. The commercial aviation, military, and railway sectors have stringent safety requirements, making MRO a highly regulated industry. To ensure a quality repair or overhaul, properly trained maintainers must have access to the appropriate parts, processes, and tools. After safety, the primary goal of fleet operators and maintainers is to maximize asset availability and maintenance resources while minimizing costs. Therefore, efficiency is a priority, and MRO providers must implement lean maintenance processes and leverage advanced tools to improve quality and profitability while meeting maintenance schedules. These same priorities apply to the refurbishment and overhaul of MHE, such as forklifts and order pickers, which play a critical role in the movement and transportation of goods. Forklifts are popular in the material handling industry due to their versatility and durability. However, they still have many moving parts that must operate safely and at peak performance to prevent accidents and injuries. Given the large loads and heavy usage that these lift trucks endure, forklift MRO must be performed to the highest quality. By using digital engineering tools and advanced maintenance processes, fleet managers and maintainers can refurbish and overhaul parts and end-item equipment more efficiently and effectively, making them more reliable and easier to maintain. With new advancements in technology, maintainers can also take advantage of predictive maintenance techniques to identify potential issues before they become critical. Refurbished forklifts are beneficial to the operators and fleet with the latest lighting, brake, suspension and safety features for improved performance at a reduced cost.

To persevere with the evolving and sophisticated technologies that meet the needs and requirements of today's consumers, the maintenance and engineering industries must remain adaptable, agile and flexible to avoid becoming obsolete. Agility is crucial for the continued operation and sustainability of both legacy and current commercial systems. Every industry that relies on technology faces this critical challenge. Obsolescence occurs when a part, service, or resource is no longer available despite still being necessary. Obsolescence significantly impacts the maintenance and sustainment of crucial components. Utilizing advanced digital engineering tools and advanced manufacturing techniques can optimize the creation of new parts and components, making systems more reliable and easier to maintain. The pace of technological advancement continues to accelerate, often making it difficult to find or obtain necessary parts. If not effectively managed, obsolescence may negatively impact a commercial business's operations and financial performance.

This issue is particularly critical for products and applications with long lifecycles and high usage, such as MHE. Original equipment manufacturers (OEMs) strive to support their products for as long as possible, but when a part essential for sustaining a system over the next decade becomes unavailable, business leaders, maintainers, and supply chain professionals must have alternative options in place before operations are affected. Reverse engineering, as it is currently practiced, involves deconstructing components to determine their fabrication process. This knowledge aids in redesigning various components and reduces the resources required compared to building the device from scratch.

By employing advanced tools like 3D laser scanning and digital engineering technologies, the reverse engineering process can be streamlined and completed more efficiently. This allows commercial companies to explore and experiment with new methods of delivering unique capabilities and benefits to their customers.

Advanced and AM technologies require meticulous attention to digital engineering tools and manufacturing processes due to their high levels of process sensitivity and complexity that result in parts with unique material properties and characteristics. Consistent mechanical performance of AM parts depends on the rigor of the digital engineering processes and tools and the complexity of controlling the AM process. Despite the numerous advantages and applications of metal AM technology in fabricating individual structural components, utilization of AM to manufacture mission-critical parts remains limited. This is primarily due to a lack of technological standards, manufacturing know-how, and material property data resulting from the rapid growth of AM technology in recent years.

Establishing standards and detailed process work instructions will ensure consistency, repeatability, and reliability of AM-fabricated components for commercial companies worldwide, reducing the likelihood of critical components failing during MRO activities. Major governing bodies have established increasingly stringent sets of testing protocols and certification steps before clearing any components for service, depending on the required application. Such certification and qualification typically involve demonstrating the repeatability of the production process and the consistency of the quality of as-fabricated components. However, process repeatability and quality consistency remain major challenges in AM technologies used in the aerospace industry, particularly when manufacturing parts in large quantities needed for MRO activities.

2.2 Purpose

The purpose of this project was to propel the state forward in the fields of modeling and simulation, advanced engineering, and maintenance methods with the ultimate goal of refurbishing and overhauling a legacy forklift. The primary objective was to pilot shipboard MHE as a surrogate to validate the effectiveness of new advanced engineering and manufacturing tools and processes.

