Transportation Systems Condition-Based Maintenance Plus – Phase II

Final Report

Prepared under:

NCMS Project No. 142072-A and
Cooperative Agreement HQ0034-20-2-0007
for the
Commercial Technologies for Maintenance Activities (CTMA) Program

September 2023

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Acronyms and Abbreviations

Term	Definition
ACR	Armored Cavalry Regiment
BLOB	Binary Large Object
CAISI	Combat Service Support Automated Information Systems Interface
CBM+	Condition-Based Maintenance Plus
CCDC	Combat Capabilities Development Command
CLOE	Common Logistics Operating Environment
CONOPS	Concept of Operations
DAC	Data Analysis Center
DD Form 5988	Equipment Maintenance and Inspection Worksheet
DLB	Digital Logbook
DSC-R	Digital Source Collector – Ruggedized
DOD	Department of Defense
FMTV	Family of Medium Tactical Vehicles
GCSS-A	Global Combat Support System – Army
GUI	Graphic User Interface
GVSC	Ground Vehicles System Center
HTV	Heavy Tactical Vehicles
ICD	Interface Control Document
IETM	Interactive Electronic Technical Manual
JDMS	JTDI Delivery Management Service
JTDI	Joint Technical Data Integration
LDAC	Logistics Data Analysis Center
LDB	Logistics Database
MPEN	Motor Pool Enterprise Node
NCMS	National Center for Manufacturing Sciences
NET	New Equipment Training
NTC	National Training Center
ODASD-MR	Office of the Deputy Assistant Secretary of Defense, Materiel Readiness
OEM	Original Equipment Manufacturer
OV-1	Operational View 1
PEO CS&CSS	Program Executive Office Combat Support & Combat Service Support
PMO	Program Management Office
PM TS TWV	Project Manager Transportation Systems Tactical Wheeled Vehicles
PPMx	Prognostic and Predictive Maintenance
RDI	Ricardo Defense Inc.
RPSTL	Repair Parts & Special Tools List
SASMO	Sustainment Automation Support Management Office
SIL	Systems Integration Lab

SME	Subject Matter Expert
SRS	Software Requirements Specification
TMDE	Test, Measurement, & Diagnostic Equipment
U.S.	United States
VoS	Voice of the Soldier
VSAT	Very Small Aperture Terminal

1. Executive Summary

1.1 Results

As the result of this project, the industry partner and government participants expanded the functionality and capability of the Prognostic and Predictive Maintenance (PPMx) pilot while providing operational data within the United States (U.S.) Army's maturing Logistics Enterprise Network. The ingested vehicle data was the result of multiple demonstrated end-to-end use cases starting first with the soldier and ending with data captured at a strategic-national repository at the Army's Data Analysis Center (DAC). Improving from Phase I, the user Graphic User Interface (GUI) Digital Logbook (DLB) was refined based on feedback. The project improved data capture and processing, data management, and data security within the central enterprise networking node for the tactical wheeled vehicle maintenance operations with direct data access, availability, and readiness to soldiers.

The availability of the platform maintenance data enabled a fleet-level view of the maintenance status. This aggregated data was used to both assess and prioritize maintenance operations, allowing more efficient use of time and manpower. In addition, the project partner, Ricardo Defense Inc. (RDI), provided engineering support in the area of Concept of Operations (CONOPS), updated Software Requirements Specification (SRS), updated architecture views, and a systems interface description for data interactions. Furthermore, the project was successfully delivered, including the support for the on-site systems integration, configurations, demonstrations setup for functionalities, and capabilities testing verification, as well as New Equipment Training (NET) for the end user.

The Project Manager Transportation Systems Tactical Wheeled Vehicles (PM TS TWV) Phase II pilot program would be assembled primarily from the existing technologies and products created to inform the Army's organic PPMx program and would be limited to 30 platforms of a single type at the National Training Center (NTC). The pilot program provided the collection, integration, distribution, and analysis of high-fidelity vehicle PPMx data, and would demonstrate improved efficiencies in vehicle maintenance and repair tasks while minimizing additions to the soldier's existing workload.

The PM TS TWV Phase II pilot program continued previous efforts that were deployed in the initial demonstration as part of PPMx Phase I at Ft. Irwin, CA. The demonstration will show the iterative improvements of maintenance operations and efficiencies when using the DLB, reaching from the Tactical to the Strategic National level. The government-led team, with project participant support, deployed and installed the DLB capability in preparation for the user feedback period that will hone requirements and configurations for future iterations.

The demonstration was a combined effort from Program Executive Office Combat Support & Combat Service Support (PEO CS&CSS), PM TS TWV and Joint Technical Data Integration (JTDI), 11th Armored Cavalry Regiment (ACR), Ft. Irwin Sustainment Automation Support Management Office (SASMO), Ground Vehicles System Center (GVSC), DAC, and RDI, among others. The activities from this cohort generally fell into the following areas:

- Combat Service Support Automated Information Systems Interface (CAISI) Very Small Aperture Terminal (VSAT) connectivity
- Motor Pool Enterprise Node (MPEN) Mid-Tier connectivity
- Digital Source Collector – Ruggedized (DSC-R) configuration & connection
- Top-Tier Binary Large Object (BLOB) file transfer

- DLB Client Node establishment
- NET for soldiers

The project planning and system engineering activity created an operational concept, architecture, requirements, interface definition, and installation plan for the system at NTC. Once the system was installed and operational, the project provided training in the use of the system for operators and maintainers at NTC. A number of issues and obstacles were encountered during system installation and integration, including those listed below and how each item was remedied:

- Network security and certificate distribution
  - Upon identifying DSC-R connection instability, RDI notified the GVSC representative. In turn, the DAC was tasked to update all certificates and harden the network connection between the DSC-R and CAISI. The DAC hardened the network with the Elliptic Curve Cryptography 384 within the Federal Information Protection Standard.
- Wireless connectivity
  - Through troubleshooting, an inconsistency in data transmission was present between the DSC-R to the CAISI and then finally to the tablet. As a result, the CAISI port, IP configuration, and other settings were changed by the Ft. Irwin SASMO.
- Data transfer through the tiered network
  - Due to the network's capability to send and receive data, a latency problem was discovered during the daytime uploads. The DAC assisted with the remedy by selecting pre-determined upload times scheduled during low usage periods early in the morning.
- Hardware configuration
  - Again, through troubleshooting, the CAISI operational time became infrequent – the Ft. Irwin SASMO provided support, including changing damaged ethernet cables and installing Power-Over-Ethernet to the wired network.
- Software robustness when stressed with multiple vehicles
  - Using multiple vehicle DSC-Rs on the network created another data latency problem. RDI changed the Automatic Data Acquisition System settings to request BLOB files from the DSC-R every ten minutes, freeing up bandwidth.

The project team addressed and resolved each of these issues and successfully created a fully operational end-to-end Predictive Logistics capability.

Funding for the collaborative effort was secured 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).

