NPS-LM-23-239

ACQUISITION RESEARCH PROGRAM SPONSORED REPORT SERIES

Weapon System Sustainment, the Fourth Industrial Revolution, and Effective Industry Logistics Practices

June 2023

Maj James R. Perez, USMC

Thesis Advisors: E. Cory Yoder, Senior Lecturer
Bryan J. Hudgens, Senior Lecturer

Department of Defense Management

Naval Postgraduate School

The research presented in this report was supported by the Acquisition Research Program of the Department of Defense Management at the Naval Postgraduate School.

To request defense acquisition research, to become a research sponsor, or to print additional copies of reports, please contact the Acquisition Research Program (ARP) via email, arp@nps.edu or at 831-656-3793.

ABSTRACT

The Marine Corps weapon systems' bill of material (BoM) frequently consist of thousands of National Stock Number items of supply. In the early acquisition phases and throughout a system's life cycle, parts management of component items is critical to ensure maintenance actions and supply chain support. Program Offices do not maintain accurate, complete BoM parts data. In this thesis, I analyze the level of matching BoM accuracy through a comparison of DOD and Marine Corps BoM websites, which each intend to capture all items of supply for respective parent weapon systems. I further compare BoM data to technical publication parts listings and retail inventory stocks. To ensure responsive actions in the Operations and Support phase of acquisition, the service should apply Toyota's supply-chain strategies and emerging technologies such as the cloud/lake, supply chain control tower, blockchain, and artificial intelligence/ machine learning to improve control, coordination, accuracy, transparency, and maintenance of BoM data throughout all phases of acquisition. In exploring Toyota's practices and 21st century business solutions, this thesis seeks to propose modernization of the integrated data environment (IDE) mentioned throughout the *Product Support Manager* handbook. The proposed IDE will be a collaborative government-commercial system that extends across all weapon systems, exists in the cloud, incorporates blockchain, and leverages AI ML across a supply chain control tower.

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

I thank Colonel Kirk Spangenberg for graciously supporting me in completing this paper as a second reader. At the same time, he undoubtedly had numerous other responsibilities to his family and Marine Depot Maintenance Command.

THIS PAGE INTENTIONALLY LEFT BLANK

NPS-LM-23-239

ACQUISITION RESEARCH PROGRAM SPONSORED REPORT SERIES

Weapon System Sustainment, the Fourth Industrial Revolution, and Effective Industry Logistics Practices

June 2023

Maj James R. Perez, USMC

Thesis Advisors: E. Cory Yoder, Senior Lecturer
Bryan J. Hudgens, Senior Lecturer

Department of Defense Management

Naval Postgraduate School

Approved for public release; distribution is unlimited.

Prepared for the Naval Postgraduate School, Monterey, CA 93943.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

4IR	Fourth Industrial Revolution
AI/ML	Artificial Intelligence/Machine Learning
AIS	Automated Information System
BOM	Bill of Materials
CAGE	Commercial And Government Entity
COTS	Commercial-off-the-Shelf
CPS	Cyber-Physical Systems
DLA	Defense Logistics Agency
DLT	Distributed Ledger Technology
DMSMS	Diminishing Manufacturing Sources and Material Shortages
DOD	Department of Defense
DSPO	Defense Standardization Program Office
ELMP	Enterprise Life cycle Maintenance Program
FAR	Federal Acquisition Regulation
FFF	Form, Fit, or Function
FLIS	Federal Logistics Information System
FOC	Fully Operations Capable
GCSS-MC	Global Combat Support System – Marine Corps
GIDEP	Government-Industry Data Exchange Program
HMMWV	High Mobility Multipurpose Wheeled Vehicle
IDE	Integrated Data Environment
IOT	Internet of Things

IPS	Integrated Product Support
IT	Information Technology
JIT	Just-in-Time (a logistics supply chain practice)
JLTV	Joint Light Tactical Vehicle
LCSP	Life-Cycle Sustainment Plan
M2M	Machine-to-Machine
MARCORLOGCOM	Marine Corps Logistics Command
MDAP	Major Defense Acquisition Program
MDMC	Marine Corps Depot Maintenance Command
MRP	Material Requirements Plan
MSA	Material Solution Analysis (an acquisition phase)
MWS	Master Work Schedule
NAVAIR	Naval Air Systems Command
NAVSUP	Navy Supply Systems Command
NSN	National Stock Number (an “item of supply”)
NWCF	Navy Working Capital Fund
O&S	Operations and Support
OCR	Optical Character Recognition
OEM	Original Equipment Manufacturer
OMIT	Operation, Maintenance, Installation, or Training
PBS	Product Breakdown Structure
PEO	Program Executive Office
PM	Program Manager
POM	Program Objective Memorandum

PPBE	Planning, Programming, Budgeting, and Execution
PSM	Product Support Manager
PSMC	Parts Standardization & Management Committee
PSS	Product Support Strategy
RFID	Radio Frequency Identification
SCCT	Supply Chain Control Tower
SCI	Supply Chain Integration
SCRM	Supply Chain Risk Management
SEP	System Engineering Process
TDM-CATALYST	Technical Data Management – Catalyst
TDP	Technical Data Package
TMRR	Technology Maturation and Risk Reduction (an acquisition phase)
TPS	Toyota Production System
USMC	United States Marine Corps
WBS	Work Breakdown Structure
WSC	Weapon Systems Code
WSDC	Weapon Systems Designator Code
WSIT	Weapon System Impact Tool

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

Marine Corps weapon systems each have a Bill of material (BoM), many of which consist of thousands of "items of supply" identified by National Stock Numbers (NSN). Throughout a system's acquisition life cycle, parts management of BoM component items and subassemblies is critical to ensure maintenance actions and supply chain support. Still, Program Offices do not maintain accurate, complete, electronic BoM parts data.

In this thesis, I analyzed the level of matching BoM accuracy for given weapon systems between two government websites, the DOD Weapon System Impact Tool (WSIT) and Marine Corps Technical Data Management CATALYST (TDM-CATALYST). The 17 systems' BoM in WSIT consisted of 71,234 items of supply, but 48,385 items were not listed in TDM-CATALYST under corresponding weapon systems making for an accuracy level of only 32 percent between the two. I further analyzed replenishment parts ordered through the Supply Management Unit (SMU) by end-users for weapon systems against their corresponding BoM data on these sites. TDM-CATALYST BoM data only matched 40% of the NSNs stocked by the SMU as informed by the related system's user parts demands. Similarly, the SMU's demand-based stocks only matched 60% of WSIT BoM NSN data. Many NSNs ordered by end-users for weapon systems were not in either government website's BoM data showing incomplete electronic, online BoM data. To further analyze the Marine Corps TDM-CATALYST BoM accuracy and completeness, I reviewed BoM data based on Marine Corps technical publications on the sister-website TDM Publications. Technical publications and MDMC BoM data only matched 501 (38%) of 1,319 items of supply from the parent systems TDM-CATALYST BoM data.

To ensure timely and responsive actions in the Operations and Support (O&S) phase of the acquisition life cycle, the Service should apply traditional OEM supply chain strategies and emerging Fourth Industrial Revolution (4IR) technologies found in commercial businesses for BoM parts management. This thesis explores 20th-century Toyota's business principles and early computational manufacturing approaches related to weapon system Acquisition. This thesis then explores emerging 21st-century 4IR technologies such as the cloud/lake, supply chain control towers (SCCT), blockchain, and artificial intelligence/machine learning (AI/ML). Such traditional and contemporary business practices offer solutions to weapon system BoM management practices. This thesis ultimately proposes a truly modern 4IR Integrated Data Environment (IDE) to seamlessly capture all BoM; PBS; TDP; Form, Fit, or Function (FFF) data; and Operation, Maintenance, Installation, or Training (OMIT) data. The 4IR IDE is a collaborative, modern, government-to-commercial Supply Chain Integration (SCI) system that extends across all weapon systems, program offices, suppliers, and contractors to improve logistics support, parts management, and warfighting readiness.

PREFACE

As an avid car enthusiast and Marine Corps Supply officer, I wrote this thesis by observing the challenges facing DOD logisticians in maintaining military equipment systems relative to the success of automobile manufacturers' parts systems. Typically, a mechanic hobbyist can easily find the correct part number and diagram based on their vehicle's readily available bill of material (BoM) data found online. Mechanics can find car parts on either the Original Equipment Manufacturer's (OEM) website or through third-party vendors such as AutoZone. When walking into a car dealership to ask for a part, the parts department employee quickly searches their computer to find the suitable component. Parts specialists use electronic databases interconnected with their suppliers to search for the correct, current part needed electronically. Unlike OEM and third-party parts specialists, Marine Corps logisticians open a physical book or download a flattened Adobe PDF to search through numerous pages and sections associated with the system model. Then, hoping nothing has changed in the DOD supply system since the document's publication, and assuming suppliers still make it, maintainers register parts needs with their unit supply department. Unfortunately, the Marine Corps is in the 20th century, with logisticians relying on print publications for weapon system parts management. The target audience for this work is senior DOD logisticians in positions to codify acquisition policy, the Parts Standardization & Management Committee, and Congressional staff who can act as change agents to modernize acquisition business practices between the DOD and defense industrial base partners.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

The Marine Corps should accurately catalog military equipment Bill of material (BoM) technical data in an electronic database to support Just-in-Time (JIT) depot maintenance actions in the Operation and Support (O&S) phase of a weapon system's life cycle. Responsibilities to accurately sustain BoM information for items of supply ultimately rests with the Acquisition Program Office, where Product Support Managers (PSM) must manage parts information throughout a weapon system's life cycle. Since 2009, PSMs have had statutory responsibilities for weapon system parts management and the Life Cycle Sustainment Plan (LCSP). One such responsibility is identifying obsolete electronic parts and approving suitable replacements (Defense Acquisition University [DAU], n.d.-a). The LCSP includes Integrated Product Support (IPS) elements such as Supply Support, which includes initial provisioning, BoM management and maintenance, cataloging, supply chain assurance, and disposal (Department of Defense [DOD], 2019). The Marine Corps system's BoM data accuracy and completeness are poor, leading to challenges in O&S activities such as depot-repair. Traditional, commercial supply chain systems and JIT logistics practices adopted by Toyota offer insights to modernize the Service's O&S planning and execution. Additionally, emerging 21st-century technology such as Supply Chain Control Towers (SCCT), Artificial Intelligence Machine Learning (AI/ML), Blockchain, and Cloud Data Lakes present possible solutions for better management of weapon system supply chains. Collectively, these technologies are part of what is known as the Fourth Industrial Revolution (4IR) (Patsavellas et al., 2021).

