ACQUISITION INNOVATION RESEARCH CENTER

Mission-Aware Integrated Digital Transformation for Operational Advantage

EXECUTIVE SUMMARY AND REPORT

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ACRONYMS AND ABBREVIATIONS

AAF	Adaptive Acquisition Framework
AFLCMC	Air Force Life Cycle Management Center
AI	Artificial Intelligence
AIRC	Acquisition Innovation Research Center
AM	Additive Manufacturing
APB	Acquisition Program Baseline
ASME	American Society of Mechanical Engineers
CAD	Computer-Aided Design
CIs	Configuration Items
DCTC	Defense Civilian Training Corps
DE	Digital Engineering
DIB	Defense Industrial Base
DLA	Defense Logistics Agency
DMM	Digital Material Management
DoD	Department of Defense
DSP	Defense Standardization Program
DTO	Digital Transformation Office
ERDC	Engineer Research and Development Center
IFE	Intelligent Front-End
IoT	Internet of Things
IP	Intellectual Property
ISO	International Organization for Standardization
JLTV	Joint Light Tactical Vehicle
KPPs	Key Performance Parameters
MBDs	Model-based Definitions
MBSE	Model-based Systems Engineering
MIL-STD-31000	Military Standard 31000
ML	Machine Learning
NATO	North Atlantic Treaty Organization
NG-NRMM	Next Generation NATO Reference Mobility Model

NIST	National Institute of Standards and Technology
NRMM	NATO Reference Mobility Model
OEM	Original Equipment Manufacturer
OSD	Office of the Secretary of Defense
OUSD(A&S)	Office of the Under Secretary of Defense for Acquisition and Sustainment
PCA	Physical Configuration Audit
PLM	Product Lifecycle Management
QIF	Quality Information Framework
RCI	Rating Cone Index
SAR	Selected Acquisition Report
SERC	Systems Engineering Research Center
SoS	System-of-Systems
STEP	Standard for the Exchange of Product
TARDEC	U.S. Army Tank Automotive Research, Development and Engineering Center
TDP	Technical Data Package
XML	Extensible Markup Language

EXECUTIVE SUMMARY

The Department of Defense (DoD) is undergoing a digital transformation to enhance defense capabilities through advanced technologies and streamlined lifecycle management. Key initiatives include adopting model-based definitions and incorporating a system-of-systems (SoS) portfolio-centric approach, along with integrating digital twin technology. Advanced simulation capabilities and decentralized production, facilitated by recent advancements in additive manufacturing, play a central role in optimizing defense system management. These efforts are critical for fostering collaboration across defense sectors, strengthening digital infrastructure, and accelerating innovation in manufacturing processes, all essential for maintaining technological superiority amidst global security challenges.

This report delves into various aspects of the DoD's digital transformation in defense acquisition and operational readiness. The report examines lessons learned and opportunities identified from ongoing digitalization efforts within the DoD, drawing insights from collaborative initiatives between the Purdue-Texas A&M team and DoD representatives. The report highlights the challenges of utilizing digital models and data to make rapid operational decisions. Specifically, the current Technical Data Package (TDP) standard, as described in Military Standard-31000 (MIL-STD-31000), is geared towards supporting routine sustainment activities but is limited in flexibility to support new missions that require adaptation of the military capabilities.

Based on the findings, the report identifies three research gaps: 1. cost-data decoupling, 2. comprehensive TDP coverage throughout the acquisition lifecycle, and 3. overarching directions for defense acquisition research. The report proposes targeted recommendations for these areas. First, it suggests integrating data alongside cost considerations early in the defense acquisition phase to optimize costs and data acquisition. Second, the report recommends enhancing TDPs by introducing Level 4 to cover operations, emphasizing agile decision-making in operational scenarios and sustainment. A practical example of a metamodel for a ground vehicle demonstrates the benefits of enhanced TDPs in defense acquisition contexts. Third, the report advocates advancing defense acquisition with robust data standards like MIL-STD-31000 and leveraging technologies such as digital twins and additive manufacturing. Emphasizing interoperability, agile decision-making, and cybersecurity, the report urges the adoption of agile acquisition methodologies and integration within a cohesive digital engineering framework.

These recommendations aim to optimize efficiency, support decentralized manufacturing, enhance readiness, and reduce lifecycle costs. Defense organizations can achieve greater interoperability and faster decision-making capabilities by integrating agile acquisition methodologies and leveraging robust data standards such as MIL-STD-31000, along with cutting-edge technologies like digital twins and additive manufacturing. This comprehensive approach ensures that defense acquisition practices remain adaptive and efficient in navigating the complexities of the digital landscape. In conclusion, the strategies discussed in this report ensure that defense acquisition programs remain adaptable and efficient, ultimately bolstering national security and mission success.

1. INTRODUCTION

The Department of Defense (DoD) has embarked on a transformative journey towards digitalization, fundamentally altering its approach to defense acquisition and operational readiness. The primary objective of this report is to inform decisions related to acquiring data and digital models concurrently while making acquisition decisions about defense capabilities.

The report offers actionable insights and forward-looking recommendations to support the DoD in harnessing digital models and data to maximize operational effectiveness. It analyzes the DoD's utilization of digital data and its efficacy in rapidly making sustainment and operational decisions. The report documents lessons learned from conversations with several stakeholders within the DoD and reflects on how operational decisions can be effectively supported in response to technological advancements and changing operational landscapes.

Digital data and models play crucial roles throughout a capability's lifecycle. These digital models can act as a single authoritative source of truth during the design phase, expedite testing processes, and be utilized for manufacturing and re-manufacturing. Different types of data are necessary to support various activities. Although the digital engineering (DE) initiatives undertaken by the DoD are crucial, a significant challenge in operational decision-making is the ability to use these models to make informed decisions within a time-constrained setting.

A critical focal point of this report is the examination of Military Standard-31000 (MIL-STD-31000) and its pivotal role in shaping technical data packages (TDPs) within defense acquisition. While MIL-STD-31000 provides a standardized framework for data management, the report highlights its limitations, particularly in effectively supporting operational and sustainment activities over the lifecycle of defense systems. The report illustrates the intricate processes of integrating diverse data types and models into the development cycle through a use case analysis centered on digital models of ground vehicles, such as the Joint Light Tactical Vehicle (JLTV). This analysis underscores the need for strategies that enhance the utility and flexibility of TDPs, proposing short-term recommendations aimed at fortifying operational sustainability and long-term strategies geared toward fostering agility in an evolving digital landscape. The report also evaluates the strategic advantages and potential pitfalls of decoupling cost considerations from data acquisition decisions, emphasizing the complexities involved in balancing fiscal considerations with the imperative for technical excellence.

This report is organized as follows: Section 2 explores digitalization efforts within the DoD, discussing lessons learned and identifying opportunities. Section 3 delves into MIL-STD-31000 and the limitations of the TDPs for sustainment use. Section 4 presents a detailed use case on ground vehicle digital models, examining the creation of various data types and models, and analyzing the JLTV Mobility Key Performance Parameters (KPPs) alongside the North Atlantic Treaty Organization (NATO) Reference Mobility Model. Section 5 articulates the problem statement. Section 6 provides recommendations, encompassing no "one-size-fits-all" in defense acquisition, short-term and long-term strategies for defense acquisition, and other opportunities including insights from Dr. Will Roper's "There is no Spoon" paper (Roper, 2020) and collaboration with the Fraunhofer Society to gain insights into how a key NATO ally approaches digital transformation. Section 7 offers concluding remarks, followed by Section 8 which includes appendices, and Section 9, which lists the references.

2. ONGOING DIGITALIZATION EFFORTS WITHIN THE DOD

During this project, the research team engaged in discussions with various DoD stakeholders, whose roles span from sustainment and redesign to supplier negotiation, contracting, production, and end-of-life management. This section of the report draws on these discussions, covering the US Air Force's digitalization efforts, strategic initiatives and critical aspects of the DoD's digitalization efforts, the enhancement of defense operations through DE, and the coupling/decoupling between intellectual property (IP) cost estimation and data acquisition decisions, along with their associated pros and cons.