1.2 Benefits

The processes, tools, lessons learned, and best practices described and demonstrated during this pilot project are directly applicable to the logistics activities of the general public and private industry, in many different business areas. The Predictive Logistics capabilities created for this pilot project integrate and demonstrate the key enhancements necessary to realize lower lifecycle costs of equipment ownership. The operational concept, architecture, and computing environment described are directly applicable to any large-scale integrated sustainment system and immediately beneficial to both the commercial and defense domains. Benefits provided by the approach include:

- An end-to-end, flexible, standards-based Predictive Logistics system architecture that may be successfully applied to large scale maintenance organizations
- Built-in support for an organization's business processes and workflow
- Timely, actionable fleet information enabling an efficient use of manpower and other resources
- A customizable software maintenance tool applicable to a wide range of mechanical, electrical, and electronic equipment

In addition, the PM TS TWV Phase II pilot has provided numerous significant benefits to the Army community:

- Demonstrated the viability of the Army's organic Predictive Logistics architecture in an operational environment, offering enhanced security, improved connectivity, and equipment commonality
- Illustrated the direct benefits of providing accurate, timely equipment information to operators, maintainers, and maintenance supervisors in the field
- Demonstrated the automated flow of equipment parametric data from the tactical environment to the equipment support organizations, including GVSC, necessary for the development of prognostic and predictive capabilities
- Identified design improvements for system components, configuration, networks, and operations necessary for enhancing system design
- Identified opportunities to distribute specific or aggregated data at echelon, enabling timely decisions for both tactical and sustainment operations
- Automation of data in populating required logistics forms, the associated tasks for remediation, and the required repair parts. This automation reduces user input errors, and increased accuracy in fault identification

1.3 Invention Disclosure

Invention Disclosure Report(s):

DD882 Sent to NCMS ☐
No Inventions (Negative Report) ☒

1.4 Project Partners

- U.S. Army Project Manager Transportation Systems Tactical Wheeled Vehicles (PM TS TWV)
- U.S. Army NTC at Ft. Irwin, CA
- U.S. Army Integrated Logistics Support Center
- U.S. Army Combat Capabilities Development Command (CCDC)
- U.S. Navy Program Management Office (PMO) JTDI
- U.S. Army Aviation and Missile Command Logistics Center *(observer)*
- U.S. Army Futures Command *(observer)*
- U.S. Army Program Executive Office Ground Combat Systems *(observer)*
- U.S. Army Program Executive Office Enterprise Information Systems *(observer)*
- Oshkosh Defense LLC
- Ricardo Defense, Inc. (RDI)
- National Center for Manufacturing Sciences (NCMS)

2. Introduction

2.1 Background

Any organization that depends on mechanized operations, be it automobiles, planes, trucks, or even automated systems, needs to consider the costs of maintenance. The ability of these systems to remain operational has a direct impact on an organization's effectiveness. When vital assets are down due to unplanned maintenance or system failures, then operations cannot be performed, which translates into reduced productivity, degraded profits, and dissatisfied customers. Having a capability that informs operators and maintainers when maintenance is required based on the condition of the system rather than an arbitrary time-based schedule would significantly reduce maintenance costs as well as improve productivity by avoiding unnecessary maintenance actions. Additionally, having the ability to predict when failures will occur before they happen offers the potential for tremendous improvements to a system's readiness, thereby increasing its operational effectiveness while avoiding costly downtime.

The goal of minimizing unplanned maintenance through condition-based and predictive maintenance is attainable. Too often, however, maintenance is put off due to incomplete and inaccurate data, resulting in unanticipated breakdowns, costly repairs, and lengthy delays in restoring the system to an operationally ready state. The creation of automated digital maintenance tools that report the condition of assets, based on complete and accurate data collected from the system, as well as from data-driven predictive analyses, would offer immediate tangible benefits to the general public. Development and demonstration of these tools was the focus of this project, which leveraged Army ground vehicle fleets and data network infrastructure to showcase continued technology maturation and capability improvement from Phase I of this effort.

The U.S. Department of Defense (DOD) is the single largest user of ground and aviation assets in the world. These assets help build the very foundation of America's military capability and enable combat operations around the world. While a highly capable fleet of DOD assets is available when duty calls, there remains a tremendous amount of maintenance redundancy and inefficiency in the effort to get our Service members the right asset available at the right place and time to accomplish their mission. Currently, most DOD Services utilize preventive maintenance to improve the availability of assets; however, it is costly, time-consuming, and does not provide Service members insight into the health or reliability of the asset. Preventive maintenance is typically performed on a pre-determined schedule, which means it is conducted whether the asset needs it or not. This can consume valuable resources in the form of time, money, parts inventory, and does little to identify if a failure will occur during the mission. These suboptimal preventive maintenance practices are still predominately used today due in part to the capability limits of legacy hardware and software tools, as well as the availability of condition-based vehicle data. However, as vehicle technology continues to evolve, and as the Army's data migration infrastructure continues to mature, the ability to perform more advanced vehicle prognostic and predictive data analyses is materializing.

Phase I of this initiative focused on developing and demonstrating digital tools in concert with the DOD maintenance philosophy commonly referred to as Condition-Based Maintenance Plus (CBM+), which is centered around maintenance that is performed based on evidence of need. The Army has recently, over the course of this project, expanded upon CBM+ to include additional focus on PPMx. As this maintenance philosophy continues to evolve and mature, the Army is using the term "Predictive Logistics" to encompass both CBM+ and PPMx and that is the term that will be used in this report.

At the foundation of the Army's Predictive Logistics capability is data. Currently, there are many disparate data sources associated with the maintenance of Army vehicles, including configuration data, usage and failure data, maintenance records, reliability centered maintenance plans, etc. These silos of data provide little value on their own and have been historically plagued by inaccurate and incomplete data collection. However, if the fidelity of the data were to be improved, and if analyses of integrated data sets could be used to generate Predictive Logistics algorithms, then powerful insights could be leveraged to improve vehicle sustainment through better, data-driven decisions. For example, the ground force commander, with visibility into the condition of his/her vehicle assets, could select the best assets for a given mission, while the Lifecycle Manager for a vehicle fleet could incorporate near real-time vehicle operation metrics to determine when fleet-wide reset or upgrade investments should be made. Across this entire spectrum, from operator to enterprise, integrating these disparate data streams, while simultaneously improving their accuracy and completeness, can help drive down a platform's lifecycle cost while improving its reliability and availability.

Phase I demonstrated a significant step forward for Predictive Logistics associated with Army tactical wheeled vehicles by introducing digitized data collection capability using both government (Organic Path) and industry (Original Equipment Manufacturer (OEM) Path) technologies, modernized digital maintenance workflows, end-to-end data migration from the tactical edge to the Army Enterprise. While Phase I proved that data collection, maintenance form modernization, and secure data transmission were achievable in an Army operational environment, it also identified infrastructure challenges, emerging user needs, and hardware/software improvements required to further the maturity of Predictive Logistics. Addressing these challenges, needs, and opportunities for improvement was the focus of Phase II.

2.2 Purpose

Organic Path

The Organic Path of Phase I of the PM TS TWV CBM+ pilot project successfully demonstrated that legacy vehicles in the Army ground fleet could be outfitted with embedded Digital Source Collectors to securely gather the data needed to modernize sustainment activities and to establish the foundation for Predictive Logistics. Figure 1 illustrates the Phase I secure data architecture demonstrated within two maintenance Motor Pools at the Army's NTC in Ft. Irwin, CA. Twenty-two Army Family of Medium Tactical Vehicles (FMTV A1P2 variants) were upgraded with DSC-R embedded Line Replaceable Units integrated with the vehicles' SAE J1939 data bus that accesses vehicle subsystems such as the engine, transmission, central tire inflation systems, and other sensor-based electronic components. Data collected by the DSC-R was transported to handheld tablets (via wired or secure wireless connections) for maintainers to perform maintenance actions, and then data from the tablets was passed to the Primary Mid-Tier, and ultimately to the Army enterprise via satellite communications.

Two lessons learned emerged from this Organic Path architecture: 1) the Army's Getac T800 tablets selected for Phase I were not technically equipped to manage the data processing and Wi-Fi network communications requirements necessary to perform the required tasks, and 2) it was unnecessary and inefficient for all of the collected vehicle data to pass directly to the tablet because the maintainers only require a very small percentage of the data to perform their maintenance and repair tasks.