A. THE ACQUISITION COMMUNITY

The United States Marine Corps (USMC) employs a variety of military weapon systems, including small arms, armored motor vehicles, engineer equipment, Command & Control systems, etc. The diverse array of systems provides USMC forces mission capabilities but also presents complex inventory management challenges. A blended workforce supports the design and implementation of these systems throughout numerous acquisition organizations, including Marine Corps Systems Command

(MARCORSYSCOM); Program Executive Office (PEO) Land Systems; PEO for Manpower, Logistics, and Business Solutions; Joint PEO for Chemical, Biological, Radiological, and Nuclear Defense; and PEO Digital (U.S. Marine Corps, n.d.). These are Marine Corps commands, Service PEOs, and Joint agencies, hereafter referred to as the acquisition commands. Such a range of organizations is subject to differing cultures, acquisition processes, policies, and design approaches. While variety is vital to unlocking key future capabilities, standardization through an emphasis on systems engineering, electronic cataloging, parts management, and Supply Chain Integration (SCI) is necessary to enable life cycle sustainment efforts in the latter O&S phase. Regardless of which agency is leading development for particular systems, the fundamental design and support management activities are responsibilities inherent to the acquisition community. Acquisition law has placed greater emphasis on life-cycle sustainment by mandating Product Support Managers (PSMs) in recent decades, but only in the past few years has the Marine Corps adopted electronic logistics systems to effectively support O&S activities (Defense Acquisition University [DAU], n.d.-a). Even with new electronic logistics systems, USMC still lags behind industry practices and has stark blind spots with grossly insufficient BoM data.

B. CAPABILITY GAPS

Without reliably organized electronic BoM data for components and subassemblies, logisticians' performance is limited across many functions they are charged with, such as attending to Supply Chain Risk Management (SCRM); Parts Management; Diminishing Manufacturing Sources, and Material Shortages (DMSMS); Counterfeit Detection; and Forecasting. Furthermore, insufficient, unreliable BoM data hampers DOD attempts at simulation and modeling to determine possible supply needs. Incomplete BoM data will yield simulation results with blind spots in the health of the DOD's supply chain supporting critical weapon systems. Missing BoM data inputs may exclude essential, deadlining parts requirements to sustain a Combatant Commander's forces in a fight.

The Marine Corps' extensive, diverse portfolio of weapon systems consists of thousands of components and subassemblies. The service maintains Federal Logistics

Information System (FLIS) item of supply data for these weapon system's components needed to support life cycle sustainment operations. The service has no reliable database to catalog weapon system components into a user-friendly BoM, Work Breakdown Structure (WBS), or Product Breakdown Structure (PBS). The service did implement a new cataloging Automated Information Systems (AIS), the TDM-CATALYST, and its sister-site, TDM-Publications, in 2020. However, as evidenced in the study herein, TDM-CATALYST continues to demonstrate objectively poor BoM accuracy and undoubtedly pales compared to supply chain and parts management standards reached by commercial, industrial manufacturers, such as Toyota, decades ago. For component items of supply, sometimes referred to as replenishment parts, the Marine Corps lacks a data-driven understanding of enterprise-wide requirements across all weapon systems.

C. EFFECTS ON SUSTAINMENT

MDMC is a core logistics capability supporting depot-level maintenance to sustain the Marine Corps weapon systems. Due to poor Service provisioning and cataloging data, MDMC has to manually recreate a BoM for its artisan maintenance staff to procure parts to repair weapon systems. Historically, this BoM process consisted of several days to transcribe item of supply data (e.g., NSN, quantity, mandatory replacement, etc.) from Adobe PDF documents to Microsoft Excel files. The Adobe PDF documents are those found on TDM-Publications for various weapon systems. As an interim solution to increase the speed of converting Program Office-developed technical manuals from Adobe PDF documents to Microsoft Excel files, MDMC partnered with Georgia Tech Supply Chain and Logistics Institute. Georgia Tech's solution successfully reduced time spent from days to hours through image-to-text, Optical Character Recognition (OCR) software colloquially referred to as the "BoM Scraper." Such interim "Band-Aid" fixes are made necessary by inattention to the cataloging item of supply data in acquisition planning of weapon systems that should begin within earlier phases of the acquisition life cycle. When Program Office PSMs fail to catalog BoM item of supply parts information into the Service's TDM-CATALYST website, artisan maintenance staff at MDMC must refer to the Adobe PDF documents. Even should a PSM capture item of supply in the TDM-CATALYST BoM, the website lacks basic functionality, such as what quantity of components falls within a given system and how parts are organized in a PBS. So the TDM-CATALYST BoM might show you an item is needed but does not say how many; similarly, the website does not classify parts by any subassembly within the system. Knowing the quantity required for an overall design, such as four wheels for a truck, is necessary for planning logistics at scale. Likewise, understanding where a part falls within a PBS is essential for planning repairs to specific subassemblies.

With the growing number of complex systems and their numerous components, the Service needs to employ new technologies that improve the accuracy and transparency of technical data. Instead of working self-reliantly to catalog and predict item of supply requirements, the Marine Corps should adopt collaborative data efforts with supply chain participants to forecast sustainment needs better. Participants include thousands of prime vendors and subcontractors who provide parts to build complete weapon systems.

D. DEPOT PRODUCTION

The Marine Corps designs its depot-maintenance requirements through the Enterprise Life cycle Maintenance Program (ELMP) in conjunction with the Program Objective Memorandum (POM) submission. The ELMP and POM process integrate within the greater Planning, Programming, Budgeting, and Execution (PPBE) process. In discussing with the former Marine Corps Logistics Command (MARCORLOGCOM) Enterprise Asset Planning Division lead responsible for ELMP development, there has traditionally been much greater flexibility in adjusting ELMP requirements during the year before execution. However, in more recent POM submissions, the Marine Corps ELMP submission may become more fixed after a certain point in the PPBE. MARCORLOGCOM's Enterprise Asset Planning Division submits a Navy Comptroller form to inform the DOD POM two years before the planned Fiscal Year where depot-maintenance is scheduled. So, if a combat vehicle needs depot-repair, it should be part of the POM submission two-years ahead of the FY when MDMC is expected to repair it (R. Glavin, personal communication, October 28, 2021). This process should provide MDMC with an effective demand signal to support Just-in-Time supply chain practices, like those in commercial manufacturing industries such as Toyota. MARCORLOGCOM maintains its MWS to perform complete rebuild or Inspect-and-Repair-Only-as-Necessary work on the Service's weapon systems. The MWS is organized only to the system level and has no integrated list of parts or subassembly data.

Consider commercial manufacturing principles, like the Toyota Production System (TPS), and how they relate to O&S activities. Toyota's information system integrates dealer sales data with its production plants and parts suppliers creating a master production schedule and corresponding Material Requirements Plan (MRP) based on parts requirement forecast using BoMs (Monden, 1994). Like Toyota's master production schedule, MARCORLOGCOM makes an annual production schedule known as the MWS for depot repair of weapon systems. As the Service's organic industrial base, MDMC executes depot-repair for Marine Corps systems listed on the MWS. The MWS covers Fiscal Years because of its relationship with the PPBE process. Unlike Toyota, MDMC does not have an MRP based on accurate, electronic BoMs. MDMC's MWS, the equivalent of Toyota's master production schedule, ends at the system-level of detail. However, newly adopted Microsoft Power Business Intelligence software has provided an improved understanding of when MDMC needs material during depot repair. Still, the MWS is not fully integrated with electronic, accurate BoM data to effectively form an MRP as Toyota has done with their SCI of suppliers. Should acquisition commands accurately catalog weapon system BoM data electronically, MDMC could apply JIT demand planning for depot-maintenance O&S actions. Unfortunately, as shown in the following data analysis section, the Marine Corps has failed to manage BoM data for weapon systems electronically. Until Program Offices fix inaccuracies in weapon system BoMs, the Service will remain incapable of applying commercial best practices in JIT logistics and supply chain management. Due to a lack of reliable, electronic BoM data from the acquisition workforce, the Marine Corps faces challenges in making an MRP component list to support JIT depot-level production, repair, and rebuild. Furthermore, inadequate BoM data may conceal supply chain risks.

THIS PAGE INTENTIONALLY LEFT BLANK

II. ACQUISITION RESPONSIBILITIES, HISTORY, STANDARDS, AND SYSTEMS

Establishing weapon system BoM data is an acquisition function according to doctrine, regulation, and statutes (Defense Acquisition University [DAU], n.d.-a). Key government acquisition staff are involved in the system design and cataloging processes. Analysis of systems performed early on should support sustainment plans and SCRM.