US AIR FORCE'S DIGITALIZATION EFFORT ON MODEL-BASED DEFINITION (MBD)

The research team discussed the US Air Force's digitalization effort with US Air Force representatives. The Air Force's digitalization effort aims to enhance the sustainment and lifecycle management of the B-21 aircraft through model-based definitions (MBD) and model-based systems engineering (MBSE). The focus is on integrating these advanced methodologies into the TDP to streamline the design, validation, and sustainment processes. This initiative seeks to leverage government-owned, government-controlled requirements while collaborating closely with Original Equipment Manufacturers (OEMs) to ensure the freedom of design and practical data utilization.

The team discussed the significance of MBD in providing detailed requirement specifications, stress information, and other critical data in a model format rather than traditional 2D drawings. The transition to MBD enables the creation of comprehensive TDPs essential for defining acceptable environments and supporting sustainment activities. The ultimate goal is to facilitate the sustainment of the capabilities by using these models to communicate effectively between the Air Force and OEMs.

Tracking and managing models are crucial to this Air Force's digitalization effort. The discussion highlighted the need for unique model identification and parametric and Product Lifecycle Management (PLM) data integration. The use of different model formats, including native formats like NX and standardized formats such as Standard for the Exchange of Product (STEP), was emphasized. An ongoing effort is to ensure these models are fully semantic and capable of seamless data exchange between MBSE and MBD frameworks.

Several challenges were identified during the discussions, including the lack of a high-level framework for digital transformation and the difficulties associated with massive data migration. The discussion underscored the need for more direct data handling and better structuring of data models to avoid costly inefficiencies. Moving forward, there is a strong emphasis on developing more organic sustainment capabilities within the Air Force, reducing dependence on OEMs, and enhancing design authority and control.

Recruitment and training are vital to the success of this Air Force's digitalization effort. The Defense Civilian Training Corps (DCTC) program highlighted a significant initiative to prepare the next generation of professionals with tailored curricula and practical internships. The initiative also seeks to establish pipelines with educational institutions such as Purdue University to ensure a steady flow of skilled personnel. Efforts streamline processes and make training programs more accessible and effective for students.

Collaborating with various stakeholders, including OEMs, government agencies, and educational institutions, is crucial for the success of the Air Force's digitalization effort. The discussion focused on the Air Force Life Cycle Management Center (AFLCMC)'s activities and contributions to the Digital Material Management (DMM) initiative (Digital Transformation Office (DTO), n.d.; Hurst et al., n.d.), emphasizing the importance of sharing knowledge and resources.

The document "Acquisition and Sustainment Data Package: Digital Transformation Contract Language" (AFLCMC Systems Integration, 2021) facilitates the digital transition of AFLCMC programs and serves as a roadmap for the digital transformation of AFLCMC programs. Its comprehensive contract language outlines the precise procedures for acquiring digital models, ensuring clarity and efficiency in procurement processes. As AFLCMC embarks on new programs or incorporates modifications into existing ones, this document stands as a cornerstone, streamlining the integration of digital assets into weapon systems seamlessly.

Moreover, the accompanying spreadsheet (*Key Digital Engineering Features Mapping to Contract Language*, n.d.) outlines various access levels, providing a structured framework for implementation. This holistic approach fosters adaptability and underscores the commitment to modernizing operations within AFLCMC. Thus, the Air Force team actively pursues continuous improvement and innovation, aiming to establish robust frameworks and practices to sustain the B-21 aircraft efficiently and effectively.

Overall, the Air Force's digitalization effort is progressing towards creating a more integrated and efficient system for managing the sustainment of the B-21 aircraft. By leveraging advanced modeling techniques, improving data management practices, and fostering collaborative efforts, the team aims to achieve significant improvements in the lifecycle management of this critical defense asset.

STRATEGIC INITIATIVES IN DOD'S DIGITALIZATION EFFORTS

The research team discussed the DoD's digitalization effort with a knowledgeable source. The discussion highlighted several critical aspects of the DoD's ongoing digitalization efforts. Central to our conversation was the DoD's strategic initiative to modernize its digital infrastructure and capabilities across various defense sectors. The representative emphasized the importance of adopting advanced digital technologies to enhance the defense enterprise's operational efficiency, effectiveness, and security.

The discussion also focused on the DoD's efforts to leverage digitalization to streamline and optimize defense operations. The representative outlined initiatives to integrate digital technologies such as artificial intelligence (AI), machine learning (ML), and data analytics into defense systems and processes. These technologies are expected to enable predictive maintenance, enhance situational awareness, and bolster decision-making with advanced data-driven insights.

Moreover, the discussion underscored the DoD's commitment to cybersecurity as a cornerstone of its digitalization strategy. The representative highlighted efforts to strengthen cybersecurity measures across all digital platforms and systems. This includes implementing robust encryption standards, enhancing network defenses, and fostering a cyber awareness and resilience culture among personnel. The DoD's proactive stance on cybersecurity aims to safeguard critical defense information and infrastructure against evolving cyber threats.

Additionally, the meeting addressed the importance of interoperability and connectivity in the context of the DoD's digital transformation. The representative emphasized the need for seamless integration of digital systems and platforms across military branches and coalition partners. This interoperability is crucial for enhancing joint operations, facilitating information sharing, and ensuring coordinated responses to dynamic operational challenges worldwide.

Furthermore, the DoD's digitalization efforts are aligned with enhancing logistics and supply chain management capabilities. The representative discussed initiatives to digitalize supply chain operations, leveraging technologies like blockchain and Internet of Things (IoT) devices to improve defense logistics networks' visibility, efficiency, and resilience. These advancements are expected to reduce costs, enhance asset tracking, and optimize resource allocation across global defense operations.

In conclusion, the insights gained from the discussion with the DoD's Specialty Engineering representative underscored the transformative impact of digitalization on defense capabilities. By embracing advanced digital technologies, enhancing cybersecurity measures, promoting interoperability, and optimizing logistics and supply chain operations, the DoD aims to strengthen its readiness and effectiveness in addressing current and future national security challenges. These efforts represent a strategic commitment to leveraging innovation and technology to maintain military superiority and safeguard national interests in an increasingly complex global landscape.

ENHANCING DEFENSE OPERATIONS THROUGH DE

The team discussed the DoD's digitalization effort with an informed source familiar with the DoD's engineering tools and environment. The discussion provided a comprehensive overview of the DoD's current initiatives and challenges in advancing DE capabilities across its operations. Key topics included integrating digital tools and technologies to enhance defense systems' efficiency, effectiveness, and security.

A significant aspect of the discussion focused on the DoD's strategic efforts to standardize DE practices across various organizational segments. The representative emphasized the importance of capturing manufacturing notes within the TDP and highlighted ongoing initiatives to standardize these practices across organizations with the Office of the Secretary of Defense (OSD). This standardization effort is crucial for ensuring consistency and interoperability across defense acquisitions and operations.

Moreover, the conversation touched upon the DoD's engagement with MIL standards and the Defense Standardization Program (DSP). The representative outlined the DoD's approach to MIL standards and stressed the importance of aligning with industry standards to facilitate interoperability and collaboration across defense sectors. This approach enhances the DoD's procurement processes and fosters innovation and efficiency in defense acquisitions.

Additionally, the discussion explored the challenges and opportunities associated with digital transformation in defense operations. The representative highlighted the power of DE in connecting disparate systems and data sources, which is critical for enhancing decision-making capabilities and operational effectiveness. They emphasized the need for a collaborative approach involving government, industry, and academic communities to drive innovation and address common challenges in DE adoption.

The insights from the discussion provided valuable perspectives on the DoD's ongoing efforts to leverage DE for enhanced defense capabilities. The DoD aims to strengthen its digital infrastructure and maintain technological superiority in an increasingly complex global security landscape by focusing on standardization, collaboration, and overcoming technical barriers. These efforts reflect a strategic commitment to modernizing defense operations through innovative digital solutions and fostering sustainable partnerships across defense sectors.