The desired outcome was a comprehensive full system overhaul that was not only cost-effective, but also extended the useful life of the equipment, and was safely and easily completed by maintainers. Additionally, the project aimed to determine if this new approach can be documented and applied to a wide range of MHE to support improved MRO activities across the DOD organic industrial base and commercial maintenance facilities. By adopting this new approach, maintainers were able to simplify and complete maintenance repairs and refurbishments with higher levels of success, find better alternative sources of supply for parts, provide a more reliable material product, and reduce the overall time and cost for the maintenance effort. Overall, this project sought to revolutionize the MHE industry introducing innovative engineering and manufacturing techniques, streamlined maintenance processes, and enhanced the overall efficiency and effectiveness of MRO activities.

2.3 Scope/Approach

A collaborative effort was deployed that embraced multiple government and industry partners. Industry provided their subject matter expertise and experience in 3D scanning, modeling and simulation, electrification components, and vehicle integration. The project team provided solutions that ensured the surrogate vehicle contained all the required modified work orders and parts to get the equipment into final configuration and operational status before performing vehicle and component scanning.

The government provided functional and tacit knowledge and specific government information that included maintenance processes, technical manuals, and interfaces to core maintenance systems. The government performed oversight of the project and documented the results of both the process and technologies. Gaps in documentation and outdated methodologies were captured to make the process updates for future efforts. As applicable, the commercial sector and DOD will use lessons learned from the pilot project for continuous improvement methodologies and expanding electrification conversions to other vehicles and equipment. Figure 1 taken from Surplus Raymond 40-R45TN Electric Forklift in Yermo, California, United States (GovPlanet Item #4599959) displays similar forklifts used during this pilot project.

Figure 1. Raymond 40-R45TN

3. Project Narrative

During this project, the achievement of the tasks and end state was a result of the collaborative efforts of three distinct entities: RDI, the government sponsor, and various suppliers. To facilitate the smooth execution of the project, RDI assigned a dedicated logistician to work closely with the government sponsor and vendors for 18 months. The primary objective of this logistician was to effectively manage and optimize the intricate aspects of the supply chain and minimize the impact of obsolescence. This involved tasks such as cataloging and determining pricing for parts, developing a new Approved Parts List (APL), procuring necessary components to enhance functionality and efficiency, and establishing key performance indicators for the 4.5K R&T Forklifts to predict potential failures and take proactive measures. The key areas encompassed by these performance indicators include inventory management, supplier management, production, and warehousing. The logistician provided subject matter expertise to ensure a timely handoff of parts and materials were delivered from the manufacturer to the shipper and from the shipper to the end user based on the government's intent for the project. The government provided clear guidance on what parts were a priority and necessary to be shipboard approved and mission-effective and ready. Through the collective efforts of these entities, the project goals were successfully attained, highlighting the value of close collaboration, the transmission of orders and the supply chain's responsiveness to demand. A communication flow chart that displays how information flows from one place to another (Figure 2).

3.1 Project Tasks

The 18-month pilot project served as a demonstration of the effectiveness by leveraging