A. PROGRAM MANAGER (PM)

The Program Manager (PM) is a crucial military or civil-service leader responsible for weapon system development and life cycle sustainment. A PM is in charge of a Program Office and will be established before Milestone A or as early as possible in a Major Defense Acquisition Program (MDAP) (Department of Defense [DOD], 2020b).

B. PRODUCT SUPPORT MANAGER (PSM)

Established under Public Law 111-84, Section 805, a PSM is responsible, by law, for developing, updating, and implementing the LCSP (Life-Cycle Management and Product Support, n.d.). Numerous system engineering and life cycle sustainment requirements exist throughout the acquisition process for weapon system planning, design, and development. Working subordinate to a PM, the PSM develops and updates the comprehensive Product Support Strategy (PSS) throughout a weapon system's life cycle. The PSS is the principal sustainment document. The PSM must update the PSS when there are major system modifications or changes to the support package, and the supporting analysis should include system components or configuration (Department of Defense [DOD], 2020b). In the Material Solution Analysis (MSA) acquisition phase, the PSM begins sustainment planning and supports determining core logistics capabilities (Department of Defense [DOD], n.d.). The PSS includes support packages with core logistics capabilities (i.e., service-organic depot maintenance). Support packages are updated throughout a weapon system's life cycle. The PSS, as the basis for all sustainment efforts, must describe a core logistics capability, which is a government-owned-and-operated organization that includes "those capabilities that are necessary to maintain and repair the weapon systems and other military equipment" (Core Logistics Capabilities, n.d.; Department of Defense [DOD], 2020b). Product support includes "functions required to field and maintain the readiness and operational capability of covered systems, subsystems, or components" (Life-Cycle Management and Product Support, n.d.).

During the TMRR acquisition phase of a weapon system's life cycle, the PSM should "ensure that all data and information is captured in a Government accessible IDE. Additionally, the Intellectual Property/Data Management Strategy should include the technical data requirements for initial provisioning and cataloging. Further, depending on the product support strategy, and to enable competition and mitigate DMSMS and obsolescence, the requirement for technical data necessary for re-manufacturing, re-procurement, and/or sustainment engineering should be addressed" (Department of Defense [DOD], 2019, p. 42).

Looking at these PSM responsibilities holistically, one can conclude they must prepare a PSS for each weapon system that electronically captures (1) planned service-organic depot maintenance activities and (2) system components in an IDE for supply chain management purposes.

C. SYSTEM ENGINEERING PROCESS (SEP)

A system is the construction of different elements, or parts, that behave with characteristics, functions, and performance as a whole, due to the relationship among how components are interconnected. The System Engineering Process (SEP) ensures problem understanding, analysis of solutions and alternatives, and verification of correct solutions across a project's life cycle: "The WBS follows the physical generation of a physical architecture in the SEP" (Rendon & Snider, 2008, p. 55). The PBS or BoM is closely related to the WBS, which consists of the components that form a system. System Engineers are integral in analyzing, designing, and controlling weapon systems. They ensure the produced weapon system achieves its intended purpose through systematic planning, documentation, and testing. Core to System Engineering, Configuration Management controls the development of a system to ensure consistency between the design and the finished product. System Engineering actions should be integrated with PSM functions regarding acquiring technical data from suppliers to form a Technical Data Package (TDP) describing all specifications and procedures to produce a system (Rendon & Snider, 2008).

Accordingly, the System Engineer's role in managing the decomposition of weapon systems is closely linked with the PSM's job in life cycle management. The PBS and TDPs should be part of the IDE to ensure material requirements to produce and repair systems area readily available to analyze.

D. LIFE-CYCLE SUSTAINMENT PLAN

The LCSP developed by the PM and PSM begins at the Material Solution Analysis phase and continuously evolves. In a weapon system's LCSP, PSMs develop twelve Integrated Product Support (IPS) elements to plan for long-term supportability and sustainment (Department of Defense [DOD], 2019). Of the twelve IPS elements, Supply Support and Technical Data are critical in ensuring long-term supportability and repair in the O&S phase.

1. Supply Support

Within the fourth IPS element, Supply Support, the PSM Guidebook lists subordinate activities, including but not limited to initial provisioning, BoM management and maintenance, cataloging, supply chain assurance, and disposal (Department of Defense [DOD], 2019). Provisioning includes "the identification of items of supply, the establishment of data for catalog, technical manual, and allowance list preparation" (Defense Acquisition University [DAU], n.d.-b). In cataloging, an item of supply is uniquely identified in FLIS with a unique NSN. As early as the TMRR phase, the PSM should have produced an Intellectual Property/Data Management Strategy, including the technical data requirements for initial provisioning and cataloging (Department of Defense [DOD], 2020b). Note that PSMs are not likely to all specialize as data scientists, database engineers, or the like, and each strategy developed may be isolated from other PSMs' approaches. As a result, with no genuinely operational government-wide IDE, the Data Management Strategy for each weapon system will most likely be compartmentalized, siloed, and unique from system to system. Each Program Office's approach to managing critical data will vary, and their fragmented solutions will present obstacles to strategic sustainment planning by the DOD across all weapon systems. As a gate following the TMRR phase, at milestone B, PSMs must identify and evaluate life-cycle sustainment costs, including program disposal. PSMs must "ensure compliance with statutory requirements to develop a disposal plan to include demilitarization and controlled inventory item coding of system, subsystems, or components" (Department of Defense [DOD], 2020b, p. 41). At this same milestone, a process must exist to prevent counterfeit material from entering the DOD supply chain. Simultaneously, a proactive DMSMS and Obsolescence Management Plan must monitor materials, technologies, and items throughout the program life cycle (Department of Defense [DOD], 2020b). Tracking the obsolescence of parts and DMSMS across the DOD's countless subcontractors is no small feat. Indeed, cataloging may capture many components at an assembly or sub-assembly level and lack detail down to the final leg of suppliers (e.g., raw materials). PSMs naturally are then only able to manage to a limited depth of the supply chain and must blindly trust prime contractors to manage the extended supply chain participants across thousands of subcontractors.

2. Technical Data

PSMs must manage the twelve IPS elements, technical data, to "identify, plan, resource and implement management actions to develop and acquire information to:

1. Install, operate, maintain, and train to maximize equipment effectiveness/ availability
2. Effectively catalog and acquire spare/repair parts, support equipment, and supply
3. Define the configuration baseline of the system (hardware and software) to effectively support the Warfighter with the best capability at the time it is needed." (Department of Defense [DOD], 2019, p. 69)

Technical Data includes technical manuals, engineering data, specifications, item data, drawings, BoM, system configuration, etc., and can be in any form. Especially when considering the use of Commercial-off-the-Shelf (COTS) items in system design and the vast number of suppliers, the TDP format may vary wildly (Department of Defense [DOD], 2019).

The government has unlimited rights to Form, Fit, or Function (FFF) data; Operation, Maintenance, Installation, or Training (OMIT) data; and item data funded 100 percent by the government (Department of Defense [DOD], 2020a). However, unless specified in the contract, the government may not have rights to item data not wholly funded by the government (*DFARS 252.227-7013*, 2023). For example, in acquiring systems containing COTS items, vendors may not have to furnish item technical data to the government. The question then becomes how the government might incentivize vendors to provide a complete TDP while protecting intellectual property and minimizing acquisition costs.

The TDP should integrate within the IDE. For example, if reviewing an NSN in an IDE for wholly government-funded applications, end users should expect to see all FLIS data alongside any FFF data, OMIT data, drawings, specifications, etc. (*DFARS 252.227-7013*, 2023). Today, we DOD logisticians know this is not the case, however, and that TDP information may be unavailable or hard to find.

3. Supply Chain Management

The PSM Guidebook vaguely discusses supply chain management. The *Defense Acquisition Guidebook* provides subtlety better hints as to how acquisition staff should approach the subject. The guidebook states, "processes are put in place to automatically and electronically share data and information between all Services, agencies, and commercial entities in the supply chain" (Department of Defense [DOD], n.d., p. 32, chapter 4). Furthermore, PMs should review supplier base health annually and monitor for DMSMS and counterfeit risks across the system's life cycle (Department of Defense [DOD], n.d.). Since the DOD lacks any prescriptive strategy or portfolio-wide Information Technology (IT) system to automatically monitor the supply chain across all parts vendors, supply chain management processes across PM government teams will inevitably vary across the numerous acquisition commands. Such a lack of unified supply chain management strategies is disadvantageous to the government's ability to realize economies of scale through information sharing. Most concerning is the omission of subjects such as SCRM from the *PSM Guidebook* and *Defense Acquisition Guidebook*. Effective SCI is imperative to determine the risks of DMSMS, counterfeits, or human trafficking.