ACQUISITION PROCESS CONSIDERATIONS: INTERDEPENDENCIES BETWEEN IP COST ESTIMATION AND DATA ACQUISITION DECISIONS

Addressing the relationship between decisions about what data to acquire and how much to pay is crucial for optimizing acquisition processes. The discussion emphasizes the complexities of balancing cost considerations with the technical and operational requirements of acquiring and utilizing data effectively. By examining the challenges associated with both approaches, decision-makers can better understand the implications of prioritizing financial constraints or technical excellence. Engaging specialized technical experts like the DoD IP Cadre helps navigate these complexities, ensuring strategies align with evolving technological standards and operational demands. This balanced approach fosters efficiency and innovation while maintaining fiscal responsibility across defense operations. Thus, we investigated the pros and cons of decoupling the cost from data in defense acquisition.

PROS OF COST-DATA DECOUPLING

Technical Excellence: Decoupling cost from data acquisition within the DoD emphasizes technical excellence by allowing decision-makers to prioritize operational requirements over financial constraints. This approach frees the acquisition process to focus on integrating high-quality, operationally relevant data for enhancing defense systems. It encourages the adoption of advanced technologies and methodologies that improve data capture, analysis, and utilization. This strategic alignment supports long-term innovation, effectively empowering defense planners to integrate emerging technologies like AI and advanced analytics. By maintaining this focus on technical excellence, the DoD enhances its ability to respond agilely to evolving threats while optimizing resource allocation across defense operations, ensuring robust readiness in a dynamic security environment.

Promotes Innovation: Removing cost constraints in data acquisition within the defense acquisition fosters an environment conducive to innovation and technological advancement. Defense agencies can explore and adopt cutting-edge technologies and methodologies by prioritizing technical requirements over immediate financial considerations. This approach encourages integrating advanced solutions (e.g., AI, ML, and advanced analytics) into data acquisition processes. These technologies have the potential to significantly enhance the effectiveness and efficiency of defense systems, improving capabilities in areas like predictive modeling, situational awareness, and decision support. By embracing innovation without the burden of cost constraints, the DoD positions itself at the forefront of technological progress, ensuring that defense operations remain adaptive and responsive to evolving threats and challenges.

Improved User Experience: Decoupling cost from data acquisition in the DoD fosters opportunities to prioritize user experience as a critical merit. By focusing on technical requirements and operational effectiveness rather than immediate financial limitations, defense agencies can tailor solutions to meet user needs and preferences better. This approach allows for the implementation of intuitive interfaces, streamlined workflows, and responsive design principles in defense systems and applications. Improved user experience enhances usability, reduces training burdens, and increases overall user satisfaction, leading to more effective utilization of defense capabilities in mission-critical scenarios. By prioritizing user experience alongside technical and operational requirements, the DoD not only enhances the usability of its systems but also ensures that defense personnel can leverage advanced technologies more efficiently and effectively to support national security objectives.

CONS OF COST-DATA DECOUPLING

Financial Impact and Risk of Overspending: Separating the cost considerations from data acquisition in the DoD introduces significant financial implications that must be managed carefully. While prioritizing technical excellence and operational effectiveness is beneficial, unchecked separation can lead to increased spending and a heightened risk of exceeding budgetary limits. Defense budgets may be strained without stringent controls and consistent financial evaluations, impacting overall fiscal sustainability and potentially diverting resources from critical defense priorities. Effective financial planning and continuous monitoring are essential to mitigate these risks, ensuring that expenditures on data acquisition align closely with operational needs and strategic priorities while maintaining fiscal responsibility and accountability to stakeholders.

Governance and Oversight Needs: Effective governance and oversight play a pivotal role in managing the complexities of separating the cost from data acquisition within the DoD. As defense agencies prioritize technical excellence and operational effectiveness, robust governance frameworks are essential to prevent potential misuse of funds and inefficiencies in data acquisition practices. Clear policies and procedures are essential for ensuring responsible management of taxpayer dollars, demanding transparency in decision-making processes and accountability in resource allocation. By implementing rigorous oversight mechanisms, such as regular audits and compliance checks, defense agencies can uphold integrity in procurement practices and sustain public trust. This structured approach safeguards against financial misconduct and enhances the efficiency and effectiveness of data acquisition efforts, supporting the DoD's mission to advance national security objectives through innovative and responsible resource management.

Dependency on External Expertise: Decoupling cost from data acquisition could result in adopting advanced data technologies, necessitating the involvement of external experts and specialized technical consultants. For instance, advanced data technologies demand specialized knowledge and skills that may not be readily available internally, compelling organizations to seek external expertise to bridge this gap. However, this dependency can introduce vulnerabilities if internal expertise is insufficient, escalating reliance on external entities and potentially undermining cost-saving goals. Moreover, managing and integrating new data acquisition systems can exceed internal capabilities, necessitating ongoing engagement with external experts to ensure alignment with industry standards and best practices. While external expertise can offer valuable insights and capabilities, careful management through strategic partnerships and robust contractual agreements is essential to mitigate risks and ensure successful implementation aligned with the DoD systems and processes.

IP: When decoupling costs from data acquisition in defense contexts, IP can present challenges. It often involves acquiring proprietary technologies or data solutions, which may incur licensing fees and dependencies on external vendors. These aspects can restrict flexibility in adapting solutions to evolving needs and introduce security vulnerabilities if not carefully vetted. Managing IP rights and compliance with licensing agreements requires careful navigation to balance the benefits of accessing advanced technologies with the potential drawbacks of increased costs and reduced flexibility in defense operations.

3. MIL-STD-31000 AND TECHNICAL DATA PACKAGES

There are numerous standards for digital implementation. Some of these are the International Organization for Standardization (ISO) 10303 STEP, S3000L, Quality Information Framework (QIF), American Society of Mechanical Engineers (ASME) Y14.41, and MIL-STD-31000. These standards exist and are evolving, with a brief description provided below.

- **ISO 10303 STEP**: Comprehensive ISO standard for the representation and exchange of digital product data throughout its lifecycle (*AP242: Managed Model-Based 3D Engineering,* n.d.; *ISO 10303 Standard for Product Model Data*, n.d.).
- **S3000L**: Logistics Support Analysis standards: International specification for conducting logistics support analysis to ensure product supportability and maintainability (S3000L, 2014).
- **QIF**: Extensible Markup Language (XML) based framework for quality information in manufacturing, supporting digital thread concepts and model-based enterprise (*QIF by DMSC: Overview*, n.d.).
- **ASME Y14.41**: Digital Product Definition: Standard establishing requirements for digital product definition data practices, including 3D Computer-Aided Design (CAD) models and associated annotations (*Digital Product Definition Data Practices Y14.41 - 2019*, 2019).
- **MIL-STD-31000**: Defines requirements for TDPs in DoD acquisitions and engineering practices (*MIL-STD-31000*, 2023).

While standards like ISO 10303 STEP, S3000L, QIF, and ASME Y14.41 are valuable for specifying *how* the product data should be represented, our current research focuses on *what* information should be provided to support operations and sustainment. To this end, MIL-STD-31000 offers a focused and comprehensive view of TDPs in the DoD context, providing a solid foundation for the optimized use of TDPs in defense acquisition. Therefore, this section of the report discusses MIL-STD-31000 in detail.

3.1 DESCRIPTION OF MIL-STD-31000

MIL-STD-31000 is a standard established by the DoD that outlines the specifications for TDPs utilized during defense procurement procedures. MIL-STD-31000 is accessible for viewing via the Defense Logistics Agency (DLA)'s Quick Search link (*DLA Quick Search*, n.d.). A TDP is the authoritative technical description of an item that supports various stages, such as acquisition, production, inspection, engineering, and logistics. The TDP specifies the necessary design configuration and procedures to ensure the item performs adequately. MIL-STD-31000 governs the creation, content, and oversight of TDPs throughout the product lifecycle, allowing customization to meet specific program requirements. This standard has evolved to incorporate technological advancements like 3D models. It categorizes product definitions into fully defined TDPs, performance-based TDPs, and those for commercial items (Windham, 2024). The standard plays a critical role in standardizing the preparation, management, and utilization of technical data across the DoD, ensuring uniformity and efficiency in acquiring and supporting defense systems. Finally, MIL-STD-31000 is currently under review for revision. The primary reason for the revision is to add Additive Manufacturing (AM) specifications to TDP (Windham, 2024).