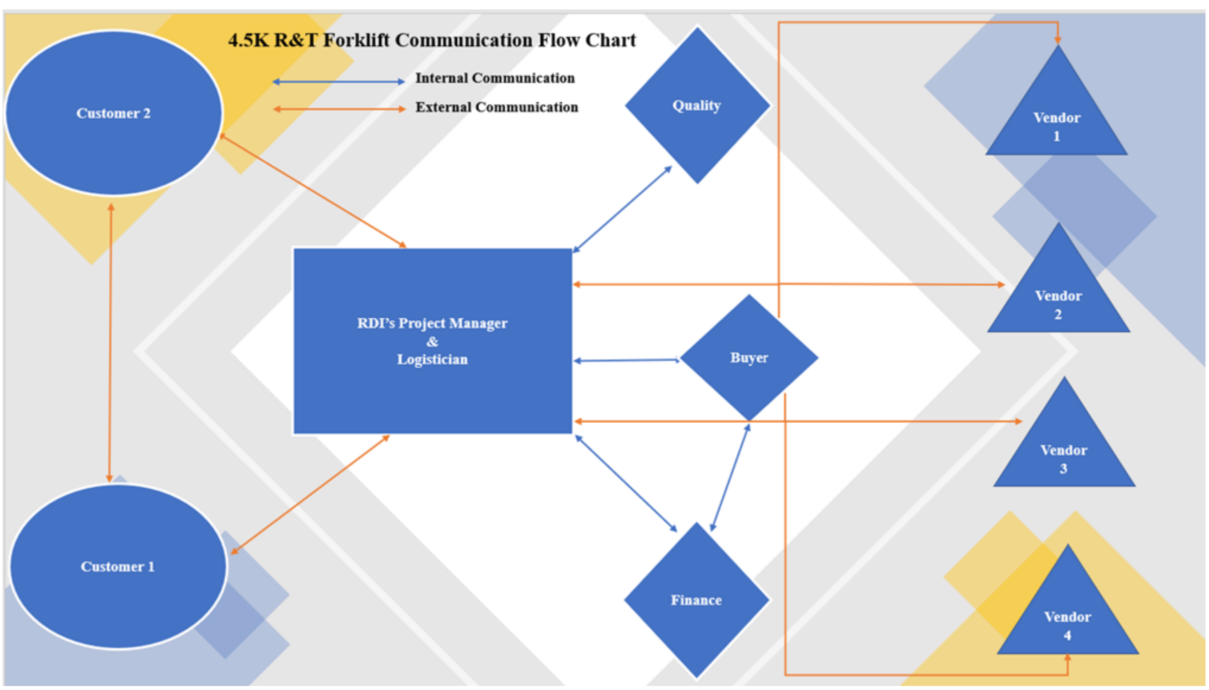


Figure 2. Communication Flow Chart

digital engineering technologies and advanced manufacturing processes of the availability of parts and the BOM for supporting vehicle MRO activities in the private industry. RDI conducted research and development on innovative technologies that focused on identifying alternative sources of supply for critical parts, thereby ensuring that vehicle fleets operated at optimal efficiency and were not hindered by prolonged periods of downtime while waiting for spare parts. The implementation of digital engineering solutions helped maintain the competitive edge by keeping fleets operational, maximizing profits, and delivering superior service to end consumers. Specific tasks carried out during this project included:

- Performed maintenance activities to ensure that the surrogate vehicle was equipped with all the necessary modified work orders and parts to achieve the final configuration and operational status.
- Analyzed the current APL (Table 1) and created a BOM that identified obsolete parts and opportunities for optimization and enhanced resistance to corrosion.
- Alternate sources of supply for obsolete and hard-to-find parts were determined to ensure that they met the required form, fit, and function.
- Analyzed and identified candidate parts that could be produced at a lower cost with improved performance to extend the life of the equipment.

Table 1. Approved Parts List

Reference RIC, Parts, & NHA/NLA RIC Data for 950006537

Report: 461 Print Date: 2/22/2022 11:41:44

Ric: 950006537 Created: Changed: 10/05/2021 Super: Cancelled: Deleted: Rptg Acti: N00104

Ric Nom: TRK,FRKLFTRCH TIERING,ELEC,MDL040-R45TN

Lssc: AU Niin: Status: V

Ainac: SP Cage: Cog: G

Superseding RIC/AINAC/Initials:

Line Item	Component Text
0001	MFR-RAYMOND CORPORATION THE GREENE NY
0002	NAVCOM PLAN-N/A
0003	MFR DWG-VARIOUS
0004	MFR ID-040-R45TN
0005	PATTERN NO-10
0006	EQUIP SPEC-N/A
0007	NSN-NONE
0008	LAPL-1390
0009	TYPE-ELECTRIC
0010	CAPACITY-4500 LBS
0011	PDCN-NH9851 SHIPBOARD
0012	*CONTRACT-DLA730-93D-8019
0013	*LIBRARY-90031-0086-00
0098	TSA IS SPCC CODE 0341, POC IS J MAURER
0099	PA IS SPCC CODE 05131, POC IS G SHARP
1178	*LINE 1179 LISTS APL NOMENCLATURE AS OF 15 DEC 09
1179	*TRUCK,FORKLIFT REACH/TIERING,ELEC,MDL 040-R45TN
1195	FSCM-90031
1198	CCF DATE -10 95