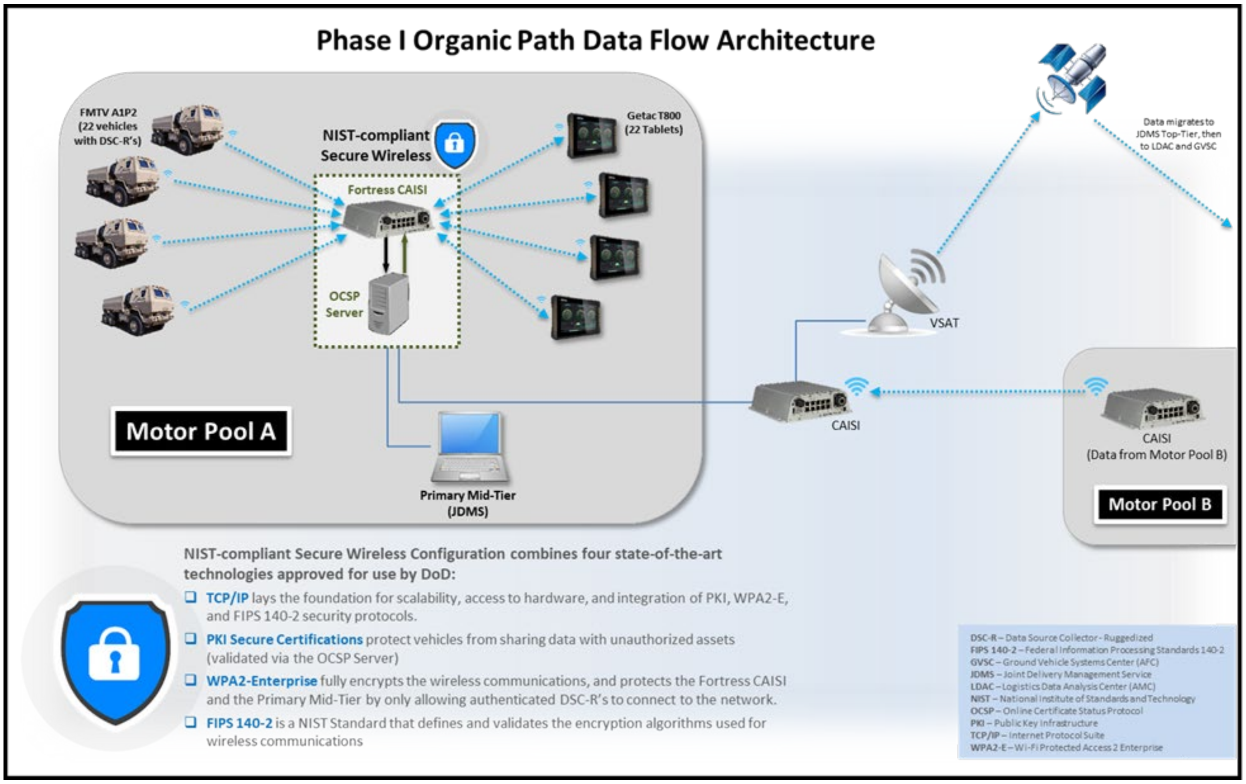

Figure 1. Predictive Logistics Data Architecture from Phase I

In addition, user feedback regarding the DLB software tool resulted in several areas for capability and efficiency improvements, including:

- Vehicle data needs to wirelessly download without the user requesting it
- The tablet needs to know what vehicle it is paired with without the user selecting the vehicle
- The digital maintenance form (DD Form 5988) needs to be more easily accessible and needs to contain the latest data from the vehicle maintenance record
- The DLB needs to integrate with the Interactive Electronic Technical Manual (IETM) to perform maintenance checks, troubleshooting steps, and repair parts identification
- The tablet needs to be able to wirelessly print the DD Form 5988 form on the motor pool printer

The purpose of the Phase II Organic Path was to improve the automation, robustness, and user experience of the Predictive Logistics infrastructure and software tools. The feedback received directly from Army soldiers who operate and maintain the vehicles was instrumental in establishing the Phase II project scope and approach.

2.3 Scope/Approach

Similar to Phase I, the Phase II project scope included two parallel paths, one which was conducted by the OEM Path to showcase capabilities from industry, and one that was conducted internally by the government (Organic Path) to showcase the maturing state of the Army's organically-developed system components, Logistics Enterprise Network, and Predictive Logistics analytics capabilities.

The scope of the OEM Path included:

- Design and physical integration of engine and hydraulic oil degradation sensors and data collection and cellular transfer capability (telematics device)

- Design modifications necessary on previous FMTV A1P2 PPMx pilot vehicles to create consistency of data collection
- Collection and migration of vehicle Predictive Logistics data
- Analysis, reporting, and visualization of vehicle Predictive Logistics data

The scope of the government Organic Path included:

- Automated secure wireless download of vehicle data, eliminating the need for soldier initiation
- Expansion of Predictive Logistics capabilities to include Heavy Tactical Vehicles (HTV)
- Enhancements to the DLB software application on the maintenance tablet that included:
  - Automated vehicle unit/platform selection
  - Suspend/resume data download capability
  - Auto-population of a DD Form 5988 digital form with easy desktop access, improving user experience and efficiency
  - Bi-directional sharing of fault and Repair Parts & Special Tools List (RPSTL) information between DLB and the IETM. This enables the soldier to select items from the IETM RPSTL that will be accurately and completely displayed in the DLB DD Form 5988 form
  - Identification and implementation of soldier experience improvements based on DLB usage and soldier feedback from Phase I

For the Organic Path, a primary objective was to engineer a new data architecture approach to streamline migration of the right vehicle data to the right stakeholder. This new architecture concept was intended to reduce network bandwidth constraints during daily operations at the tactical edge, while improving robustness of the motor pool network by centralizing the software logic driving wireless downloads rather than forcing every individual tablet to perform those operations. Figure 2 illustrates this concept using an analogy of a “six pack” of beer versus a “keg” of beer. The six pack represents the very small data packets required for daily maintenance operations, while the keg represents the larger bulk data files that contain a full time-series history of vehicle operations that can be used by Enterprise engineers to assess performance, model reliability trends, and perform predictive analyses.

The Organic approach was further represented in an end-to-end operational concept view of an improved Army data infrastructure, shown in Figure 3.

In this conceptual approach, the DSC-R embedded on the vehicle would collect Army Bulk CBM+ Data (ABCD) files from the J1939 vehicle data bus and then perform a parsing operation to wirelessly send “six pack” data to the tablet, which would then auto-populate the digital DD Form 5988 maintenance form within the DLB software application to support maintenance and repair activities. The “keg” ABCD bulk data files would simultaneously be wirelessly sent to a local storage server, where collected files would then make their way to a PPMx Data Repository for analysis at the Enterprise. Achieving this concept would reduce the size of the data files being sent to the maintainer tablets by 99.95%, as shown in the blue pie chart in Figure 3.