Industry and academia provide better insights into how PSMs might band together to share supply chain data electronically. Regarding SCI, IBM discusses smart factories, the "digital twin," AI/ML, cloud computing, edge computing, the Internet of Things (IoT), and cybersecurity technologies driving "Industry 4.0" to achieve supplier integration for inter-organizational strategies, the internal organization for collaboration between departments, and customer integration that enhances the prediction of changes in customer requirements and companies' abilities to react. The first industrial revolution was in the 18th century Britain; the second with assembly-line oil, gas, and electric powered manufacturing; the third industrial revolution in the mid-20th century with computers, telecommunication, and data analysis with programmable logic controllers embedded in machinery. "We are now in the fourth industrial revolution, also referred to as Industry 4.0. Characterized by increasing automation and the employment of smart machines and smart factories, informed data helps to produce goods more efficiently and productively across the value chain. Flexibility is improved so that manufacturers can better meet customer demands using mass customization—ultimately seeking to achieve efficiency with, in many cases, a lot size of one. By collecting more data from the factory floor and combining that with other enterprise operational data, a smart factory can achieve information transparency and better decisions" (International Business Machines, n.d.). Sharing information and collaborative decision-making is essential to SCI, and 4IR technology catalysts enable transparency across supply chain participants. How supply chain information is automatically shared is evolving through the emerging cloud, A.I. machine learning, the IoT, Cyber-Physical Systems (CPS), and blockchain technologies. These digital tools revolutionize the enablement of SCI in the latest concept dubbed "Industry 4.0," otherwise known as the Fourth Industrial Revolution (4IR), which maximizes value, efficiency, effectiveness, cost, flexibility, quality, and reliability through an intelligent network of the entire chain. Based on 212 business respondents to an empirical survey, 4IR has a positive performance on SCI and supply chain performance. Industry 4.0 improves supply chain forecasting, planning, supplier performance, customer service, and logistics networks. (Erboz et al., 2021).

E. PARTS MANAGEMENT

The DOD established the Defense Standardization Program to comply with the Defense Cataloging and Standardization Act which directed a unified standardization program. Congress enacted this law to uniquely catalog, name, describe, classify, and number each item of supply repetitively used, purchased, stocked, or distributed by the DOD and it's departments to reduce duplicate identification of items and reduction of similar things. The act established a single supply catalog for use across all Services from requirement determination through disposal, i.e., the whole life cycle. This law further required obtaining cooperation and industry participation in the program through liaisons and advisory groups. New items are periodically added, while obsolete items are deleted from the single catalog. The law required biennial reports to Congress on cataloging efforts (Defense Cataloging and Standardization Act, 1952). The Assistant Secretary of Defense (Supply and Logistics) reported 3,128,613 items of supply identified in the newly implemented Federal Catalog System as of 31 December 1956 and said, "this provides for the first time true knowledge of those actually different items which are managed, stocked, and issued in the supply system of the Department of Defense." (McGuire, 1957, p. 1). The report to congress described the need to make over 1 million transactions to keep the catalog current with new items, revisions, and obsolete items dropping out of military supply systems. An IBM 705 was installed to process data in the central cataloging organization. Efforts were made to convert supply catalog data from Electronic Accounting Machine (EAM) cards to magnetic tape for this new system. Each military department contributed one-third of central cataloging operations costs to support the Federal Catalog System. The central cataloging organization remained in the Office of the Assistant Secretary of Defense (Supply and Logistics) (McGuire, 1957).

Congress and DOD made significant efforts to advance supply chain management practices in the mid-20th century. That era's transactional data was substantial enough to require investment in more advanced computing infrastructure. For example, the move from IBM 407 EAM cards to IBM 705 magnetic tape must have been a revolutionary advancement; see these legacy machines used in cataloging items of supply data in Figure 1 and Figure 2 respectively. These past DOD professionals would be amazed to see contemporary 4IR technologies used to manage data. They would likely also be shocked by the growth of items of supply in use as the military departments' weapon system portfolios have evolved in complexity, diversity, and number.

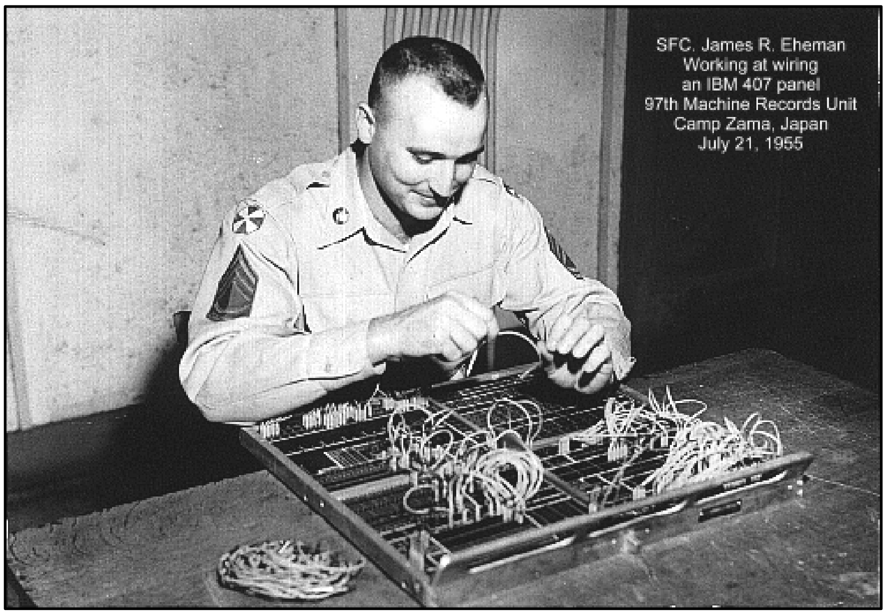

Figure 1. IBM 407 Electronic Accounting Machine Control Panel. Source: Cruz (2022).

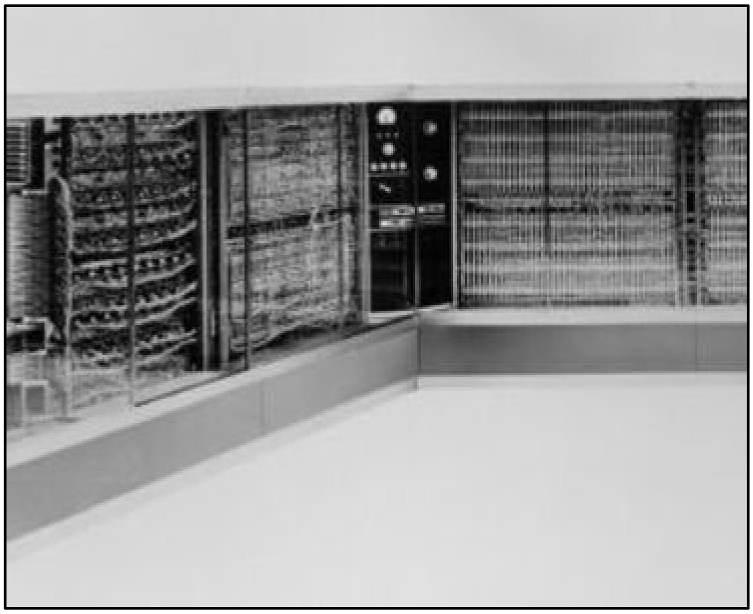

Figure 2. IBM 705 Data Processing Machine. Source: International Business Machines (2003).

The Defense Standardization Program Office (DSPO) chartered Parts Standardization & Management Committee (PSMC) serves to "establish Parts Management best practices across DOD to increase system operational availability and reduce total ownership costs." Along with its charter group, five principal PSMC subcommittees make recommendations to the DSPO:

1. The Systems Engineering, Procedures, Contracting, and Education Subcommittee make "recommendations to the DSPO concerning DOD Parts Management Program procedures, contractual implementation, and education to address Weapon System and Equipment Acquisition Program and Systems Engineering life-cycle objectives. This subcommittee will develop appropriate language concerning performance-based parts management requirements in DOD procedures, contractual, systems engineering, and training documentation."

2. The Counterfeit Parts & Risk Mitigation Subcommittee "reviews issues concerning counterfeit items and materials and makes recommendations to the DSPO, concerning their detection, risk mitigation, and reporting."

3. The Parts Management Tools & Data Subcommittee "provides an Industry/Government forum for suggesting improvements and additional services for parts management tools and data which aid our customers in their standardization efforts."

4. The DMSMS Subcommittee "provides recommendations to the PSMC Advisory Group, concerning parts management policy and contractual implementation of mitigation strategies for DMSMS."

5. The Implementation & Marketing Subcommittee "develops and defines processes and training for the implementation of the Parts Management requirements in MIL-STD-3018." (Defense Standardization Program Office [DSPO], n.d.).

The two principal DOD documents governing parts management are MIL-STD-3018 Parts Management and SD-19 Parts Management Guide. MIL-STD-318 is used in conjunction with SD-19. Both documents cover the following:

1. Contractual parts management needs and requirements

2. Establishing parts management procedures for contractors and suppliers

3. Part selection procedures (Department of Defense [DOD], 2015), (Defense Standardization Program Office [DSPO], 2013).

To obtain parts management data in the contractor's format by vendor part number and manufacturer Commercial And Government Entity (CAGE) code, Contracting Officers should incorporate DI-SDMP-81748 Parts Management Plan into contract agreements. (Department of Defense [DOD], 2015)

1. Work Breakdown Structures for Defense Materiel Items

MIL-STD-881E specifies WBS standards and should be included as a contract requirement during the acquisition of defense materiel items which are the weapon systems, equipment, and supplies of a military force such as aircraft systems, ordnance systems, ground vehicle systems, launch vehicle systems, etc. The WBS is "a product-oriented family tree composed of hardware, software, services, data, and facilities. The family tree results from systems engineering efforts during the pre-acquisition and acquisition of a defense materiel item" (*MIL-STD-881E*, 2020, p. 4). Among other benefits to the program life cycle management, a WBS decomposes defense materiel items into components, clarifies relationships among parts, and provides a common thread for the Integrated Master Plan and Integrated Master Schedule. Integrating parent-child program considerations is increasingly vital across joint program environments in Systems-of-Systems. Child programs develop stand-alone WBS structures; such child systems may be common to separate parent systems at varying levels of parent-WBS structures (Department of Defense [DOD], 2020c).