Currently, there are three TDP levels, per MIL-STD-31000, encompassing production data. These TDP levels include (1) Conceptual Level, (2) Developmental Level, and (3) Product Level (MIL-STD-31000B, 2018) as follows:

- **Level 1: Conceptual Level.** A level (1) Conceptual TDP defines design concepts and includes the appropriate information to analyze and evaluate those concepts. The data will generally consist of simple sketches/models, artist renderings and/or basic textual data. The data may consist of the system performance specification and conceptual design data specified by the contract.

- **Level 2: Developmental Level.** A level (2) Developmental TDP provides sufficient data to support the analysis of a specific design approach, the fabrication of prototype material for test or experimentation, and limited production by the original design activity or with assistance from the original design activity. The data may consist of the unique item specifications for all system Configuration Items (CIs), developmental design data, and any required associated lists as specified by the contract.

- **Level 3: Product Level.** A level (3) Product Level TDP provides the information necessary to fully define the item and enable the procurement or manufacture of an item. The product shall be defined to the extent necessary for a competent manufacturer to produce an item duplicating the original product's physical, interface, and functional characteristics without additional design engineering effort or recourse to the original or current design activity. Product data shall reflect the defined delivered item's approved, tested, and accepted configuration. See Physical Configuration Audit (PCA) for more information.

3.2 LIMITATIONS OF THE CURRENT STANDARD IN SUPPORTING OPERATIONAL DECISIONS

In discussions with DoD representatives, the team explored the MIL-STD-31000 standard and its implications, focusing on the acquisition and utilization of TDP. The conversation began with thorough inquiries into the intricate details gathered during contract creation, highlighting the pivotal roles of specialized teams in navigating the complex landscape of project requirements. Participants universally recognized the critical importance of gathering comprehensive and precise information right from the outset to facilitate informed decision-making throughout the project lifecycle.

Throughout the discussion, the team consistently emphasized the need for metamodels or standardized approaches to enhance connectivity and streamline project processes. Discussions on methodologies to improve data capture efficiency prompted dialogue on integrating stringent quality requirements into designs. This approach was deemed essential for meeting specific operational needs and ensuring compliance with regulatory frameworks. Deep dives into hazard and failure models underscored the imperative of achieving optimal design reliability, with considerations on OEMs' capabilities to conduct thorough post-production analyses and the potential benefits of reevaluating these analyses to sustain ongoing operational effectiveness. Environmental considerations and ongoing vehicle production were also highlighted, emphasizing the necessary link between initial project requirements and subsequent design and manufacturing phases. Participants explored strategies to effectively integrate non-mandated design data into project workflows to enhance operational efficiency.

Additional topics included the introduction of the National Institute of Standards and Technology (NIST) model concept and the role of uncertainty quantification in refining design processes. The dynamic adaptation of vehicle designs in response to evolving threats emerged as a recurring theme, underscoring the pivotal role of flexible metamodels in maintaining readiness across diverse operational scenarios. The meeting also reflected a commitment to leveraging data to influence industry standards, positively enhancing reliability and operational efficiency. Discussions culminated in exploratory talks on digital twin concepts and integrating operational parameters into MBD to complement and elevate existing TDP frameworks.

Lastly, the team addressed challenges with the current TDP, particularly its effectiveness in undergoing comprehensive review and application during manufacturing processes. Detailed evaluation of the criteria used was discussed, especially when manufacturing procedures were finalized. Emphasis was placed on the flexibility needed to negotiate specific details within the TDP framework to meet project-specific needs and align with evolving standards. As a result, the team began exploring the "TDP Level 4 (Operation)" concept, which will be further discussed later in this report.

4. USE CASE: GROUND VEHICLE DIGITAL MODELS

4.1 DIFFERENT TYPES OF DATA AND MODELS CREATED DURING THE DEVELOPMENT PROCESS

In defense acquisition, integrating physics-based models and data-driven approaches plays a critical role in enhancing the effectiveness and reliability of military systems. Physics-based models serve as the cornerstone for predicting and optimizing system performance based on fundamental principles of mechanics, thermodynamics, and electromagnetics. These models enable engineers to simulate and analyze complex interactions within defense systems during the design phase, helping to refine designs, predict potential failure modes, and optimize performance parameters before physical prototyping. By integrating these models into the digital thread of defense systems, the DoD ensures continuous data flow from initial design through to operational deployment and maintenance, facilitating ongoing improvements and updates based on real-world performance data.

Complementing physics-based models, data-driven approaches provide empirical insights that validate and enhance predictive capabilities. These approaches leverage large volumes of operational data, test results, and simulations to refine models and validate their accuracy against real-world conditions. Through advanced analytics, defense organizations can identify trends, anomalies, and performance metrics that contribute to risk assessment, decision-making, and resource allocation. Data-driven insights support continuous improvement initiatives by optimizing maintenance schedules, adapting systems to threats, and enhancing operational efficiency.

The synergy between physics-based models and data-driven approaches amplifies their impact on defense acquisition. While physics-based models provide the foundational understanding and predictive capabilities, data-driven approaches validate and enrich these models with empirical data, ensuring they accurately reflect operational realities. This integration enables defense planners and engineers to make informed decisions throughout the lifecycle of defense systems, from initial development and deployment to ongoing maintenance and modernization efforts, ultimately strengthening national defense capabilities and readiness.

4.2 USE CASE: JLTV MOBILITY KPPS

OVERALL DISCUSSION ON JLTV ACQUISITION

The team discussed the critical aspects of the JLTV program with DoD representatives. The meeting highlighted challenges accessing essential contract documents and underscored efforts to enhance collaboration with the program office. Detailed scrutiny of the supplier's reliability assertions, supported by credible data, reinforced the need for maintaining stringent standards throughout the procurement process.

Furthermore, the meeting addressed the evolution of digital modeling requirements within the JLTV contract framework. It revealed historical oversights in prioritizing digital deliverables during testing and evaluation phases, prompting a reevaluation of future supplier engagements. Emphasis was placed on aligning DE practices with evolving technological standards to optimize system integration and operational efficiency. Stakeholders explored the benefits of adaptable modeling approaches tailored to diverse operational needs, moving away from traditional single-model methodologies. This forward-thinking approach aims to improve resource allocation and decision-making throughout the JLTV program lifecycle.

Moreover, the sponsor meeting emphasized the necessity for clarity in contract language and strict adherence to MIL-STD-31000 standards. Proposals were discussed to standardize quality assurance frameworks and integrate advanced simulation methodologies across defense applications. Collaborative efforts with external entities were identified as crucial for leveraging industry expertise and ensuring compliance with international standards. The meeting concluded with a comprehensive roadmap outlining key milestones and expectations for reporting, reaffirming ongoing commitments to advancing DE capabilities within the JLTV program. These initiatives reflect a proactive approach to fostering innovation and operational excellence within defense technology integration.

MOBILITY KPPS FOR JLTV

The KPPs are integral to the Acquisition Program Baseline (APB) document. For past acquisition programs, contents of the APB document are included in the Selected Acquisition Reports (SARs) submitted periodically to Congress by the DoD (*DoD SARs*, 2023).

In this context, the research team examined the mobility KPPs specific to the JLTV. It analyzed how these parameters are articulated within the APB and reported in the SAR (SAR DEC 2022, 2022). The screenshot of Mobility KPP is shown in Appendix A. Screenshot of Mobility KPP.

The Mobility KPPs below describe the mobility requirements for the JLTV. There are two KPPs: the “Current Baseline Objective” represents a more stringent target for the JLTV’s mobility capabilities, whereas the “Threshold” represents the minimum acceptable performance level. The following are direct quotations. The abbreviation “RCI” stands for Rating Cone Index.