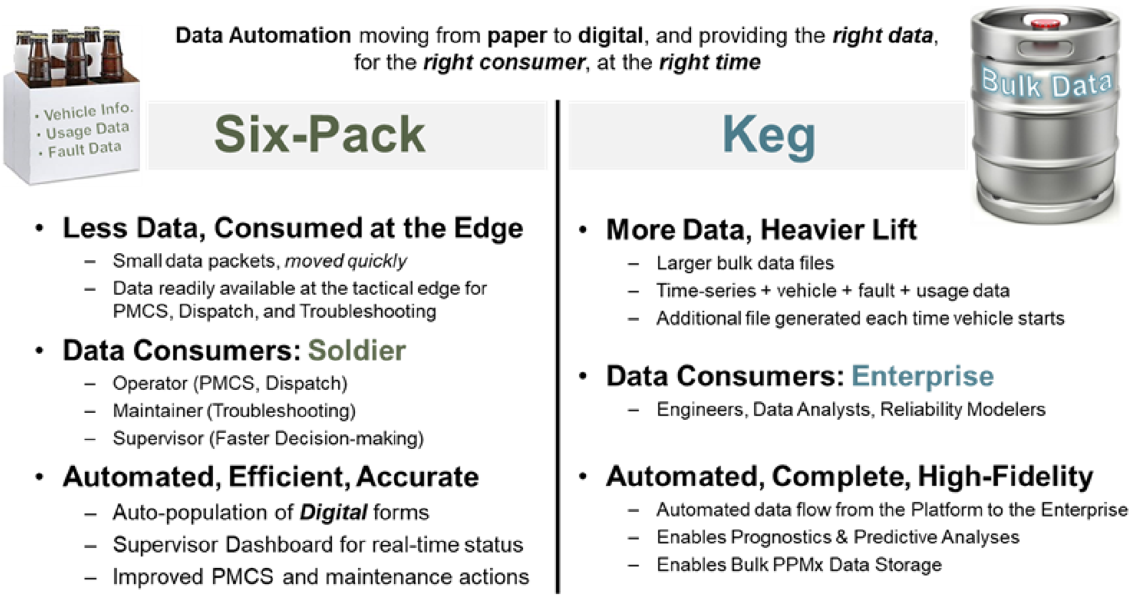

Figure 2. Data Architecture Analogy: Six Pack vs. Keg

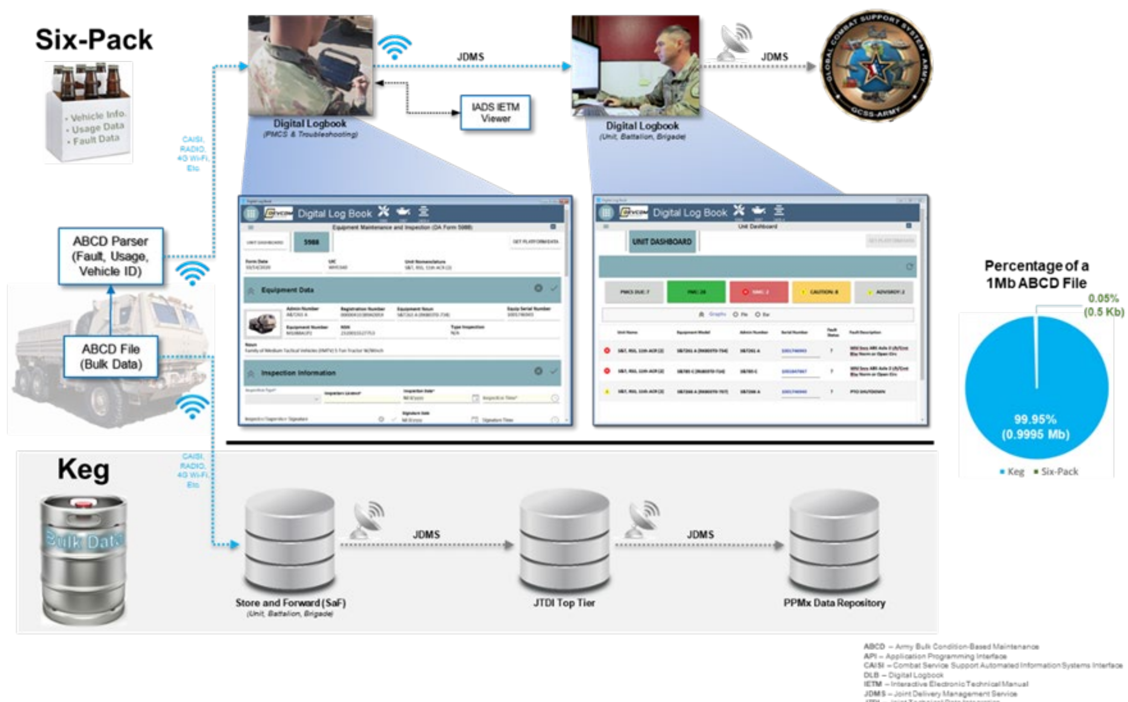

Figure 3. Operational Concept View of Objective Organic Data Infrastructure

In addition to the concept architecture objective to support the streamlined collection and migration of DSC-R data files, the following specific Systems and Software Engineering tasks were included in the Organic Path scope:

Task 1 – Systems Engineering Support

Provide Systems Engineering support to ensure that all participating organizations have a common understanding of the project demonstration scenarios, architectures, interfaces, and technical requirements associated with the DLB. Participating organizations included PM TS TWV, JTDI, CCDC DAC, CCDC GVSC, Test, Measurement, & Diagnostic Equipment (TMDE), NTC, NCMS, Project Convergence 2021 (PC21) Integrated Product Team, and RDI.

The following Systems Engineering artifacts were required to define the program technical details in an effort to manage project complexity and minimize ambiguity:

a) CONOPS: Updated CONOPS from Phase I to reflect changes in project objectives, and project scenarios (i.e., use cases). The CONOPS contained a description of:
   i. Each demonstration scenario, or use case
   ii. The workflows involved in each use case
   iii. The functions that must be carried out, along with the project participant that is responsible for executing the function
b) SRS: Updated DLB software requirement specification from Phase I, derived from the updated CONOPS, that was used to verify compliance of the enhanced DLB feature enhancements described following in Task 3.
c) Architecture Document: Updated Architecture Document containing Architecture Diagrams that illustrate the re-engineering data infrastructure for Phase II.
d) Interface Control Document (ICD): Updated ICD from Phase I that described each interface where information, data, files, etc. were passed or requested between each node of the architecture.
e) Systems Integration Support: Subject Matter Experts (SMEs) that supported DLB requirements verification testing during Systems Integration Lab (SIL) set-up at GVSC and in the RDI Goleta, CA SIL. In addition, on-site SMEs were provided to support DLB requirements verification testing during site set-up and demonstration at the NTC.

Task 2 – Logistics Database (LDB) Configuration and Test

a) LDB Model: The LDB model was created for the Palletized Load System HTV platform by populating the LDB with that platform's specific Reliability Centered Maintenance data associated with the 50 most frequently detected faults.
b) LDB Testing: Testing SMEs were provided to perform SIL testing on the LDB to ensure the data was properly displayed in the expected DLB data field.

Task 3 – DLB Feature Enhancements

a) Automated Wireless Download: The DLB shall initiate wireless data collection when its paired tablet/vehicle are in range of the wireless network. This feature will eliminate the need for the soldier to manually initiate data download.
b) Automatic Vehicle Selection: The DLB shall identify the tablet/vehicle pairing without filtering. This feature will

eliminate the need for the soldier to use the DLB Filter feature to manually select the unit and vehicle associated with the tablet.

c) Suspend & Resume Data Download: The DLB shall be capable of resuming wireless data collection if the data collection session is interrupted (e.g., vehicle turns off, moves out of range).

d) Auto-Populated Desktop DD Form 5988: The DLB shall enable the soldier to access the digital DD Form 5988 directly from the tablet desktop screen. The digital 5988 shall be auto-populated with the latest downloaded vehicle data file. This feature will eliminate the need for the soldier to manually launch the DLB application and navigate to the digital DD Form 5988.

e) Logbook-IETM Cooperation: The DLB shall be capable of importing RPSTL content directly from the IETM to the appropriate field(s) within the DLB digital DD Form 5988 form. This feature will enable the soldier to select items from the IETM RPSTL, and those selections will be displayed in the DLB digital DD Form 5988.

f) User Experience Modifications: Voice of the Soldier (VoS) feedback was collected to improve the DLB user experience. Examples included improvements to displayed information, workflows, references (i.e., terminology), accessing data (i.e., page navigation, button press/location, filtering, etc.), receiving notifications, etc. On-site soldier interactions were conducted to assist the soldier in using the DLB application and to gather VoS feedback.