F. PARTS SYSTEMS

While no single, comprehensive site exists for DOD parts management, MIL-STD-318 states, "DOD is currently developing a parts management tool for the users to access parts management information through a single point of entry. The intent of the tool is to provide engineering and material data relevant to design, parts availability, parts obsolescence, and parts program management information" (Department of Defense [DOD], 2015, p. ii).

1. TDM-CATALYST

Implemented in 2020 as the Marine Corps Program of Record to electronically catalog items of supply for weapon systems, the BoM data contained within TDM-CATALYST is inaccurate and incomplete. Further, the system interface leaves users wanting when viewing BOM data in list form from the website. In TDM-CATALYST, when reviewing the BoM data for weapon systems, users are presented with an item of supply list with no apparent organization by subsystems. The BoM has no proper PBS format. Child systems in the parent system's BoM data do not list the child system's subordinate level of BoM item data. Accordingly, developing a complete BoM for a system of systems would require the end user to aggregate several lists together. Should a BoM exceed fifty items of supply, users must load subsequent pages for each successive batch of fifty items. Worse still, users cannot download or export results into more useful formats such as Microsoft Excel. TDM-CATALYST has no traditional WBS/PBS organization applied to meaningfully organize system components and subassemblies in such a way as is common commercially with OEMs. Sadly, the quantity of BoM items within a system is absent from the list.

Compare the below screenshots in Figure 3 and ask yourself which you would prefer to use to find parts information: the Marine Corps' TDM-CATALYST BoM listing or a user-facing design such as the Mercedes-Benz OEM parts website. The OEM parts website lists common subsystems in a PBS taxonomy such as "engine," "cooling system," "fuel system," "front suspension," etc. The OEM site often provides users with a picture with a numbered part listing by subassembly. The OEM site further provides superseded part numbers and current price data. The TDM-CATALYST provides NSN, CAGE code, and Part Number, but users must research price and availability data elsewhere. TDM-CATALYST also does not show superseded and updated part NSN information, which can often present challenges for Marine Corps supply and maintenance personnel to identify currently available, correct FFF parts.

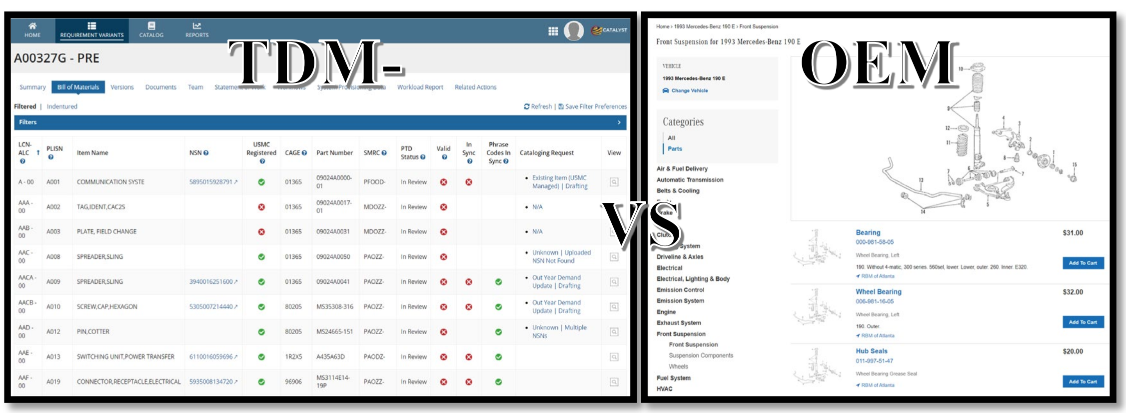

Figure 3. Screenshots Comparing TDM-CATALYST vs. OEM BOM and PBS

Provided TDM-CATALYST adds data fields and improves its organization with a PBS, the website may serve as a valuable central repository for all weapon system BoMs, which could integrate with demand-based MWS production systems to form an MRP. For example, suppose PSM acquisition staff kept BoMs accurate in TDM-CATALYST, and the website interfaced with the Marine Corps MWS. In that case, the service might be able to produce a timely MRP listing to forecast parts requirements to rebuild weapon systems similar to that of Toyota. However, in its current design, TDM-CATALYST is of limited value added to warfighters, maintainers, and front-end equipment users in the O&S phase.

2. TDM Publications

Co-located with TDM-CATALYST, TDM Publications is the Marine Corps publication website for Technical Manuals, Supply Instructions, Fielding Plans, Stock-List Manuals, Modification Instructions, and all documents related to the management of weapon systems. TDM Publications is the only semi-reliable source of BoM information, but records do not exist in practical electronic formats. Many publications exist in non-searchable Adobe PDF form. Even when documents are searchable, no universal format exists across weapon system portfolios to organize component information to support conversion into electronic BoMs. Marine Corps technical publications, over varying periods, have been organized subtly differently. Marine Corps Program Offices may follow different TDP standards in documenting system PBS and BoM information. The lack of unifying standard formatting for weapon systems' BoM found in technical publications even presented challenges for MDMC's automated "BoM scraper" tool by Georgia Tech. Cataloging is poorly executed and lacks strategic integration across all Marine Corps weapon system portfolios.

3. Weapon System Impact Tool

The WSIT website (https://wsit.xsb.com/) provides a BoM with NSN status, essentiality code, and a list of governing specifications. The DOD's WSIT site was pivotal to the analysis herein this thesis by allowing a comparison of BoM data to the Marine Corps TDM Catalyst site. The parent Weapon System's NSN served as the key between the two government databases to reconcile BoM data sets that should match. The TDM Catalyst Weapon Systems Code (WSC) and WSIT Weapon Systems Designator Code (WSDC) also validated matching data sets for parent systems. Rationally, BoM lists in these two government websites should match, but the data analysis showed them to be incongruent, demonstrating a lack of adequate internal organizational SCI within the DOD.

4. PinPoint

The PinPoint website (https://pinpoint.xsb.com/) links to the WSIT website. It displays further NSN information, including procurement history by purchase quantities, prices, vendor company name, award unit prices, Federal Business Opportunities solicitations, etc. The Pin Point site also shows associated weapon systems through the "Coherent View data mining process." For example, NSN 2930–01-405-9885, a radiator component, is used in 15 different systems to include the Marine Corps A00327G AN/MRQ-13(V)1. As depicted in Figure 4, the website explains how subassembly NSNs relate to parent Weapon Systems. WSIT and PinPoint used a Marine Corps SL 6–2 data source to identify a radiator component to the AN/MRQ-13(V)1 that oddly was not listed in the Marine Corps' own TDM-Catalyst website. Such an example is evidence of the lack of inter-organizational SCI within DOD IT systems.

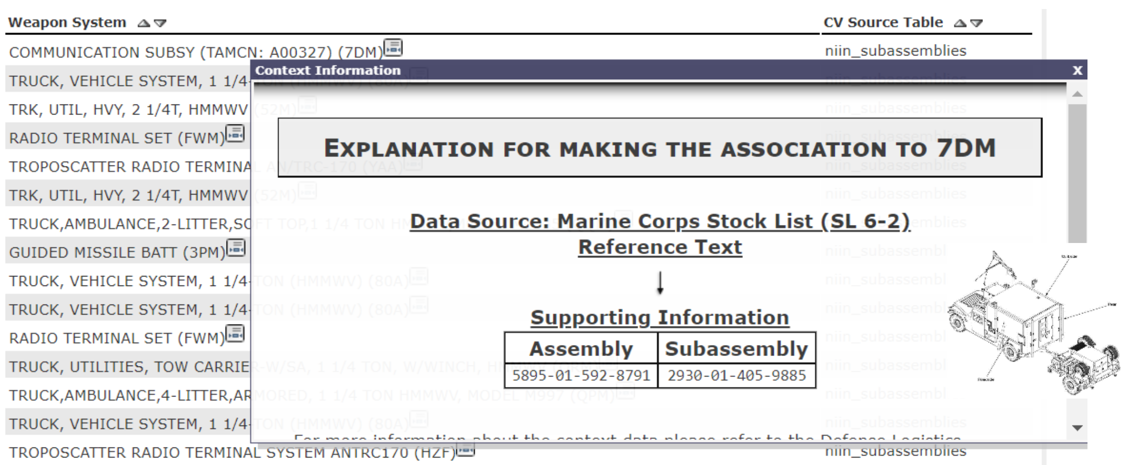

Figure 4. Screenshot of WSIT Parts Association Data

5. Government-Industry Data Exchange Program

The Government-Industry Data Exchange Program (GIDEP) is a part tracking that provides information concerning when a manufacturer discontinues a part (Defense Standardization Program Office [DSPO], 2013). The GIDEP aims to serve as a DMSMS supply chain tool. Once accessed, the GIDEP website was a manual exercise of searching items of supply one NSN at a time. The GIDEP only offers a batch service via email for more than one item of supply, which is an arduous approach that lacks real-time integration with weapon system BoM websites and is not an effective 21st-century SCI model when considering 4IR.

G. ACQUISITION PARTS MANAGEMENT OVERVIEW

Within Program Offices, a Product Support Manager is responsible for parts, BoM, maintenance, cataloging, and supply chain management as part of the LCSP. Key Program Office weapon system SEP practices include WBS, PBS, BoM, and TDP management. These key acquisition responsibilities lack standardized electronic SCI tools across the gamut of DOD's portfolio of weapon systems, but 4IR technology exists to improve collaborative coordination across DOD supply chain participants. The Defense Cataloging and Standardization Act and government investments in technology of that era to manage DOD supply chain standardization demonstrate the importance of parts management to Congress and the Executive branch. The DSPO PSMC is presently responsible for parts management across DOD, and some standards exist. Unfortunately, those standards and currently available IT systems such as TDM-CATALYST, TDM-Publications, WSIT, PinPoint, and GIDEP are ineffective in achieving SCI and acquisition responsibilities to the same degree as performed by OEMs such as Toyota.