Niin	Item Name	Anc	Qty	Uoi	Unit Price	SM&R	Cog	Fsc	Cage	Prime Apl Ref No	P# Type
004885420	COUPLING,ELECTRIC M		000001	EA	$9.02	PA2ZZ	9B	6105	90031	900-008-110	P
008594238	SHAFT ASSEMBLY,SPID		000001	EA	$4,911.55	PAGZZ	9B	2520	90031	900-002-025	P
011238171	RESISTOR,VARIABLE,N		000001	EA	$155.43	PA2ZZ	9B	5905	90031	1-120-050	P
012882600	CONTROL,REMOTE SWIT		000001	EA	$4,590.45	PA2ZZ	9B	6110	90031	900-003-412	P
015839293	FILTER ELEMENT,FLUI		000001	EA	$117.36	PA2ZZ	9B	4330	90031	520-508/01	P
016733002	CONNECTOR,PLUG,ELEC		000001	EA	$64.26	PA2ZZ	9B	5935	034K5	A32502-10C9	P
016733007	CONNECTOR,PLUG,ELEC		000001	EA	$49.22	PA2ZZ	9B	5935	034K5	A32402-10C9	P

- Assessed the potential risks associated with the integration of new parts into subsystems and the overall system, which could impact the overhaul and performance of the vehicles.
- Created a BOM from the APL and the outdated Navy Technical Manual to act as the team's central record of materials, components and processes used to modernize and maintain a 4.5K R&T Forklift.

3.2 Project Deliverables

The project deliverables focused on enhancing specific tools that could showcase improvements and efficiencies for maintenance organizations, particularly through the utilization of advanced tools and methodologies in digital engineering and advanced manufacturing. The development of these tools aided in expediting maintenance and sustainment processes, resulting in reduced vehicle downtime and improved readiness. These deliverables exemplified how organizations can enhance supply chain responsiveness and decrease costs through improved efficiencies. The project deliverables include the following:

- The BOM for the surrogate system was examined and revised displaying an extensive list of parts and components to manufacture and repair the 4.5 R&T Forklifts in the assembly and reassembly process.
- The Revised BOM (Table 2) can be filtered to display obsolete parts that can be reclaimed or use alternative sources of supply through advanced and AM techniques. It facilitated efficiency and helped the government manage operation costs.
- Revised BOM comprised all assemblies and parts required to construct the finished forklifts and ship them to the warfighter in the Fleet.