Task 4 –NET

a) A training package was prepared to support NET events at NTC.

b) RDI conducted multiple NET classes on-site at NTC.

3. Project Narrative

3.1 Organic Path

For the Phase II Organic Path, the following describes the progression of tasks leading to a successful demonstration of end-to-end data collection, migration, and workflow digitization for the Medium and Heavy Tactical Wheeled Vehicle Predictive Logistics capability enhancements.

3.1.1 Data Architecture Re-Engineering

For the Phase II Organic Path, the initial task was to improve the data architecture. RDI led CONOPS, software requirements, and architecture assessments, leveraging lessons learned from Phase I and the concept objective architecture shown in Figure 3, to re-engineer Phase II data architecture illustrated in Figure 4.

Updating the CONOPS began with a review of the Phase I system design and the documented outcomes of that prototype demonstration. The review provided the manual, user operations that were chosen for replacement, and the rationale for a capability that would assist in reducing error and provide prototype capability nested to the Army's PPMx strategy. The update started with a review and validation of the current operating environment, including:

- Authoritative government reference documents (e.g., Department of the Army forms, Army pamphlets, and regulations)
- User or personnel duty scope and maintenance related task definitions
- Description of substantive changes resulting from the Phase I outcomes

RDI then used the objectives and the actors to develop the update for the Phase II path. The update identified multiple systems and their functions, the required technical support, and ultimately updated Operational View 1 (OV-1). The OV-1 was decomposed into the following four operational scenarios: DSC-R, Equipment Services, Faults, and Preventative Maintenance Checks & Services. Each of the operational scenarios were further decomposed to individual activities as illustrated in Figure 5. The design of the scenarios and activities would enable the objectives for Phase II. Completion of the CONOPS update provided the description of the operational architecture.