THIS PAGE INTENTIONALLY LEFT BLANK

III. BOM ANALYSIS, TPS, AND 4IR OVERVIEW

This study of the Marine Corps weapon system's BoM data demonstrates the logistician's challenges to maintain essential parts listings in a PBS to support production and life cycle management decisions. Effective cataloging and parts management is necessary for SCRM and SCI between the DOD and industrial base. Additionally, conventional logistics principles found among OEMs, such as the Toyota Production System (TPS) and emerging 4IR technologies, offer insights into how best to cooperatively manage BoM parts data through an IDE to support logistics actions in the O&S phase of weapon systems.

A. SYSTEM-SYSTEM BOM ANALYSIS

I analyzed weapon systems listed for the Marine Corps' FY22 MWS, where MDMC is the Depot Source of Repair (DSOR). I chose systems from the MWS because the Marine Corps generally places greater importance on equipment inducted into depot repair due to costs. The Service must value their relevance to warfighting missions enough to expend funds, so naturally, the Service should also continue to manage these system's BoM parts information. Furthermore, since logisticians form depot-repair strategies early in the acquisition planning phases, weapon systems undergoing scheduled depot maintenance during the O&S phase of their life cycle should have accurate BoM data to support an MRP and MWS. The PSM Guidebook states DSOR location recommendations should be finalized within 90 days of Critical Design Review (CDR) within the Engineering & Manufacturing Development (EMD) phase. The PSM guidebook further states how, for depot repair, supply spares and the rights to FFF technical data are critical to maintenance, repair, and overhaul functions. Weapon systems with a Production Support Package fully in place, including depot repair capability, are described as Fully Operations Capable (FOC) with the highest Sustainment Maturity Level (SML) of 12. (Department of Defense [DOD], 2019). To warrant a rebuild and depot repair, weapon systems on the MWS should all be well in the O&S phase of their life cycle, as brand-new weapon systems are unlikely to need depot repair. Naturally, such FOC, high SML systems undergoing depot repair in the O&S phase should have mature, electronic BoM data essential to support depot DSOR work which logisticians should have planned in a preceding phase of the weapon system's life cycle. Accordingly, BoM listings for weapon systems on the MWS should be accurate between TDM-CATALYST and WSIT but were not. Furthermore, end-user parts purchased for these weapon systems should have been found matching in these two websites' BoM data but were not.

1. TDM-CATALYST vs. WSIT

The primary analysis method below compared TDM-CATALYST BOM data and WSIT BoM data. In total, I analyzed 17 systems from the FY22 MWS. The 17 systems BoM in WSIT consisted of 71,234 items of supply, but 48,385 found therein were not listed in TDM-CATALYST under corresponding weapon systems making for an accuracy level between systems of only 32 percent. Across all 17 systems, TDM-CATALYST BoM listed 22,999 items, and 142 were not found in the respective WSIT BoM primarily because TDM-CATALYST also included non-NSN items where no match could be made. Below is an overview of the more detailed analysis found in Appendix A.

Table 1. TDM-CATALYST vs. WSIT BoM NSN Analysis

#	System	TDM Catalyst BoM Items	TDM Items not in WSIT	TDM Items in WSIT	WSIT BoM Items	WSIT Items not in WSIT	WSIT NSN in TDM
1	A00317G	741	42	94%	8,496	7,822	8%
2	A00327G	869	28	97%	11,609	10,770	7%
3	A02577G	421	2	99.5%	5,297	4,878	8%
4	A21797G	2,757	18	99%	12,124	9,385	23%
5	A26007G	504	10	98%	9,652	9,068	6%
6	B00667B	276	7	97%	381	113	70%
7	B00717B	2	0	100%	1,046	1,044	0.2%
8	B12987B	240	12	95%	559	332	41%
9	B15837B	192	0	100%	908	716	21%
10	B17857B	1,610	3	99.8%	2,504	894	64%
11	B19227B	3,300	0	100%	3,388	88	97%
12	B20857B	57	0	100%	57	0	100%
13	B21277B	2,907	18	99%	3,530	623	82%
14	B24837B	2,519	0	100%	4,172	1,653	60%
15	B25667B	1,777	2	99.9%	1,809	34	98%
16	D00037K	4,709	0	100%	5,641	932	83%
17	E09947M	118	0	100%	151	33	78%
Totals	**17**	**22,999**	**142**	**99%**	**71,324**	**48,385**	**32%**

Between WSIT and TDM-CATALYST, for the same given weapon system, each provided a different BoM listing of NSNs. Only one system, a B20857B Fuel Storage Tank Module (SIXCON), had an exact match consisting of a mere 57 items of supply in both WSIT and TDM-CATALYST. Most often, WSIT included all items found in TDM-CATALYST except for items without an NSN in the TDM-CATALYST BoM. WSIT only lists items with NSNs, so no exact match could be made for TDM-CATALYST BoM components that lacked this key data element. TDM-CATALYST most often lacked significant portions of weapon system component data reported in WSIT. The Marine Corps' TDM-CATALYST system appeared to be the less reliable of the two BoM listings, as evidenced by a water purification system listing only two items of supply. In contrast, the DOD WSIT tool showed a much more realistic BoM of 1,046 NSN items. Similarly, Marine Corps BoM listing for vehicles had only a few hundred items versus several thousand found in WSIT. Commercial vehicles typically have several thousands of components, so users should be cautious of TDM-CATALYST'S BoM accuracy and completeness.

For the sake of this analysis, I used a webpage scraper to automate TDM-CATALYST page clicks and download BoM results in batches of fifty items which amounted to significantly tedious work considering some systems consisted of over ten thousand components. The webpage scraper was necessitated by TDM-CATALYST's inability to export or download BoM results. Fortunately, WSIT did have a simple download button that immediately resulted in thousands of BoM components being made readily available for analysis. Once I downloaded BoM lists into Microsoft Excel, formulas could match NSN data between the two data sets on WSIT and TDM-CATALYST.

TDM-CATALYST and WSIT provided different data for BoM items of supply listed. TDM-CATALYST showed Source Maintenance Recoverability Code, Part Number, and CAGE Code. WSIT did not show those data points but provided the NSN's Essentiality Code and related specifications. Both systems had crucial data omissions in that neither provided the quantities of each component needed within the system BoM data nor where those items fell within a subassembly of the PBS. To effectively support system analysis and macro-enterprise inventory planning where many platforms may share parts, quantities, and PBS organization is needed in BoM lists. Since both systems lacked this quantitative detail and neither had a PBS, they have limited value for supply chain management and life cycle sustainment planning purposes (U.S. Marine Corps, 2021) (Department of Defense [DOD], 2021).

2. Retail-level Inventory vs. WSIT and TDM-CATALYST

The 3d Supply Battalion's Supply Management Unit (SMU) maintains a retail-level inventory of items of supply in support of weapon systems. Retail-level inventory is calculated based on end-user demand for repair parts. Stockage criteria include, among various calculations, an item's Combat Essentiality Code (e.g., 5/6), war reserve, and initial provisioning stocks procured by Program Offices to support 3d Marine Expeditionary Force's weapon systems. The SMU stocks inventory items based on actual customer demand corresponding to these specified weapon systems' maintenance service requests in GCSS-MC. Maintainers order parts based on parts listed in the weapon system Technical Publications. Naturally, then TDM-CATALYST and WSIT should list all ordered parts, but this is not the case. SMU inventory includes many items held for weapon systems, where those components are not listed in BoM data. For the 17 systems analyzed, TDM-CATALYST BoM data only matched 40% of the NSNs stocked by the SMU as informed by the corresponding system's user parts demands. TDM-CATALYST's electronic, online BoM data did not match 1,210 of 2,015 items the SMU stored for a related weapon system's parts requirements. Omitted data represents a mismatch between real-world parts usage and Program Office cataloging efforts demonstrating incomplete and inaccurate BoM data. Similarly, the SMU's weapon system demand-based inventory for these 17 systems only matched WSIT BoM data for 60% of items held on hand; 815 of 2,105 NSNs ordered by end-users for weapon systems were not in WSIT BoM data. Following is an overview of the more detailed analysis found in Appendix B.

Table 2. SMU Inventory vs. TDM-CATALYST and WSIT BoM NSN Analysis

#	System	SMU NSNs Stocked	SMU NSNs not in TDM	SMU NSN Match in TDM BoM	SMU NSNs not in WSIT	SMU NSN Match in WSIT BoM
1	A00317G	43	32	26%	15	65%
2	A00327G	138	107	22%	41	70%
3	A02577G	47	41	13%	9	81%
4	A21797G	78	75	4%	11	86%
5	A26007G	35	25	29%	9	74%
6	B00667B	27	24	11%	21	78%
7	B00717B	51	51	0%	51	0%
8	B12987B	46	43	7%	18	61%
9	B15837B	86	192	5%	74	14%
10	B17857B	23	10	57%	9	61%
11	B19227B	30	15	50%	15	50%
12	B20857B	53	46	13%	46	13%
13	B21277B	8	3	37%	2	75%
14	B24837B	35	22	37%	22	37%
15	B25667B	65	43	34%	43	34%
16	D00037K	1,124	360	68%	320	72%
17	E09947M	126	110	13%	109	13%
Totals	17	2,015	1,210	40%	815	60%

The incongruence of real-world parts requirements for weapon system maintenance versus both WSIT and TDM-CATALYST is evidence that electronic BoM management is presently nowhere near reliable for use in O&S life cycle management practices. Logisticians, maintainers, and supply personnel cannot use BoM data on either TDM-CATALYST or WSIT solely and instead must use PDF or hardcopy technical publications to identify parts required corresponding to weapon systems. Last-century parts management practices relying on print or soft-copy publications instead of electronic data are unsuitable for supply chain management of numerous, complex DOD weapon systems (C. Hernandez, personal communication, March 15, 2023) (U.S. Marine Corps, 2021) (Department of Defense [DOD], 2021).