Table 2. Revised Bill of Material

Figure	Index No.	System	NSN	Prime Contractor Part Number	OEM Part No.	OEM CAGE	Description	Dimensional Data	Qty per forklift	SLEP Determination
6.1.0	6.1.0	Tractor Assembly		903-003-494/405		90031	Tractor Assembly		2	N/A
6.1.0	1			903-003-145/405		90031	Tractor Rework		1	N/A
6.1.0	3			411-016		90031	Deadman Brake Pad		1	MRP
6.1.0	5		5305-00-839-7731	701-119		90031	Rd. Hd. Mach. Screw	#10-32 x 7/8	6	MRP
6.1.0	6			702-206		90031	Fl. Hd. Mach. Screw	1/4-20 x 1-1/4	4	MRP
6.1.0	7			710-006		90031	Hex Hd. Cap Screw	1/4-20 x 1/2	2	MRP
6.1.0	9			710-010		90031	Hex Hd. Cap Screw	1/4-20 x 3/4	11	MRP
6.1.0	10			710-070		90031	Hex Hd. Cap Screw	5/16-24 x 3/4	2	MRP
6.1.0	10.2			*772-119		90031	Lockwasher	5/16	2	MRP
6.1.0	11			760-006		90031	Hex Nut	1/4-20	3	MRP
6.1.0	12			750-054		90031	Hex Nut	3/4-16	4	MRP
6.1.0	13			760-117		90031	Hex Locknut	3/8-24	2	MRP
6.1.0	14			771-116		90031	Flat Washer	1/4	7	MRP
6.1.0	15			771-143		90031	Flat Washer	41/64	2	MRP
6.1.0	16			771-152		90031	Flat Washer	3/8	2	MRP
6.1.0	17		5310-00-515-9962	772-116		90031	Lockwasher	1/4	21	MRP
6.1.0	18			772-128		90031	Lockwasher	3/4	4	MRP
6.1.0	19			774-012		90031	Lockwasher	#10	6	MRP
6.1.0	20			812-002-828		90031	Flange		1	%
6.1.0	20.1		5330-01-295-2957	*531-140	531-140	20097	Gasket		1	N/A
6.1.0	20.2			*709-119		90031	[illegible]. Hd. Mach. Screw	#10-32 x 1/2	6	MRP
6.1.0	20.3			*774-012		90031	Lockwasher	#10	6	MRP
6.1.0	21		2930-01-532-3195	850-516/868		90031	Filler Cap W/Dipstick		1	%
6.1.0	22			900-003-270/868		90031	Plate		1	RECLAIM
6.1.0	22.1			*741-015		90031	Drive Screw #2		3	N/A
6.1.0	23			900-005-070		90031	Handle		2	RECLAIM
6.1.0	25			900-100-302		90031	Latch Machining		2	RECLAIM
6.1.0	26			900-123/404		90031	Main Door Hinge Alteration		1	%
6.1.0	27			902-010-015		90031	Floor Cushion		1	MRP
6.1.0	28			903-003-165		90031	Pedal Tread - Ext.		1	MRP
6.1.0	29			903-003-166/404		90031	Floor Tread - Ext.		1	MRP
6.1.0	30			903-003-430		90031	Battery Anchor Weldment		2	RECLAIM
6.1.0	31			903-003-445		90031	Cable Shield		1	%
6.1.0	31.1			780-419		90031	Mech. Plug (Not illustrated)	3/4-14	1	%
6.1.0	32			820-000-646/868		90031	Handle Bar		1	RECLAIM
6.1.0	33			860-108		90031	Knob		1	MRP
6.1.0	34			791-505	840FS06	30327	Sleeve		1	%
6.1.0	35			724-548		90031	Set Screw	3/8-16 x 1-1/4	1	MRP
6.1.0	36			716-012		90031	Shoulder Screw		1	MRP
6.1.0	37			830-160		90031	Spring		1	MRP
6.1.0	38			820-000-645/868		90031	Spacer		1	RECLAIM
6.2.0	6.2.0	Dash Panel Sub-Assembly		903-003-228/415		90031	Dash Panel Sub-Assembly		1	N/A
6.2.0	3			710-015		90031	Hex Hd. Cap Screw	1/4-20 x 1	1	MRP
6.2.0	4			710-078		90031	Hex Hd. Cap Screw	5/16-18 x 1-1/2	2	MRP

- Created and maintained a Backorder Tracker (Table 3) to monitor the supplier's dependability and responsiveness.
- Backorder Tracker helped to minimize negative impacts and to date constraints due to lag variables.
- Built an actionable Risk Register (Table 4) that identifies and mitigates risks to minimize the negative impact of the project threats and maximize the positive impact of project opportunities.
- Charted important achievements, events and the life of the project with a Milestone Chart (Table 5).
- Milestone Chart tracked and monitored the overall success of the project, identified specific techniques used to get results and recorded what features, practices, and processes proved to be strengths and weaknesses.