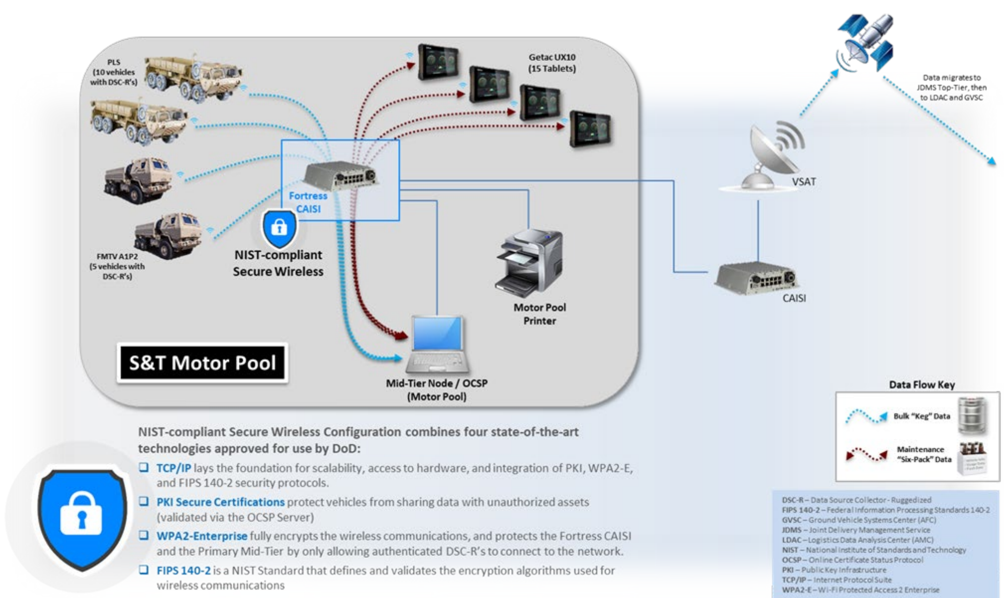

Figure 4. Re-Engineered Phase II Organic Data Infrastructure

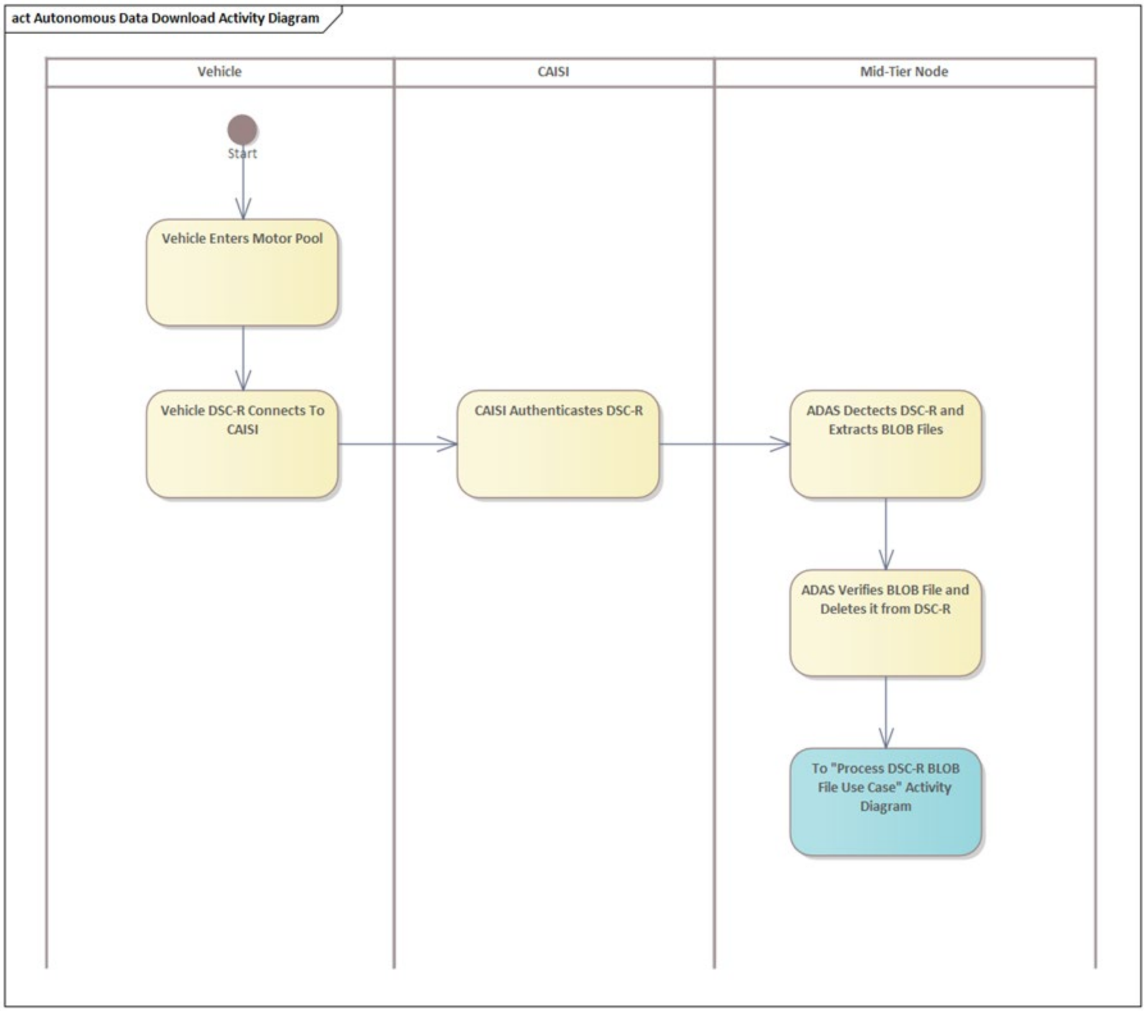

Figure 5. Data Download Activity Diagram

The central hub of the architecture was the Fortress CAISI secure wireless router, which enabled the flow of data from the vehicle DSC-R to a Mid-Tier Node (laptop), the handheld tablets, the motor pool printer, and the satellite communications to the Enterprise. The Mid-Tier node was placed within the Motor Pool and was designed to consolidate several operational functions, including:

- Wireless detection of vehicles and wireless data download
- Data file management and storage
- National Institute of Standards and Technology-compliant security authentication between devices
- Bulk data file parsing (i.e., creating six pack data)
- Data integrity checks via the LDB
- Interfaces to the DLB software to enable auto-population of DD Form 5988 data fields, digital workflow management, and wireless printing
- Bulk data file (i.e., keg data) migration to the Army Enterprise

Acting like a switchboard operator, the Mid-Tier node managed the flow of data throughout the localized network, as well as the release of bulk data files to the Enterprise during times of lower network bandwidth demand. Another improvement to the Phase II data architecture was an upgraded Getac Tablet, moving from the

T800 to the UX10. The upgraded tablet had a more powerful and faster processor (Intel i7), 8GB of RAM (double that of the T800), and an integrated wireless network card.

With the identification of the hardware and the operational functions, RDI developed the ICD. The ICD formalized the description of how separate entities would both provide input and receive output from a specific system. Each of the descriptions supported the data transfer required within the activity diagrams (e.g., Figure 5 Data Download Activity Diagram) as seen in Figure 6.

3.1.2 SIL Set-up and Software Development

With the data architecture re-design completed, the next set of tasks became implementing the architecture within both the Army's GVSC SIL and the RDI Goleta, CA SIL, where the majority of Phase II DLB software enhancements were developed. The intent of the SIL implementation at GVSC was to establish a fully operational environment (hardware, software, integration, and configuration) that could be replicated at both Camp Grayling (Grayling, MI) and NTC (Ft. Irwin, CA) in an operational environment. The intent of the RDI Goleta SIL was to have the necessary equipment and interfaces in a local network environment to facilitate the development and testing of the DLB and LDB before delivering the software to GVSC.

RDI, in parallel, began software development in a series of agile sprints that were designed to deliver all upgraded software and LDB capabilities in time for delivery to the GVSC SIL for the test, and ultimately the first operational test site at Camp Grayling. Figure 7 illustrates the software sprint schedule, with multiple teams concurrently developing software feature enhancements to meet the aggressive GVSC SIL delivery dates. A description of each software enhancement is shown in Figure 7, along with the intended benefit each enhancement brings to the user. The User Interface/User Experience task shown in the bottom row of Figure 7 reflects the continuous cycle of gathering user feedback during software sprint demonstrations, SIL risk reduction exercises, field-based installation testing, and formal pilot implementations at NTC.

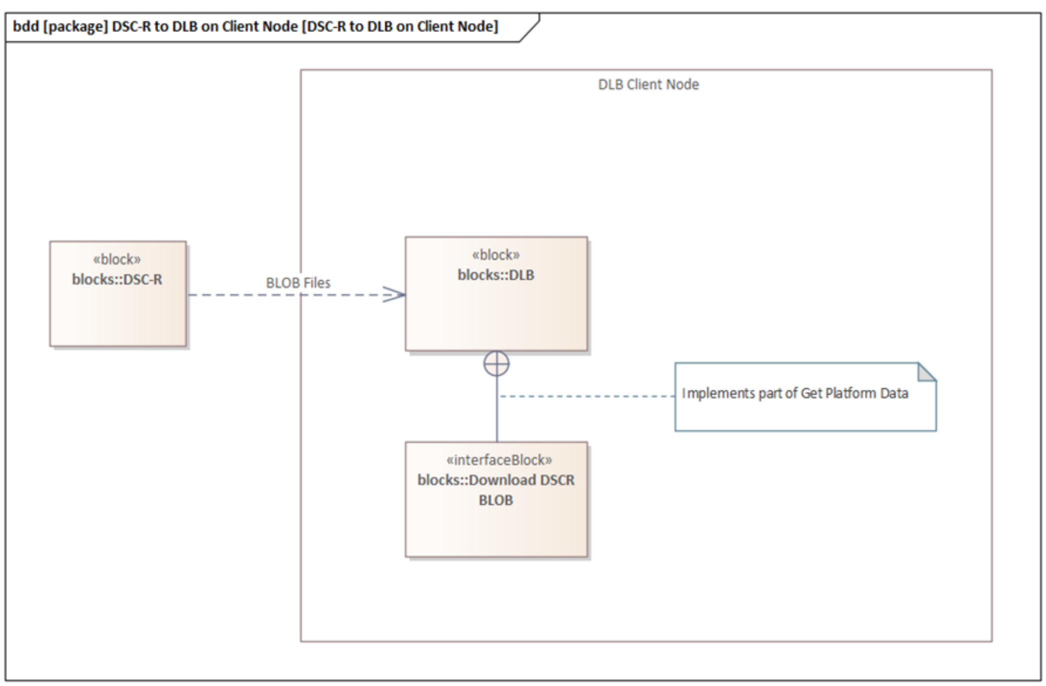

Figure 6. DSC-R to DLB on Client Node

DLB Enhancement	Description	Benefit
Automated Wireless Data Download	PLS vehicle will automatically begin wireless downloading PPMx data onto the Motor Pool Enterprise Node (MPEN) when it comes into range.	Reduce Soldier Burden
Suspend & Resume Data Download	If data download is interrupted (vehicle turns off, moves out of range, etc.), then the MPEN will resume download when reconnected to the network. Maintenance data sent to Digital Logbook (DLB) and bulk data to JTDI Top-Tier.	Reduce Soldier Burden
Automatic Vehicle Selection	Tablet will automatically identify with its paired PLS vehicle.	Reduce Soldier Burden
Auto-Populated Desktop 5988	The 5988 form will be immediately available when launching from the desktop vice navigating to it within the DLB. The 5988 will be auto-populated with the latest downloaded vehicle data file, without Soldier involvement.	Increase Maintenance Task Efficiency
Logbook-IETM Cooperation	Bi-directional sharing of Fault and RPSTL information between DLB and the FMTV/PLS IETMs. Enables Soldier to select items from the IETM RPSTL that will be displayed in the digital 5988 form within the DLB.	Increase Maintenance Task Efficiency
User Interface / User Experience (UI/UX) Modifications	Voice of the Soldier (VoS) modifications to improve the way information is displayed, organized, referenced (i.e. terminology). Also includes optimization of page navigation, button press/location, filtering, notifications, etc.	Increase Maintenance Task Efficiency