> ***Mobility KPP: Current Baseline Objective***
> *The JLTV mobility shall support continuous operation across worldwide terrains, climatic conditions, and soil types at speeds consistent with conducting fastpaced military operations. This includes paved primary road networks, gravel/dirt secondary roadways, single track trails with no manmade improvements, and cross-country terrain with no roads, routes, or well-worn trails. The JLTV at GVW shall be capable of traversing fine grain soils with an **RCI of 22** in a single pass and also ascend and descend coarse grained, dry sand (less than 1% moisture content) **40% longitudinal slopes**. The threshold applies within the confidence bounds of established soft soil test procedures.*

> ***Mobility KPP: Threshold***
> *The JLTV mobility shall support continuous operation across worldwide terrains, climatic conditions, and soil types at speeds consistent with conducting fastpaced military operations. This includes paved primary road networks, gravel/dirt secondary roadways, single track trails with no manmade improvements, and cross-country terrain with no roads, routes, or well-worn trails. The JLTV at GVW shall be capable of traversing fine grain soils with an **RCI of 25** in a single pass and also ascend and descend coarse grained, dry sand (less than 1% moisture content) **30% longitudinal slopes**. The threshold applies within the confidence bounds of established soft soil test procedures.*

Although both KPPs share the same general wordings/requirements for continuous operation across various terrains and conditions, the specific numerical targets differ from the Current Baseline Objective, setting higher performance goals. The main differences between the two Mobility KPPs for the JLTV are as follows:

- RCI:
  - Current Baseline Objective: RCI of 22
  - Threshold: RCI of 25

- Longitudinal Slopes for Coarse-Grained, Dry Sand:
  - Current Baseline Objective: 40% longitudinal slopes
  - Threshold: 30% longitudinal slopes

These differences reflect varying levels of performance expectations. More specifically, the Current Baseline Objective sets more challenging goals for the JLTV's mobility capabilities. It requires the vehicle to traverse fine-grain soils with a lower RCI of 22, indicating softer soil conditions. This means the vehicle should be able to operate effectively in more challenging terrain. Additionally, the Current Baseline Objective expects the JLTV to handle steeper longitudinal slopes of 40% in coarse-grained, dry sand, compared to the Threshold requirement of 30%. This indicates a higher performance target for the vehicle's ability to navigate steep sandy inclines.

4.3 USE OF NATO REFERENCE MOBILITY MODEL AS A DATA-DRIVEN APPROACH

The NATO Reference Mobility Model (NRMM) has been a critical tool since the 1970s and 1980s, developed by the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC) and Engineer Research and Development Center (ERDC). It predicts how vehicles will perform on various terrains, both on-road and off-road. By considering terrain type, soil moisture, surface roughness, vehicle design, and driver skill, NRMM helps military planners and vehicle designers compare vehicle designs and understand how well existing vehicles will perform in specific situations. Although NRMM uses real-world data effectively, its reliance on past data can limit its usefulness for new and different scenarios (Jayakumar & Dasch, 2017).

Over time, NRMM has encountered difficulties due to advancements in vehicle technology and the increasing complexity of military operations. Its approach, which focuses mainly on simple, one-dimensional analysis and soil data, struggles to model the complex dynamics of today's vehicles accurately. Moreover, NRMM's compatibility with other models and its ability to work with various systems have become issues for modern military planning. To tackle these challenges, NATO has been developing the Next Generation (NG) NRMM (McCullough et al., 2017).

The NG-NRMM is NATO's effort to enhance mobility predictions for modern warfare. This new model addresses NRMM's limitations using advanced, physics-based modeling methods, supporting three-dimensional simulations, and leveraging the latest computational technologies. NG-NRMM seeks to provide military planners with a more robust and flexible tool to forecast vehicle performance across various challenging environments accurately. With these improvements, NATO aims to ensure its mobility assessment tools stay effective and relevant for future military operations (Bradbury et al., 2016).

5. RESEARCH GAPS

Decoupling of Cost from Data
(Recommendation Discussion in Section 6.1)

Decoupling cost from data in defense acquisition remains a contentious issue without a clear consensus. While initiatives such as the Adaptive Acquisition Framework (AAF) aim to enhance procurement agility by recognizing the diversity of acquisition programs (Houston et al., 2021), challenges persist in defining standardized approaches. The complexity is compounded by evolving digital technologies and IP considerations. Varying perspectives between the DoD and defense industrial base (DIB) on IP rights further complicate efforts to separate cost considerations from data acquisition.

TDP Coverage for the Entirety of Acquisition Lifecycle
(Recommendation Discussion in Section 6.2)

The current three-level TDP framework under MIL-STD-31000 (i.e., 1 Conceptual, 2 Developmental, and 3 Product Levels) provides explicit support for the acquisition of new systems and provides support for re-manufacturing parts in the field. However, it does not support operational flexibility for rapidly changing mission conditions. While these levels address design, prototype development, and production stages, they do not comprehensively support the ongoing operational phase of systems. This limitation highlights the need to extend the TDP framework to include operational-level data that supports maintenance, repair, upgrade, and logistical support throughout the system's lifecycle.

Overarching Direction for Defense Acquisition Research
(Recommendation Discussion in Section 6.3)

The current challenge in defense acquisition suggests a need for a more cohesive overarching direction for key data segments critical to future readiness. Specifically, there is a need to establish comprehensive strategies for enhancing data standards, adopting agile acquisition methodologies, integrating a unified DE framework, and leveraging AM technologies. Without a unified approach, defense programs risk fragmentation and inefficiencies across these areas, hindering their ability to effectively respond to dynamic operational demands and capitalize on technological advancements. Addressing these challenges requires a strategic alignment harmonizing these critical segments to support robust and adaptive defense capabilities throughout their lifecycle.

6. RECOMMENDATIONS

To implement the recommendations incrementally, start with engaging stakeholders to define needs, develop and standardize templates and guidelines, and train personnel on the new methods. Launch a pilot program to test the changes in real-world scenarios and use feedback to refine the approach. This step-by-step process ensures effective integration and adaptation to any challenges that arise.

6.1 NO "ONE-SIZE-FITS-ALL" IN DEFENSE ACQUISITION

In 2020, the Office of the Under Secretary of Defense for Acquisition and Sustainment (OUSD(A&S)) launched the AAF, recognizing that no single approach can effectively manage all acquisition programs, thereby providing agility in procurement (Houston et al., 2021).

CROSS REFERENCE TO AIRC WRT-1081 TASK 18

While the current project under WRT-1081.7.7 was ongoing, AIRC also conducted research under AIRC WRT-1081.18, titled "Pilot Program Design to Test Innovative Approaches in Negotiating Intellectual Property." It is crucial for the research team of WRT-1081.7.7 to acknowledge and cross-reference the research efforts of WRT-1081.18 as follows:

Effective management of program information, product information, and collaboration among the DoD and DIB stakeholders is essential for safeguarding innovation and maintaining global defense competitiveness in a data-driven era. Managing IP becomes crucial when dealing with defense acquisition from a digitalization perspective. As the DoD adopts data analytics and digital tools, questions about data ownership consistently arise. Traditional IP concerns have existed even before the digitalization effort, based on differing perspectives on IP rights between the DoD (seeking access) and DIB entities (seeking protection). These IP concerns create some degree of tension between the DoD and DIB.

The shifting landscape of digital acquisition processes and recent advancements in AM add challenges to IP management, necessitating careful contractual considerations. The aforementioned IP concerns and the need for agility in procurement prompt new thinking on IP rights and data sharing (Moschler et al., 2020). Thus, stakeholders in defense digitalization must be aware of IP management, which is the leading research discussion in WRT-1081.18.

One key finding from the WRT-1081.18 project was that each IP scenario differs due to a) differing perspectives on IP rights between the DoD and DIB companies, creating unique challenges, and b) each IP uniquely affecting the DoD. As a result, the research team proposed a decision framework to address AM IP challenges, covering scenario screening, the AM lifecycle, IP asset identification, and strategy options. The research illustrated the framework through three vignettes: 1) limited access to OEMs, 2) demand surge, and 3) maintenance, repair, and operations. From these vignette exercises, WRT-1081.18 emphasized the importance of implementing an IP decision framework early in the acquisition phase (i.e., during the supplier negotiation phase). Otherwise, once the contract is signed, it is very challenging to address the cost of data with DIB entities.

RECOMMENDATION BASED ON THE COST-DATA DECOUPLING DISCUSSION

The research team recognizes the critical importance of incorporating data alongside cost considerations at the initial stages of the defense acquisition process. This approach will minimize costs while obtaining the most available data for defense acquisitions and providing proper compensation to DIB entities. Decoupling cost from data in the defense acquisition process has pros and cons. However, from the IP viewpoint, as cross-referenced to WRT-1081.18, a complete dissociation of data from cost is impossible. Nevertheless, additional research is required to enhance this integration, potentially as part of future AIRC projects.