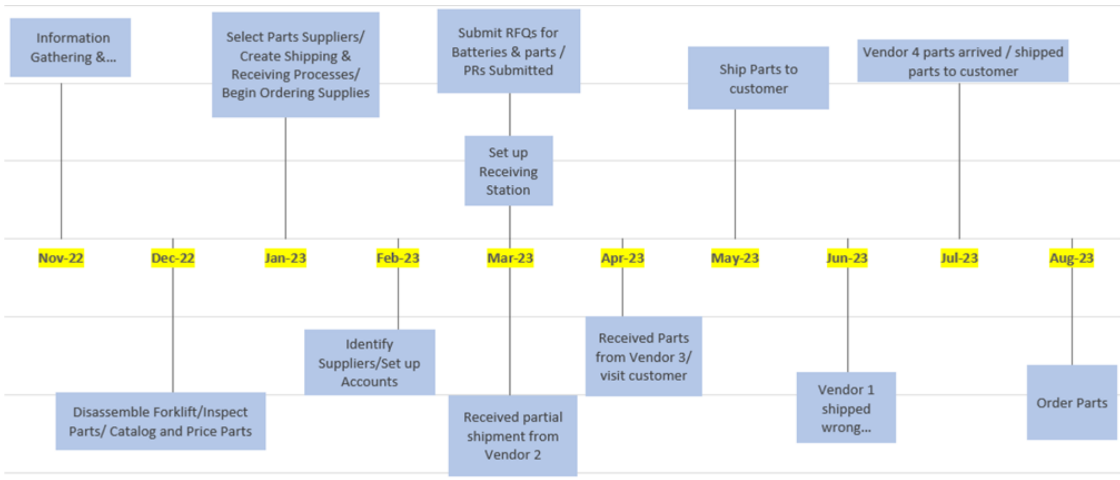
Table 3. Backorder Tracker

Manufacturer	Purchase Order	Part Number	Description	Qty Ordered	Received	Backord	Comments
Vendor 1	N/A	623-032-210	YOKE	4	2	2	packed 2 in Forklift 1
Vendor 3	SQ23-12827	154-005-350/417	CONTROL ASSY	2	0	2	backordered 5-10 weeks/ Aug 31
Vendor 3	SQ23-12827	1-150-398	SWITCH	1	0	1	backordered 5-10 weeks/ Aug 31
Vendor 3	SQ23-12827	3-000-096	SWITCH	2	0	2	backordered 5-10 weeks/ Aug 31
Vendor 3	SQ23-12827	3-000-078	SWITCH	2	0	2	backordered 5-10 weeks/ Aug 31
Vendor 3	SQ23-12827	591-454	LIGHT FLOOD (1317006)	2	0	2	backordered 5-10 weeks/ Aug 31
Vendor 3	SQ23-11862	900-023-208-216 / 520-816-	FUSE	2	0	2	charged for 2 but not in shipment
Vendor 3	SQ23-11862	520-838/03 (NO STOCK)	SEAL KIT	2	0	2	charged for 2 but not in shipment
Vendor 3	SQ23-42192	772-104	LOCKWASHER	2	0	2	Shipping this week
Vendor 3	SQ23-42192	441-025	BEARING	2	0	2	Shipping this week
Vendor 3	SQ23-42192	443-021	BEARING	6	0	6	Shipping this week
Vendor 3	SQ23-42192	446-017	BEARING	2	0	2	Shipping this week
Vendor 3	SQ23-42192	447-092	BEARING CONE	2	0	2	Shipping this week
Vendor 3	SQ23-42192	447-569	BEARING CUP	2	0	2	Shipping this week
Vendor 3	SQ23-42192	530-445	O-RING	2	0	2	Shipping this week
Vendor 3	SQ23-42192	530-458	O-RING	2	0	2	Shipping this week
Vendor 3	SQ23-42192	530-476	QUAD RING	2	0	2	Shipping this week
Vendor 3	SQ23-42192	760-159	HEX HD. LOCKNUT	2	0	2	Shipping this week
Vendor 3	SQ23-42192	771-133	FLAT WASHER	2	0	2	Shipping this week
Vendor 3	SQ23-42192	810-039	SNAP RING	6	0	6	Shipping this week
Vendor 3	SQ23-42192	810-063	SNAP RING	2	0	2	Shipping this week
Vendor 3	SQ23-42192	810-127	SNAP RING	6	0	6	Shipping this week
Vendor 3	SQ23-42192	840-005	GREASE FITTING	4	0	4	Shipping this week
Vendor 3	SQ23-42192	810-154	SNAP RING	2	0	2	Shipping this week
Vendor 3	SQ23-42192	773-023	HI COLLAR LOCKWASHER	10	0	10	Shipping this week
Vendor 3	SQ23-42192	442-208	ALL BEARING - COMM. EN	2	0	2	Shipping this week
Vendor 3	SQ23-42192	442-244	ALL BEARING - DRIVE EN	2	0	2	Shipping this week
Vendor 3	SQ23-42192	530-637	OIL SEAL	2	0	2	Shipping this week
Vendor 3	SQ23-42192	701-180	RD. HD. MACH. SCREW	8	0	8	Shipping this week
Vendor 3	SQ23-42192	570-813-09	C.E. LOAD SPRING	2	0	2	Shipping this week
Vendor 3	SQ23-42192	570-823-06	SPRING	16	0	16	Shipping this week
Vendor 3	SQ23-42192	750-420	BRASS HEX NUT	8	0	8	Shipping this week
Vendor 3	SQ23-42192	700-003	HEX HD. MACH. SCREW	24	0	24	Shipping this week
Vendor 3	SQ23-42192	715-083	SOC. HD. CAP SCREW	16	0	16	Shipping this week
Vendor 3	SQ23-42192	726-026	CONE PT. SET SCREW	8	0	8	Shipping this week
Vendor 3	SQ23-42192	5-018-004	FLAT WASHER	8	0	8	Shipping this week
Vendor 3	SQ23-42192	772-112	LOCKWASHER	2	0	2	Shipping this week
Vendor 3	SQ23-42192	870-673	HOSE GUARD	2	0	2	Shipping this week
Vendor 3	SQ23-42192	701-184	RD. HD. MACH. SCREW	4	0	4	Shipping this week