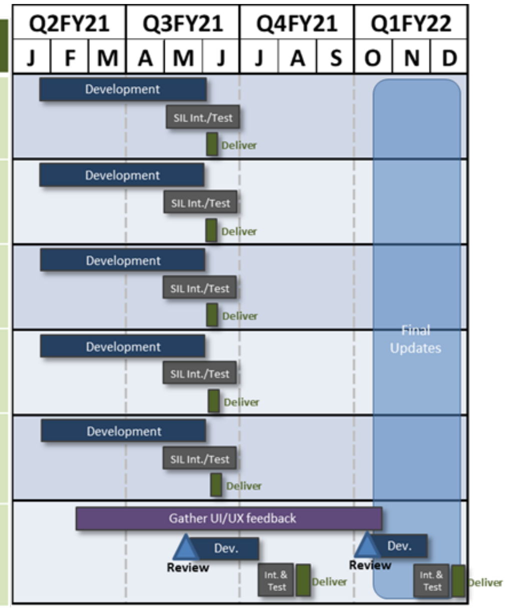

Figure 7. DLB Software Development Schedule

RDI's DLB and LDB software components were delivered to the GVSC SIL, integrated in the SIL hardware, and thoroughly tested using a comprehensive DLB test plan. Over the course of 6-8 weeks of SIL-based testing, several refinements and improvements were made to prepare the software and equipment configuration for the operational environment at NTC. SIL testing was successfully completed and delivery of all equipment to NTC was completed on time.

3.1.3 Operational Site Installation and Test

RDI led the process of receiving, unpacking, inventorying, installing, and verification testing the complete network environment at NTC. RDI collaborated with the receiving 11th ACR unit, CCDC DAC, PM TS TWV, PM TMDE, GVSC, PMO JTDI, and the Ft. Irwin SASMO to ensure proper equipment installation, effective network configuration, and CONOPS testing was successfully completed.

While providing on-site system integration support, RDI supported the following areas:

- CAISI VSAT connectivity
- MPEN Mid-Tier connectivity
- DSC-R configuration & connection
- Top-Tier BLOB File Transfer
- DLB Client Node establishment

Enabling the CAISI VSAT for Wi-Fi operations was not routine mode of use; the set-up required troubleshooting that resulted in a delay of two days. The delay was caused by encryption settings that prevented stable communication. While establishing connectivity with the MPEN via the CAISI Local Area Network, JTDI confirmed connectivity to the top-tier via JTDI Delivery Management Service (JDMS), as seen in Figure 4. The connectivity validated the conditions for receiving data from the instrumented vehicles and sending historical files to the DAC through the top-tier, allowing future PPMx driven analysis. Personnel from JTDI confirmed the transfer occurred and modified the automatic transfer time to the early morning hours to reduce bandwidth usage during vehicle maintenance periods.

The DSC-R captures current and historical diagnostic files from the platform and provides the means to transfer the data over Wi-Fi or a hardwired connection. To confirm DSC-R configuration, personnel from the DAC and RDI validated the DSC-R's configuration for each vehicle and confirmed the wireless connection to the MPEN. During testing, several of the DSC-Rs were inoperable; however, DAC personnel provided support to repair the hardwired connection to the vehicles. The DSC-Rs, while within range of the CAISI Wi-Fi network, did perform automatic downloads. The most recent diagnostic file downloads are the data that allows the DLB user to identify and troubleshoot faults during maintenance activities.

3.1.4 NET and Demonstration

RDI-certified NET trainers held multiple sessions at Ft. Irwin to train Army operators, maintainers, and motor pool supervisors on the proper operation of the Predictive Logistics DLB software, the process for downloading vehicle data both wired and wirelessly, and the integration between the DLB application and the vehicle IETM.

The NET included multiple sequences of briefing individual features, feature demonstration from the NET trainer, soldier hands-on demonstration, and the soldier physically receiving fault information from the assigned vehicles to perform the workflow. Tailoring the size of each training sequence was determined by the amount features and actions that complement a workflow.

All observations and interactions from NET were positive. Right-sizing the amount of training and the repetitive sequencing of NET steps enabled the soldiers to learn separate, but interrelated groups of actions. The soldiers received the entire NET package in less than three hours.

4. Conclusions

The PM Transportation Systems Predictive Logistics pilot has successfully demonstrated the Predictive Logistics capability enhancements identified at the conclusion of Phase I of the effort. By leveraging lessons learned, user feedback, and innovative architecture improvements, the pilot project created an enhanced end-to-end Predictive Logistics capability that captures data from deployed vehicles and makes it available to users at the tactical edge of operation and at the Enterprise. The pilot program has shown full or partial achievement of three of the four primary capabilities identified as the focus of the activity:

- End-to-End Data Transmission: Predictive Logistics data has successfully been distributed through the Army's unclassified production network infrastructure, originating at the platform and ending at the Logistics Data Analysis Center (LDAC) Data Warehouse and GVSC. All data was transmitted securely and reliably.
- Maintenance Task Performance Improvement: The project has demonstrated improvements in the speed and accuracy of maintenance tasks performance, replacing paper-based forms with auto-populated digital forms, showing improvements in accuracy and completeness.
- Serialized Asset Management Visualization: The pilot has successfully supported the display of high-fidelity Predictive Logistics data for individual and collections of vehicles.

No significant progress was made on the fourth primary capability, Predictive Analysis. This was primarily due to time lost under COVID-19 restrictions, and the challenges described in Section 3, including network integration, wireless communications within the motor pool, and certificate distribution and management.

All of these successes can be improved upon. Future programs should continue to leverage the capabilities available through the Army's organic Predictive Logistics system, providing continuous incremental system enhancements as experience with the system grows. The issues encountered and addressed should be used to inform activities within the Predictive Logistics community and provide guidance for future deployments.

5. Project Benefits

Benefits to the General Public

The processes, tools, lessons learned, and best practices captured from this pilot project can greatly benefit the general public and private industry in many different areas (commercial/ fleet vehicle maintenance, rail, power, manufacturing, healthcare, etc.). Properly sustaining assets is evolving from a reactive "just fix it" mindset, to preventive maintenance, to an eventual truly predictive maintenance approach through Predictive Logistics.

Traditionally, fleet maintenance managers and industry suppliers have used reliability statistics from standardized testing to structure preventive maintenance intervals and schedule component replacement, for example. This Predictive Logistics project offered real-time capabilities, processes and approaches to developing diagnostic/prognostic algorithms to replace traditional time-based methods. The result is the potential for a significant reduction in maintenance costs, improved asset performance, and increased asset time in-service (uptime).

Ancillary benefits include increased equipment lifetime, increased safety, fewer accidents with negative impact on environment, and optimized parts inventory and usage. As vehicles and assets become increasingly connected to the internet via telematics systems, more and more maintenance managers are collecting performance data into their maintenance systems. Collected data not only helps inform maintenance decisions but also could extend the productive lifespan of the equipment. Telematics technology has become so helpful to fleets using it, they are now beginning to ask suppliers to add sensors onto their vehicles and assets to gather more data and monitor more systems, such as: tire pressures, oil quality, filter status, battery life, brake life, alternator performance, and starter amp draw. More data requires more streamlined and repeatable approaches to usefully disseminating and acting upon that data. This also requires better ways of securing and validating the data. This approach, while focusing on vehicles, could also be beneficial to manufacturing equipment, power generators, aircraft, ships, and other complex motorized assets.

The key is having the right information at the right time. By knowing which piece of equipment needs maintenance, the work can be better planned for parts and personnel resources. In addition, what would have been unplanned downtime is transformed to shorter and fewer instances, thus increasing general asset availability. A general strategic predictive maintenance approach is a key component of achieving lowest cost of ownership. This is an untapped opportunity for fleet managers to lower their costs through more sophisticated, data-driven predictive maintenance systems than what are currently available.