6.2 SHORT-TERM RECOMMENDATIONS: TDP LEVEL 4 OPERATION

6.2.1 PROPOSAL: TDP LEVEL 4 OPERATION

The research team proposes to extend the existing TDP framework to include TDP Level 4 – Operational Level. This additional level will focus on data necessary for rapid operational decisions, addressing what-if scenarios to enhance the comprehensiveness and utility of the TDP for operational purposes.

The proposed TDP Level 4 for operation is designed to support the long-term maintenance, repair, adaptation, and upgrade of fielded systems. This level covers the entire operational lifecycle of the item, ensuring that the right level of fidelity of the technical data and simulation models are available for sustained performance and operational readiness.

TDP Level 4 includes detailed technical data crucial for various operational aspects, such as manufacturing replacement parts using available manufacturing technologies, adaptation of the system for different operational conditions (e.g., operating temperature), management of component obsolescence, and efforts towards system modernization. It also encompasses service instructions, updates, replacement parts, and considerations for end-of-life disposal. By providing this operation-oriented information, the TDP Level 4 Operation ensures that all facets of the system's lifecycle are adequately supported.

Moreover, TDP Level 4 offers comprehensive information essential for ongoing logistical support, encompassing guidelines for performance improvements and technology insertions, particularly for legacy equipment. Addressing these areas, the TDP Level 4 Operation aims to enhance the longevity and efficiency of operational systems, ensuring that they remain practical and up-to-date throughout their service life.

Proposed Contents for TDP Level 4

TDP Level 4 should focus on operational aspects, providing comprehensive data required for the system's effective operation, maintenance, and support throughout its lifecycle, particularly considering operating environments for which the system was not originally designed. These elements would include the following: 1) operational performance under different operating conditions, 2) maintenance procedures, 3) training materials, and 4) logistics support documentation as follows:

1. **Operational Performance:** Detailed guides on the system performance under various conditions.

    - **System Overview**
      Describes the system's purpose, capabilities, and critical components. Outlines system architecture and interfaces, offering essential background for effective operation.

    - **Operating Procedures**
      Details step-by-step instructions for normal operations, including startup, shutdown, and configuration processes. Ensures consistent and efficient system use across various scenarios.

    - **Emergency Procedures**
      Outlines protocols for handling system failures and emergencies. Includes emergency shutdown procedures and troubleshooting guides for critical issues to enhance safety and responsiveness.

    - **Performance Optimization**
      Offers best practices and tips for maximizing system performance in different environments. Guides operators in interpreting system feedback for optimal performance.

    - **Metamodels**
      Provides data and models for understanding operational boundaries and performance deterioration outside the bounds. Includes metamodels that provide insight into changes in key performance metrics based on variable operating conditions and/or system configuration. Specifies ideal operating conditions and map out system performance as a function of operating conditions.

2. **Maintenance Procedures**: Step-by-step instructions for routine and corrective maintenance, including troubleshooting guides.

    - **Preventive Maintenance**
      Describes scheduled maintenance tasks, frequencies, and procedures for routine inspections. Includes checklists to ensure comprehensive system upkeep and longevity.

    - **Corrective Maintenance**
      Provides diagnostic procedures and repair instructions for common issues. Includes guidelines for component replacement and system restoration to minimize downtime.

    - **Troubleshooting Guides**
      Presents flowcharts and solutions for identifying and resolving typical problems. Offers advanced diagnostic techniques for complex issues to aid efficient problem-solving.

- **Calibration and Testing**
  Outlines procedures for system calibration, performance testing, and quality assurance. Ensures the system maintains accuracy and meets operational requirements over time.

- **Metamodels**
  Defines different maintenance levels (organizational, intermediate, and depot), standardizes maintenance tasks and procedures, specifies required tools and equipment for each task, includes maintenance schedules and intervals, and provides diagnostic procedures and troubleshooting steps. Provides models that provide insight into changing maintenance schedules and safe lifetime predictions based on variable operating conditions and/or system configuration considering the critical failure modes.

3. **Training Materials**: Comprehensive training programs for operators and maintenance personnel, including multimedia resources.

- **Operator Training**
  Provides a comprehensive curriculum for system operators, including hands-on exercises and simulations. Includes assessment tools to evaluate operator proficiency and ensure competence.

- **Maintenance Training**
  Offers technical courses and practical workshops for maintenance personnel. Includes certification programs for different levels of expertise to ensure skilled system support.

- **Multimedia Resources**
  Presents interactive e-learning modules, video demonstrations, and virtual/augmented reality applications. Enhances learning through diverse, engaging formats for various learning styles.

- **Reference Materials**
  Compiles quick reference guides, technical manuals, and FAQs. Serves as a readily accessible knowledge base for operators and maintenance staff during daily operations.

- **Data and Models for Training**
  Defines clear learning objectives for each training module, standardizes the structure and format of training content, includes standardized assessment methods and criteria, specifies different media types (text, video, interactive simulations), and defines different user profiles and corresponding training paths.

4. **Logistics Support Documentation**: Information on spare parts, supply chain management, and support equipment.

- **Spare Parts Management**
  Details part catalogs, recommended spare parts lists, and inventory management procedures. Ensures efficient procurement and availability of critical components.

- **Supply Chain Information**
  Lists approved suppliers, lead times, and procurement processes. Provides quality control requirements to maintain system integrity throughout the supply chain.

- **Support Equipment**
  Specifies required tools and test equipment, including calibration and maintenance procedures. Guides the selection and procurement of essential support equipment.

- **Lifecycle Support Planning**
  Outlines long-term operation strategies, obsolescence management, and upgrade pathways. Ensures the system remains operational and relevant throughout its lifecycle.

- **Metamodels**
  Maps out supply chain entities and their interactions, standardizes inventory management procedures, includes models for forecasting spare parts and consumables needs, defines lifecycle stages and corresponding support requirements, and ensures integration with existing logistics systems and databases. Provides data and models to support a supply chain redesign in case of material changes or disruption in existing suppliers.

By incorporating these elements, a Level 4 TDP can provide operational-level data to support defense systems' effective use and maintenance throughout their lifecycle. Facilitating TDP Level 4 represents a proactive step towards optimizing technical data management in defense acquisitions. By balancing comprehensiveness with flexibility, the TDP Level 4 effectively addresses current project needs and lays the groundwork for future adaptability and innovation. This approach ensures that TDPs remain dynamic and responsive, aligning closely with the evolving landscape of DE and maximizing the project's operational success.

Example of TDP Level 4 Operation Manual: Metamodeling for JLTV

As previously discussed, data-based models are essential for scenarios when detailed physics-based models are either not readily available or when a decision must be made quickly. Therefore, the team considered the following goal concerning the JLTV: Enable informed decision-making within 48-72 hours – potentially by non-engineers – about changes to an existing system up to 10 years after that system is acquired. These changes could be related to acquiring a new system that interfaces with the existing system (e.g., new weapons and armor) or operating conditions (e.g., deploying in a desert versus a tundra). In either case, a decision maker must have some understanding of the effects on the system performance metrics, maintenance schedule, and reliability.

To demonstrate a metamodel capable of quick analyses, consider adding weight to an existing JLTV caused by acquiring new weaponry and armor. Though detailed physics-based analysis would be the highest fidelity information to enable decision-making, a quick estimate may be required due to the timeframe of the decision. Additionally, having the original designer perform more analysis may be impractical or impossible if the vehicle was acquired years ago. If the original designer had put together a metamodel based on their prior analyses in a format usable by another decision-maker, this task would have become much more manageable.

For this demonstration, a stakeholder must decide whether to upgrade the JLTV-mounted weapon or armor. Each upgrade adds weight to the vehicle and changes its performance. Based on publicly available information and educated guesses, the team put together a metamodel that evaluates how the JLTV's top speed (longitudinally and laterally) and range are affected by additional weight at various locations on the vehicle. Figure 1 shows the predicted effect of adding a mounted weapon that adds 3,000 pounds. Similarly, Figure 2 shows the predicted effect of adding an armor system that adds 4,000 pounds.