3. TDM-CATALYST vs. Technical Publications

I performed a limited, tertiary analysis to compare TDM-CATALYST BoM data to TDM Technical Publications documents, i.e., Technical Manuals and Stock-List Manuals. TDM-CATALYST and TDM Technical Publications exist on the same website.

Any incongruence of BoM information between TDM-CATALYST BoM lists and TDM Technical Publications evidences ineffective parts management within a given Program Office that should be responsible for the weapon system. Below is an overview of the more detailed analysis found in Appendix C.

Table 3. Technical Publication vs. TDM-CATALYST BoM NSN Analysis

#	System	TDM Catalyst BoM Items	Tech Pub NSNs	Tech Pub NSNs not in TDM	Tech Pub BoM in TDM
1	A23352B	350	499	245	51%
2	A23372B	402	477	227	52%
3	D00037K	4,137	343	29	92%
Totals	**3**	**4,889**	**1,319**	**501**	**62%**

MDMC provided locally developed BoM lists from their "BoM-scraper" tool, which I used to compare Technical Publication BoM printed media to electronic TDM-CATALYST BoM data for the three above systems. Upon review, 501 (38%) of 1,319 component items listed in Technical Publications or MDMC BoM lists used for depot maintenance were not found in the TDM-CATALYST BoM data for matching weapon systems.

Highlighting the grotesque inaccuracy of one system as an example, in reviewing TDM-CATALYST BoM data, the A00327G AN/MRQ-13(V)1 Communications System did not even include a High Mobility Multipurpose Wheeled Vehicle (HMMWV) found in its associated Technical Publication. As a result, the TDM-CATALYST BoM only had 869 items of supply due to the omission of HMMWV parts data, whereas WSIT accounted for 11,609 components. This problem exemplifies the challenges of Systems-of-Systems and PBS management between parent and child systems.

While TDM-CATALYST did not list quantities needed for items of supply, Technical Publications did provide the required number per parent system (e.g., two axles per vehicle). Unfortunately, Technical Publication's archaic nature (simply a repository of multiple Adobe PDF files) was not valuable for aggregating data strategically. As a result, answering a seemingly simple question based on BoM information becomes near impossible. For example, "how many wheels of a given item of supply would be needed across all 7-ton truck variants and similar motor transportation equipment?" To answer this question, an entire family of vehicle and related system publications would have to be downloaded, read, scanned for matching NSN data, and manually aggregated. Accordingly, attempting to check quantities of items of supply was not evaluated due to the present limitations of WSIT and TDM-CATALYST BoM data (U.S. Marine Corps, 2021).

4. BoM Analysis Conclusions

The result of the weapon system BoM analysis between various sources makes the DOD and Service's ability to perform parts management, standardization, and supply chain management throughout a weapon system's life cycle questionable. TDM-CATALYST BoM data did not record many NSNs listed in Technical Publication documents. While most items of supply listed in TDM-CATALYST BoM matched WSIT BoM data, the opposite was not the case. Numerous NSNs listed on the DOD's WSIT BoM were not in TDM-CATALYST BoM data. Worse still, end-users, the Marines performing O&S actions in the Fleet Marine Force, are ordering parts not listed in either TDM-CATALYST or WSIT BoM data. Marines are reading traditional printed publications or PDF versions that do not match BoM data online to procure repair parts. Such poor cataloging management of weapon system BoM data demonstrates the need for 4IR technologies to overcome human struggles in managing large sets of component data across the DOD's portfolio of weapon systems. 4IR tools such as the Cloud/Lake, SCCT, Blockchain, and AI/ML should improve the accuracy of BoM and PBS data through government and industry collaboration to realize actual hybrid logistics.

Inaccurate and omitted electronic BoM data will negatively impact simulations. AI/ML can only process electronic data ingested within its model. Where gaps occur in data input due to omission, such as in missing weapon system BoM data, gaps also exist in the output of any simulation. Contemporary concepts such as a "digital twin" or CPS cannot paint an accurate picture of the real world when foundational BoM data sets have massive holes with no PBS. Before leveraging AI/ML and simulation, DOD must get a handle on making weapon system BoM data accurate through inter-organizational SCI with OEMs and suppliers.

B. TOYOTA PRODUCTION SYSTEM (TPS)

Toyota's principal business practices are relevant to weapon system acquisition, production, repair, and sustainment. Their approach to customer demand-based planning with computerized SCI incorporating BoM and PBS data to automate the scheduling of end products was once novel but now must be considered conventional as it is several decades past introduction. None-the-less, Toyota's business practices merit review alongside 4IR technologies, as the DOD has neither adopted traditional SCI practices nor emerging technologies. Moreover, the fundamental principles Toyota has codified into disciplined processes are foundational to ideas such as "hybrid logistics," which seek to integrate new technologies, such as a 4IR IDE, with old ideas, such as Kanban cards.

Toyota is an iconic example of how an organization can effectively use data in a world of uncertain supply and demand. Toyota's logistics ideas are rooted in history. From American supermarket supply-pull practices in the mid-20th century, Toyota incorporated revolutionary changes by tracking and communicating the consumption and production of finished goods and all materials used in manufacturing. Toyota affixed Kanban cards to inventory, signaling demand to manufacturing employees and parts suppliers (Kanban Tool, n.d.). These Kanban cards were used as an early form of signaling material consumption to maintain inventory levels. As cards are returned from the point of consumption backward within the supply chain, suppliers are informed to produce and deliver additional quantities to match demand.

The TPS lean manufacturing model aims to eliminate waste and unreasonable requirements on the production line. One tenant of Toyota's JIT concept is to ensure production instructions are issued as soon as possible once a vehicle order is received (Toyota, n.d.). Now, consider how the Marine Corps MWS depot-repair schedule may constitute an "order" and how incomplete BoM data is a roadblock to immediately procuring parts for production upon demand. The TPS incorporates Toyota's philosophies of 5S, Kanban, and Kaizen (Monden, 1994). The TPS is a demand-based system with practical applications in the depot maintenance and sustainment of weapon systems scheduled in advance for repair. The TPS achieves reduced inventory and level production, both advantageous for Navy Working Capital Funded (NWCF) organizations such as MDMC. JIT systems require an in-depth understanding and integration of both demand and suppliers. Fundamentally, JIT strategies are SCI practices in an IDE. The OEM commercial industry has fared better than DOD in SCI and shared supply chain communication implementation.

1. The Kanban "Signboard" System

Kanban, translated from Japanese to English, means signboard, sign, or card. In Toyota's initial adoption of Kanban, workers affixed cards to materials to signal production based on consumer demand. The Kanban system identifies and tracks the production of finished goods and materials used in their manufacturing processes to achieve a highly efficient, waste-free business. The Kanban system identifies waste as Muda, Mura, and Muri. Muda, or "unnecessary effort," includes that which lends no production value, such as waiting and inventory. Mura, or "unevenness," can stem from improper allocation of material parts and cause work stoppages and production spikes. Muri, or "overburden," is when Muda and Mura consistently affect production, causing an unsustainable environment for people and equipment (Creative Safety Supply, n.d.).

"The Toyota Kanban system is a pulling system … where subsequent processes order the necessary parts from the preceding processes in the right quantity at the right time" (Monden, 1994, p. 279). Alternative inventory control systems within Toyota include the "constant order-quantity" (constant quantity, nonconstant cycle) and "constant order-cycle" (constant cycle, nonconstant quantity) systems. In contrast with these two systems, the Kanban system alleviates the need to continuously monitor inventory levels as the number of cards detached at subsequent processes is what must be ordered. Toyota recognizes that an increase in inventory is the ultimate origin of all kinds of waste and increases lead times. Instead of minimizing Kanban levels, however, Toyota gives workstation supervisors specific instructions that they can have as many Kanbans as they want but should reduce Kanban inventory levels one sheet at a time down to the minimum possible limit as they improve processes (Monden, 1994).

Successful application of Kanban requires detailed schedules of each production process prepared in advance using a computerized information system. Toyota's Technology Data Base Subsystem maintains basic data for production controls, including a BoM parts database to compute materials and quantities required for each finished product. For JIT production, required materials must be prepared in advance. Computerized Kanban master tables list required materials for internally and externally produced parts and material usage. Additionally, Toyota implemented artificial intelligence in production processes with radio-frequency memory cards attached to vehicle body chassis to determine the proper sequencing of work to prevent line stoppages during assembly. AI processing to automate conveyors of vehicles replaced the judgment of skilled workers to smooth processes and eliminate unevenness (Monden, 1994). In contrast, the Marine Corps does not have an accurate BoM parts database for computing materials and quantities required for any system's repair. Such computerized SCI with required materials procured before scheduled work is a prerequisite for JIT production. It has been about three decades after the published study of TPS by Professor Yasuhiro Monden, where he noted Toyota's adoption of computer-integrated manufacturing and strategic information systems integrated into Toyota's JIT approach. Still, DOD is barely now struggling to catalog BoM materiel electronically, let alone implement similar production strategies (Monden, 1994).