Benefits to the DOD

Integrating the current disparate sources of vehicle data across the Army, and presenting that information in a simple, single user interface results in powerful insights. This enables a new maintenance philosophy of leveraging vehicle data to provide visibility into the asset's condition while improving availability and decreasing the overall maintenance burden.

This information will allow the entire Army enterprise to make data-driven decisions from the ground force commander with visibility into the condition of the vehicles, allowing the right asset to be selected for the right mission. Consolidated information and dashboards will also ensure parts, maintenance, and mission planning all use the same terminology to reduce clerical errors.

In an environment where equipment reliability and availability are top priorities, this consolidated information can enable the PEO to incorporate fleet-wide trends into platform upgrades and better mission readiness planning. Correlating these data streams across the entire spectrum, from operator to enterprise, can help drive down a platform's lifecycle cost while improving reliability and availability.

Additional Benefits to the Army/DOD include:

- Enhanced Security: The movement of logistics data through the Army's Logistics Network via the technology solution provided by PMO JTDI offers a secure, bi-directional information delivery service. The capability is called JDMS and it is the Army's chosen path forward to securely move PPMx data from end-to-end.
- Increased Connectivity: The PM TS TWV CBM+ pilot efforts will showcase PEO CS&CSS platform connectivity and interoperability with the Army Enterprise Logistics Network to support the transfer of platform PPMx data including faults, hours, miles, and time-series engineering data. The data message format supports the Army-standard Common Logistics Operating Environment (CLOE) Interface Design Definition to ensure interoperability with other sustainment systems including Global Combat Support System – Army (GCSS-A) and LDAC.
- Commonality: JDMS and the CLOE Interface Design Definition provide a common, secure solution for data message format and transport for all PEO CS&CSS platforms. In addition, the digitized equipment maintenance forms (e.g., DD Form 5988) offer significant improvements in data accuracy and completeness and can apply to the maintenance activities of all Army ground vehicle platforms.

6. Recommendations

The demonstration was a combined effort from PEO CS&CSS, PM TS TWV and JTDI, 11th ACR, Ft. Irwin SASMO, GVSC, DAC, and RDI, among others. The activities from this cohort generally fell into the following areas:

- CAISI VSAT connectivity
- MPEN Mid-Tier connectivity
- DSC-R configuration & connection
- Top-Tier BLOB File Transfer
- DLB Client Node establishment
- NET for soldiers

The initial priority was establishing connectivity with the CAISI VSAT; the team learned that configuring the Wi-Fi network was difficult. Using the CAISI for Wi-Fi is not a routine mode of operation; the setup required more troubleshooting than expected. The CAISI did successfully operate; however, the establishment required approximately two days. After, the focus was to validate the MPEN's functionality, where the core attributes of the capability coalesce to enable both the DLB and file transfer to the top tier.

Recommendation: Test the CAISI Wi-Fi configuration two days before the capability installation.

The joint team then established connectivity with the MPEN via the CAISI Local Area Network. The JTDI team confirmed connectivity to the top-tier with JDMS. These activities established conditions for receiving data from the instrumented vehicles and sending historical files for further analysis. After the data files are received, they are transferred through the top-tier, and analysis is performed by the DAC. The team from JTDI confirmed the transfer occurred and modified the automatic transfer time in the early morning hours to reduce bandwidth usage. The next activity was to enable the ability to receive current and historical data files from the platforms.

Recommendation: Installation of the MPEN must include a team from the following organizations: JTDI, RDI, GVSC, and the NTC SASMO.

The DSC-R captures current and historical diagnostic files from the platform and enables transfer over Wi-Fi or a hardwired connection. To confirm the DSC-R configuration, personnel from the DAC validated the DSC-R's configuration for each vehicle and confirmed the wireless connection to the MPEN. Several of the DSC-Rs were inoperable; DAC personnel fixed the issues via a hardwired connection to the vehicles. These efforts confirmed that automatic downloads occurred when the DSC-R was within range of the CAISI Wi-Fi network. The most recent diagnostic file downloads are the essential pieces of data that allow the DLB to operate for the user while they perform maintenance activities.

Recommendation: Maintain in-person validation with DAC personnel during the initial set-up; this will reduce risk and speed troubleshooting for connectivity and data transfer problems.

Establishing DLB Client Node included confirming that the diagnostic file parsed and was received on the DLB via the messaging component of JDMS. During testing at GVSC SIL, government and RDI personnel developed a contingency plan for the DLB's operation. In the event CAISI Wi-Fi is nonoperational, the contingency plan allows maintenance functions to continue. Maintenance operations continue by hardwiring the DLB to its vehicle and receiving, parsing, and displaying fault information, allowing personnel to perform maintenance procedures immediately. After, the data files are transferred to the MPEN once the Wi-Fi network becomes operational. Further, the essential messaging attribute of JDMS, which is the means for two-way data transfer between nodes, enables two-way communication between nodes. During installation, both the primary wireless configuration and the contingency plan were tested. While testing the DLB, activity between the MPEN and DLB was inconsistent as they are designed to mirror each other. Several inconsistencies occurred in two areas: displayed DLB data while the user transitioned between the digital pages and the MPEN mirroring the DLB user inputs. The testing team discovered a page cache bug, GUI data synchronization problems, and database inconsistency. RDI addressed these problems and tested a new software version. Once the items above were documented, training the soldiers was the next task.

Recommendation: Ensure SIL environments between the project participant and government are replicated and thorough regression testing.

Instructors completed NET for the soldiers in a series of classroom sessions and hands-on practical exercises. The NET was taught using instruction presentation slides and a second monitor where an additional instructor demonstrated the tasks in real-time via an actual DLB screen projection; the soldiers followed the training using their individual DLB tablets. Once a portion of instruction was complete, the soldiers went to the motor pool and performed the action(s) on the vehicles; the NET period was less than two hours. At this point, soldiers provided initial feedback that fell into two general areas and is captured in the following quotes:

- Operator: "We don't have to go inside to get our DD Form 5988, and I can hand the tablet to my supervisor."
- Mechanic: "I can search codes, troubleshoot, select the repair parts, and print all on this tablet."

Recommendation: Maintain the current format of the NET instruction.

The government-led team, with contractor support, deployed and installed the DLB capability in preparation for the user feedback window that will hone requirements and configurations for future iterations. Throughout the process, inconsistencies were discovered at NTC that did not appear in the SIL. Through government feedback and direction, RDI cataloged the problems and produced an updated software version to remedy the discrepancies.

The following was documented for improvements:

- Incorrect acronym displayed on dictator, i.e., BA showed for semi-annual service
- RPSTL button not functioning on tablet GUI
- The diagnostics tests requiring a physical cable did work within the IETM
- Generated PDF DD Form 5988 for wireless printing did not include observed fault comments
- Usage Data for M1075A1 not transferred to the MPEN
- When transitioning between DLB tabs (pages) screens did not retain current data

The next steps for the DLB are to gather soldier feedback and an additional deployment and demonstration of the capability:

- RDI installed a new software version in fall of 2022
- Perform a focused demonstration on August 25th for leadership from both PM TS TWV and Combined Arms Support Command's (CASCOM) Sustainment Integration Branch
- Collect soldier feedback on potential future iterations at the NTC through PC21 ending in November
- Deploy, install, and perform NET for the GVSC in preparation for the Project

Convergence 21 (PC 21) demonstration sometime in the near future. As part of PC21, demonstrate how maintenance information will transfer to GCSS-A.