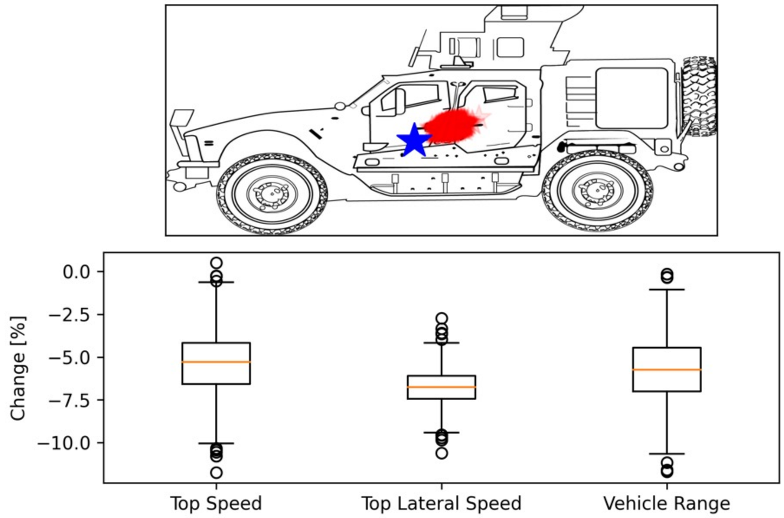

Figure 1. Predicted Effects of Adding a 3,000-pound Weapons System

The blue star indicates the vehicle's intended center of gravity. The red region represents the likely new center of gravity based on the additional weight with some uncertainty. In each case, the top speed and vehicle range are reduced in response to the added weights, but the armor has a lesser effect on the maximum turning speed due to the location of the added weight. For a mission where maneuverability is essential, one could use this information to better understand the relevant tradeoffs before making deployment decisions.

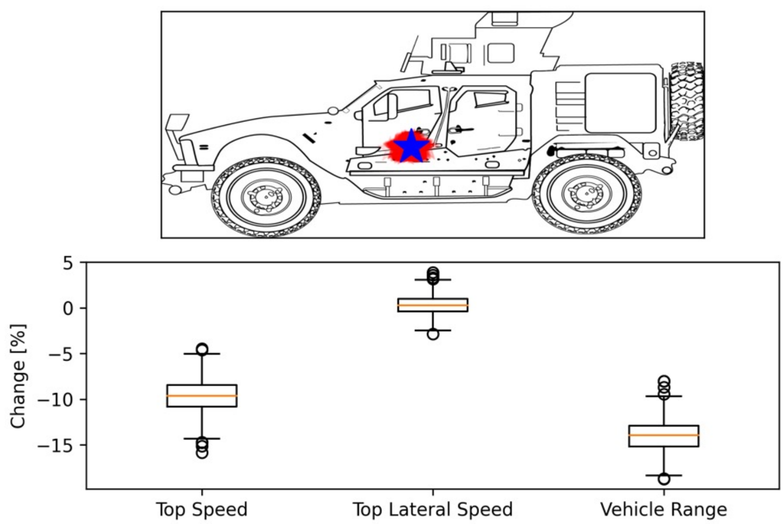

Figure 2. Predicted Effects of Adding a 4,000-pound Armor System

6.2.2 PILOT IMPLEMENTATION

A strategic phased approach is essential to facilitate the adoption and effective implementation of TDP Level 4, beginning with stakeholder engagement and pilot testing within the current acquisition cycle. Stakeholder involvement will be critical, engaging operators, maintenance personnel, and logistics managers to identify specific data requirements necessary for operational support. This collaborative effort ensures that Level 4 TDPs meet diverse operational needs.

Standardization efforts will focus on developing uniform templates and guidelines for creating Level 4 TDPs, ensuring consistency and ease of use across different systems and platforms. Training programs will be implemented to educate personnel on the new requirements and methodologies for effectively implementing and utilizing Level 4 TDPs.

The phased implementation approach includes initiating a pilot program to validate the effectiveness of Level 4 TDPs in real-world applications. This pilot aims to gather practical insights and refine the model based on stakeholder feedback and industry standards such as MIL-STD-31000. Collaboration with organizations like SERC/AIRC will further support seamless integration across diverse acquisition programs, reinforcing our commitment to modernizing data management practices.

Through this pilot initiative, we will integrate the Level 4 Operation into current acquisition processes to assess its operational impact and gather valuable data. This approach aims to streamline long-term maintenance, repair, and upgrade activities by developing best practices and actionable recommendations derived from lessons learned. The pilot's findings will provide critical feedback on the feasibility and benefits of Level 4 TDPs, enhancing our ability to meet the comprehensive operation needs of the DoD.

Ultimately, this phased implementation strategy underscores our commitment to enhancing readiness, improving logistical support, and facilitating performance enhancements and technology insertions for legacy equipment across defense acquisition programs.

6.3 LONG-TERM RECOMMENDATIONS: AGILITY FOR EVOLVING DIGITAL LANDSCAPE

Several essential long-term strategies are necessary to prepare defense acquisition programs for the future digital landscape. These strategies aim to enhance adaptability and efficiency in response to dynamic operational challenges and technological advancements.

ENHANCED DATA STANDARDS FOR AGILE ACQUISITION

Enhancing data standards such as MIL-STD-31000 and embracing digital thread and digital twin technologies ensure seamless interoperability, data integrity, and security throughout defense programs. Robust data standards facilitate effective communication and collaboration across diverse platforms and stakeholders. Defense organizations can streamline information exchange, enhance decision-making processes, and improve operational effectiveness by implementing standardized data formats and protocols. Integrating advanced data standards also supports enhanced cybersecurity measures, safeguarding critical defense information from potential threats and vulnerabilities.

Adopting agile acquisition methodologies enables defense organizations to respond swiftly to emerging threats and evolving mission requirements. By embracing iterative development, rapid prototyping, and continuous stakeholder engagement, these methodologies facilitate early validation of requirements and quick adaptation to changing operational needs. This approach reduces time-to-field for critical capabilities, enhancing overall agility and responsiveness in defense acquisitions.

INTEGRATED DE FRAMEWORK LEVERAGING AM TECHNOLOGIES

Integrating a unified DE framework, from initial concept to end-of-life management, is foundational in optimizing efficiency and collaboration across all phases of defense acquisition. This comprehensive framework incorporates MBSE, system-of-systems (SoS) tools like portfolio optimization, and digital twins, allowing us to conduct simulations. Streamlining design processes and enhancing performance predictions empowers defense programs to achieve higher levels of operational efficiency while ensuring that technological advancements are effectively integrated throughout the lifecycle of defense systems.

MIL-STD-31000 is currently under review for revision to include AM (Windham, 2024). These standards facilitate transparent data exchange and traceability, which is crucial for maintaining operational readiness and reducing lifecycle costs. Furthermore, leveraging AM and 3D scanning technologies revolutionizes defense sustainment efforts by enabling decentralized, on-demand manufacturing of spare parts and complex components. AM reduces logistics dependencies, enhances readiness, and facilitates rapid customization. Meanwhile, 3D scanning supports efficient reverse engineering, integrating legacy systems into modern digital environments to strengthen overall resilience and readiness in defense capabilities.

6.4 OTHER OPPORTUNITIES

6.4.1 INCORPORATING IDEAS FROM "THERE IS NO SPOON" BY DR. WILL ROPER

Dr. Roper, the Former Assistant Secretary of the Air Force for Acquisition, advocates for a government-owned open architecture framework in his paper, "There is No Spoon" (Roper, 2020). Dr. Roper argues that government control over infrastructure is crucial in digital acquisition and development. Dr. Roper stresses the importance of the government owning key parts of the technology stack. By taking ownership of the tech stack and its architecture, the government can effectively manage and secure its digital assets, foster rapid innovation, and reduce dependence on individual vendors. Dr. Roper's strategy aligns with his broader vision of transforming military procurement through DE and cutting-edge technologies, facilitating more agile and efficient development of military systems.