Table 4. Risk Register

Risk Assessment											
Area Name:	1754-100 RRAD NAVSUP 4.5K Forklift Logistics		Updated by:	RDI			Last updated:	8/10/2023			
				Inherent Risk (without controls)					Residual Risks (with controls)		
Unique ID	Risk Description	Caused by and Consequences	Risk Owner(s) Name and Roles	Probability	Impact	Risk Rating	Control(s)	Control Owner Name and Role	Very Low	Impact	Risk Rating
NPP1	COVID-19 on Potential Supplier	Natural Causes	Vendor	Medium	Medium	Moderate			Medium	Low	Sustainable
NPP2	Difficulty of Disassembly of Forklifts	Customer. Mechanic was out with Covid and Holidays	Government	Medium	Low	Moderate			Very Low	Very Low	Sustainable
NPP3	Difficulty Finding Technical Manual	Government	RDI	Medium	Medium	Moderate			Medium	Low	Sustainable
NPP4	Allowance Parts List (APL) did not include all forklift parts.	RDI. Pricing was incomplete-so parts list was incomplete.	RDI	Medium	Low	Moderate			Medium	Low	Sustainable
NPP5	National Stock Numbers (NSN) not provisioned	Age of Equipment. Unable to locate parts and pricing via Webflis, Publog and other Internet Search Engines	RDI	Medium	Medium	Moderate			Medium	Medium	Moderate
NPP6	Obsolete Parts	Logistics: Supply & Demand	RDI	Medium	Medium	Moderate			Medium	Medium	Moderate
NPP7	Backordered Parts	Logistics: Supply & Demand	RDI	Medium	Medium	Moderate			Medium	Medium	Moderate

Table 5. Project Milestone Chart



4. Conclusions

MRO is crucial for ensuring the safety and reliability of various transportation assets, from aircraft to forklifts. Safety standards, efficiency, and cost-effectiveness are paramount concerns in this highly regulated industry. Leveraging digital engineering tools and advanced maintenance processes can enhance the quality and profitability of MRO activities and MHE while meeting urgent demands and schedules.

Moreover, the challenge of obsolescence is a pressing issue, given the rapid pace of technological advancements. Obsolescence can disrupt operations and financial stability, particularly for equipment with long lifecycles. The ability to reverse engineer components and leverage advanced manufacturing techniques becomes essential to mitigate obsolescence-related risks and maintain systems.

In the realm of AM, there is a need for rigorous attention to digital engineering tools and processes to ensure the consistent mechanical performance of AM-fabricated parts. Standards, certifications, and quality controls are crucial for reducing the likelihood of critical component failures, especially in government and related industries.