The research team tried to outline a potential mechanism for the gradual evolution of such an open architecture using the Intelligent Front-End (IFE) concept detailed in a final technical report for the AIRC WRT-1057.18d project (Tsutsui et al., 2024) based on the suggestion by Dr. Mikhail Atallah. AIRC WRT-1057.18d was a predecessor of WRT-1081.7.7. The proposed ML process would enhance data utilization and institutional memory. Over time, this evolution would be driven by new experiences, insights gained, and changing requirements. Through iterative refinement akin to IFE, the open architecture would adapt, ensuring its relevance and efficacy amidst evolving technological landscapes and user needs.

6.4.2 RESEARCH COLLABORATION WITH FRAUNHOFER SOCIETY

The need for digital solutions extends far beyond the boundaries of the DoD. To address this broader context, the project engaged with the Fraunhofer Society, a German research organization known for its advancements in applied sciences. The collaboration included interactions with Fraunhofer Society's American branch, Fraunhofer USA. This partnership aimed to gain insights into how a key NATO ally approaches digital transformation for both military and civilian applications.

Fraunhofer Society's extensive network and collaborative model offer significant advantages for research partnerships. By leveraging its vast resources and expertise, Fraunhofer can facilitate technology transfer from academic research to industry application. This collaboration model supports the rapid development and implementation of innovative solutions. The partnership with Fraunhofer Society could enhance the research community and defense industry stakeholders' ability to develop and deploy advanced technologies efficiently, ensuring they meet the evolving demands of various sectors. For instance, integrating Fraunhofer's advanced manufacturing techniques and digital models could significantly boost the research team's capabilities, fostering an environment of cutting-edge technological progress.

The research team's engagement with Fraunhofer USA highlighted the importance of strategic partnerships in advancing technological innovation. Working together allows both organizations to share knowledge, resources, and expertise, leading to more effective solutions for industry challenges. Collaborative efforts can drive the development of new technologies and processes, ultimately benefiting the research community and defense industry stakeholders. This partnership aligns with the broader goals of promoting innovation and fostering sustainable growth in technology-driven sectors. In addition, Fraunhofer's established reputation and extensive network can increase the research team's visibility and credibility in the global research community.

In addition to the potential benefits for technology development, collaborating with Fraunhofer USA can provide valuable opportunities for knowledge exchange and capacity building. Researchers can gain insights into best practices and advanced methodologies employed by Fraunhofer's experts, enhancing their skills and competencies. This knowledge exchange can lead to improved research outcomes and foster a culture of continuous learning and innovation within the research team. Such collaborations can also open doors to future research opportunities and funding sources, supporting the long-term goals of the research team. For example, involvement in Fraunhofer-led projects like Catena-X, an open data ecosystem explicitly designed for the global automotive industry, could provide the team with hands-on experience in tackling complex issues like supply chain optimization, further enriching their expertise could provide the team with hands-on experience in tackling complex issues like supply chain optimization, further enriching their expertise (*Catena-X*, n.d.).

Our preliminary discussions with Fraunhofer USA have highlighted the potential impact of our collaboration. Since no formal research agreement was in place with Fraunhofer USA during the 2024 research period, our engagements with their representatives remained at a high-level discussion. Despite this, these discussions provided valuable insights that have influenced our research approach to addressing challenges within the DoD. By focusing on enhancing manufacturing methods, diversifying the supply chain, and implementing predictive maintenance strategies, our team aims to develop robust solutions to critical issues. Continued engagement with Fraunhofer USA will be crucial in refining these strategies and ensuring their successful implementation. This ongoing collaboration promises to foster innovation, drive technological progress, and mutually benefit both organizations while contributing to broader advancements in technology and industry.

7. CONCLUSIONS

The DoD's digitalization efforts mark a transformative shift towards enhancing defense capabilities through advanced technology. By adopting methodologies like MBD and systems engineering, the DoD aims to streamline lifecycle management and operational efficiency, as seen in the B-21 aircraft project. Leaders like Dr. Will Roper advocate for a government-owned open architecture to enhance security and foster collaboration, while partnerships with institutions like Fraunhofer USA advance digital infrastructure and innovation. Prioritizing cybersecurity, interoperability, and user-centric design will be crucial for maintaining technological superiority in a complex global security landscape, ensuring the DoD remains agile and effective in its mission.

MIL-STD-31000 is a cornerstone in defense procurement, governing the creation, content, and oversight of TDPs essential for the acquisition, production, and lifecycle support of defense systems. Accessible through the DLA's Quick Search link, this standard integrates advancements like 3D models to meet modern defense needs. As the DoD reviews MIL-STD-31000 to enhance flexibility and relevance, its role in promoting standardized, efficient data management across defense acquisitions remains paramount. Recognizing that a one-size-fits-all approach does not work in defense acquisition, there is a need to incorporate data alongside cost considerations at the initial stages of the acquisition process. Additional research is required to enhance this integration.

Integrating the proposed TDP Level 4 into MIL-STD-31000 is a proactive step towards comprehensive lifecycle support, ensuring systems are sustained effectively from production through operational phases. By fostering collaboration and adapting to emerging technologies, the standard supports the development of agile, compliant, and interoperable defense systems crucial for national security and operational readiness. Adopting agile acquisition methodologies enables defense organizations to respond swiftly to emerging threats and evolving mission requirements. Embracing iterative development, rapid prototyping, and continuous stakeholder engagement facilitates early validation of requirements and quick adaptation to changing needs.

Integrating a unified DE framework, from initial concept to end-of-life management, optimizes efficiency and collaboration across all phases of defense acquisition. This comprehensive framework incorporates MBSE, SoS tools like portfolio optimization, and digital twins, allowing advanced simulation and performance prediction. Leveraging AM enables decentralized, on-demand production, enhancing readiness and rapid customization. As MIL-STD-31000 undergoes revision to include AM standards, transparent data exchange and traceability will become even more critical for maintaining operational readiness and reducing lifecycle costs. These long-term strategies ensure that defense acquisition programs remain adaptable and efficient, ultimately bolstering national security and mission success.

8. APPENDIX

APPENDIX A. SCREENSHOT OF MOBILITY KPP

The following Mobility KPP for JLTV is publicly available (SAR DEC 2022, 2022).

UNCLASSIFIED

JLTV SAR DEC 2022

Performance

JLTV

Performance Characteristics

Milestone Baseline	Current Baseline Objective/Threshold		Demonstrated Performance	Current Estimate/Actual	Deviation
(KPP) - Mobility					
	The JLTV mobility shall support continuous operation across worldwide terrains, climatic conditions, and soil types at speeds consistent with conducting fast -paced military operations. This includes paved primary road networks, gravel/dirt secondary roadways, single track trails with no manmade improvements, and cross-country terrain with no roads, routes, or well-worn trails. The JLTV at GVW shall be capable of traversing fine grain soils with an RCI of 22 in a single pass and also ascend and descend coarse grained, dry sand (less than 1% moisture content) 40% longitudinal slopes. The threshold applies within the confidence bounds of established soft soil test procedures.	The JLTV mobility shall support continuous operation across worldwide terrains, climatic conditions, and soil types at speeds consistent with conducting fast-paced military operations. This includes paved primary road networks, gravel/dirt secondary roadways, single track trails with no manmade improvements, and cross-country terrain with no roads, routes, or well-worn trails. The JLTV at GVW shall be capable of traversing fine grain soils with an RCI of 25 in a single pass and also ascend and descend coarse grained, dry sand (less than 1% moisture content) 30% longitudinal slopes. The threshold applies within the confidence bounds of established soft soil test procedures.	Rating Cone Index - Single Pass = 24;Sand Slopes =28%	Met Threshold	

UNCLASSIFIED 11

APPENDIX B. LIST OF PUBLICATIONS RESULTED

Building on the research conducted under WRT-1057.18d, the predecessor to WRT-1081.7.7, the following conference paper was published:

Tsutsui, W., Atallah, M., Malak, R., Hartman, N.W., DeLaurentis, D.A., Panchal, J.H. (2024). Challenges and Opportunities in Enhancing Department of Defense Ground Vehicle Capabilities through Digital Transformation. 2024 Annual Acquisition Research Symposium, Monterey, CA.

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