In conclusion, embracing advanced technologies, including digital engineering, reverse engineering, and AM, is essential for the MRO industry to adapt to the evolving landscape, maintain safety standards, and effectively manage obsolescence challenges. These innovations not only enhance operational efficiency but also ensure the longevity and reliability of critical assets.

5. Project Benefits

5.1 Benefits for the General Public

The purpose of this project was to utilize the statistics and methods obtained from mission deliverables as a substitute for enterprise. This demonstrated how digital engineering equipment and advanced production can improve the effectiveness and efficiency of vehicle overhaul activities.

Private enterprises and the public will experience several benefits because of this project, including, but not limited to:

- Enhancing the reliability of critical parts and components while reducing weight and increasing overall performance. This will extend the useful life of equipment and contribute to the improvement of the economic sector.
- Leveraging digital engineering tools to achieve design flexibility and minimize material waste. This will enhance the efficiency and effectiveness of current and future production lines and maintenance centers, benefiting aerospace manufacturers and other MRO groups.
- Recent lifecycle assessments have shown that various digital engineering and AM techniques can result in significant cost savings in AM. It is estimated that these savings could reach $113-370 billion by 2025.
- The integration of AM into existing supply chain distributions in the aerospace and other industries has the potential to create a more efficient and responsive supply chain. Currently, companies rely on estimates of future needs when purchasing and manufacturing products. This often leads to excess inventory and wasted capital. By using AM to manufacture spare parts that are not mass-produced through conventional methods, companies can improve cost efficiency and take advantage of economies of scale. AM offers the potential for significant cost savings and reduced risk of obsolescence.
- As equipment ages, the acquisition of repair and spare parts becomes problematic. Often, OEMs cease production of these parts due to a lack of demand or the need to retool for newer models. Organizations heavily rely on their equipment to maintain productivity, and the unavailability of even a single asset due to a shortage of replacement parts can determine the difference between success and failure.
- Maintenance and sustainment technicians heavily rely on a robust supply chain that can promptly fulfill orders for custom tools and replacement parts, regardless of their location. When this fails to occur, the entire workflow breaks down. Using AM to fabricate metal parts quickly and on demand, organizations gain the necessary freedom to continue uninterrupted production and maintenance activities.
- Enhancing efficiency within the maintenance and sustainment workspace will not only boost job satisfaction but also expand the skillsets of maintenance and sustainment staff, ultimately improving the bottom line of the American industrial base. This will be achieved through increased productivity, improved product quality, and enhanced customer service.

5.2 Benefits for DOD

For the DOD, a strong and powerful use of digital engineering tools and superior manufacturing strategies will provide superb benefits to increasing the ability of DOD employees to conduct MRO activities required to maintain and sustain important weapon systems at a high level of readiness. In addition, demonstrating those technologies and techniques can provide huge contributions to enhance the middle maintenance and supply chain structures and procedures that increase speedy responses and repair broken systems. Other advantages consist of:

- Providing the military and defense agencies with the ability to speedy measure new or used components, vehicles, or aircraft for inspection, space claim or product development.
- Offer the capability to capture precise measurements of complete components quicker than traditional dimension strategies could capture a finite number of measurements reducing maintenance repairs and improving reliability.
- These advantages can be carried out at any point in an average production cycle, saving time, cash, and cloth for all DOD weapons systems.
- Results in higher quality, better fitting and extra dependable parts that are less costly to manufacture. The value of an ordinary manufacturing design cycle is reduced by 75% through digital engineering and superior manufacturing strategies which lowers acquisition and lifecycle charges to taxpayers.
- Military vehicle and aircraft maintenance often mean long-term grounding, resulting from errors in custom repairs. Since dependable facts are typically unavailable, the platforms must be measured using digital parts to make repairs.
- Each contribution can be used to accelerate reverse engineering, MRO operations and 3D printing applications, thus increasing mission readiness, effectiveness and system availability.
- Provides the data required to perform full-scale engineering, manufacturing and development of parts and structures. Digital engineering reduces the user error factor and provides unmatched traceability for documentation purposes.
- Vehicles and aircraft are typically down for many days when a replacement part is needed. However, a solution comprising digital engineering and advanced manufacturing dramatically decreases out-of-service time and increases weapons availability.