2. Kaizen, "Improvement," 5S

Toyota's five "S" principles in Japanese are Seiri, Seiton, Seiso, Seiketsu, and Shitsuke. Seiri, or "Sort," seeks to maximize space and efficiency in the first stage by identifying unnecessary equipment and inventory to declutter through divestment (Toyota, 2018). Otherwise known as Kaizen or "improvement," the method is used to diminish slack hidden in production. Seiri separates necessary and unnecessary things, abandoning the latter, through a red-label process. Seiton serves to organize and identify things for ease of use. Seiso is to clean and keep tidy. Seiketsu is to constantly carry out Seiri, Seiton, and

Seiso. Lastly, Shitsuke is to have workers in the habit of conforming to rules. As part of Seiri, red-label projects should be conducted to mark waste visually. Red-label projects may be done at the workplace level or companywide to seal potential wasteful inventory waste, including materials, work-in-progress (WIP), parts, half-finished products, and finished products. Management must set specific criteria to determine which items are unnecessary and should also carry out the actual labeling. Management evaluates sealed inventories for classification as defects, dead stock (obsolete, old models), staying items (excess), and leftover materials(scraps). Sealed, unnecessary inventory stocks are compiled in a list with actions recommended (Monden, 1994). The ability to trace inventory relevance toward systems in a BoM or PBS is essential in determining the usefulness of items. While Toyota has computerized BoM lists, the Marine Corps has no similarly reliable tool to inform recommended actions for stocks to carry out Seiri and separate useful from useless things. The Service has no computerized ability to compile a list of unneeded replenishment parts from that used towards production within in-service weapon systems.

While the Marine Corps has trained its workforce to be especially mindful of Shitsuke as obedient conformists, Seiri is a weakness. The Marine workforce obeys rules but is challenged to sort its component items due to a lack of practical BoM database tools. Obedience to rules and orders is fundamental to the military. The "fog" of uncertainty for what items may be necessary for a future war is also a common military characteristic. However, knowing what is required is critical to enabling workers to sort and identify inventory waste. Accordingly, an accurate cataloging system that identifies BoMs for current systems in demand lends to military workers' abilities to practice Seiri. Without an effective BoM and PBS tool, risk-averse Marine Corps employees will fear retribution for disposing of items they assume might find future use. The "better to have it and not need it than need it and not have it" mentality takes hold when workers cannot easily screen parts held against an accurate cataloging system.

3. COVID-19 and JIT Supply Chain

Following the COVID-19 pandemic, misconceptions exist that JIT practices were purportedly partially to blame for supply shortages. In reality, JIT techniques create resilient supply chains with tightly woven relationships that allow supply to be responsive to changing demand. Companies practicing JIT logistics do maintain some level of inventory buffer where necessary. The Kanban cards used by Toyota are an excellent example of where safety stocks are held throughout each workstation. "When it is found that the present number of Kanban is not suitable and causes trouble in the shop, the number of Kanban should be changed (increased) immediately" (Monden, 1994, p. 287). During the COVID-19 pandemic, Toyota understood the automotive industry's limited supply of semiconductors. As a result, it surpassed all other car manufacturers in vehicles sold in the U.S. by amassing a safety stock of microchips. Toyota made deliberate efforts to establish safety stocks early in 2021 in response to changing market conditions due to their clairvoyant understanding of supply chain risks. Toyota had learned of supply chain risks to semiconductors over a decade earlier, following the Fukushima disaster, which led the company to make a business continuity plan. Understanding their supply chain resulted in identifying more than 1,200 parts and 500 priority items key to sustaining lean production. After Fukushima, Toyota required suppliers to stockpile up to six months of chips, depending on lead times. Since then, Toyota's continuity plan has cushioned it from natural disasters such as typhoons. In addition, their effective SCI and JIT practices give them a keen sense of climate change and other threats, such as global chip shortfalls during the pandemic (Norihiko, 2021).

Similar to Toyota, U.S. defense contractor manufacturers have supply chain risks. Accurately understanding weapon systems' many parts and materials informs business continuity plans. Hence, an electronic BoM listing of all systems is essential to analyze and understand risks before globally impactful crisis events occur. However, since the Marine Corps has not adopted computer-integrated manufacturing and strategic information systems with accurate BoM and PBS data, the Service cannot effectively identify priority items to stockpile. The Service can only rely on historical demand data for individual items of supply but cannot see replenishment part needs and spares where users have not yet registered real-world demand, as is the case in newly fielded weapon systems. While Toyota can rely on a completely accurate BoM, PBS listing across all of its products to perform SCRM, the Marine Corps and DOD has no such tool and must instead reactively wait for demand data.

C. THE INTEGRATED DATA ENVIRONMENT (IDE) AND THE FOURTH INDUSTRIAL REVOLUTION (4IR)

The PSM Guidebook touts the IDE, how it should capture all data and information, be accessible to the government, and be a place where every activity involved with a weapon system can "cost-effectively create, store, access, manipulate, and exchange digital data" (Department of Defense [DOD], 2019, p. 70). Technical Data includes BoM and system configuration. The IDE data management should meet the needs of system engineering, simulation and modeling, and support strategies (Department of Defense [DOD], 2019). To realize a beneficial IDE, the DOD and defense industrial base organizations must partner and leverage emerging 4IR technological opportunities such as Artificial Intelligence Machine Learning, Cloud/Edge/IoT computing, Supply Chain Control Towers, and Blockchain security. To effectively employ these new technologies and maximize the leverage of business-to-business data sharing, DOD must collaborate with supply chain participants just as commercial OEMs such as Toyota traditionally have done with JIT logistics practices. In truly realizing SCI, Toyota integrated its systems with front-end dealers and back-end suppliers for decades, and DOD should take a page from their strategy while implementing 4IR tools for SCI (Monden, 1994). While certainly challenging to achieve at scale across the whole government and its many suppliers, 21st-century technologies are making this achievable more than ever. Contemporary 4IR technological opportunities enable horizontal integration across the DOD weapon system supply chain to achieve the goals depicted in Figure 5. Until DOD adopts a 4IR IDE, Program Offices spanning the Army, Navy, Marine Corps, and Air Force may be considered competitors in the current acquisition environment. Each Service competes for limited procurement appropriation resources and PM staff members are self-interested in achieving positive performance evaluations among their disparate Program Offices. Each Service has different acquisition cultures and business practices. Universally incorporating

4IR technologies through a standard IDE across the Services should help to replicate business practices and improve economies of scale across all DOD Program Offices. Program Offices can remain separate with a degree of autonomy. Still, through standardized 4IR technology, the DOD should improve collaborative acquisition efforts and situational awareness of parts and suppliers in the supply chain affecting multiple systems.

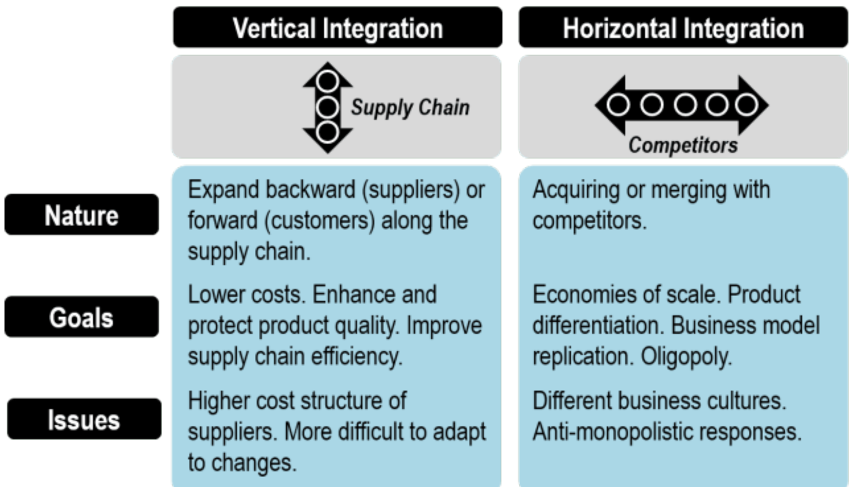

Figure 5. Horizontal Supply Chain Integration. Source: Rodrigue (2017).

1. Artificial Intelligence/Machine Learning

Machine learning is a disruptive technology offering revolutionary supply chain analytics advancements. The effectiveness of AI/ML is affected by collaboration as it becomes more effective with greater access to datasets across the entire supply chain. Conversely, collaboration barriers reduce the effectiveness of machine learning for supply chain forecasting and analysis.

The European Journal of Operational Research analyzed traditional forecasting techniques versus advanced machine learning supply chain demand forecasting methods. Traditional techniques included naïve forecasting, moving averages, linear regression, and time series models. Advanced techniques used Neural Networks, Recurrent Neural Networks, and Support Vector Machines. The study concluded by noting the better accuracy of machine learning forecasts for distorted demand signals in the extended supply chain (i.e., reduction of the "bullwhip" effect depicted in Figure 6). Study authors pointed to prior research indicating supply chains are not typically collaborative all the way to the OEM. The study further noted that barriers between supply chain participants constrain decision-making and that further research is warranted on using the Internet or other technologies to coordinate decisions with various partners (Carbonneau et al., 2008).

Figure 6. Bullwhip Effect across Supply Chain Participants

Understanding the unfavorable effects of distorted demand signals from the customer, OEMs have an intrinsic incentive to collaborate as the supply chain participants most in need of accurate forecasting. With the classical bullwhip depiction above, OEMs lacking accurate supply chain forecasts may have radical swings of overproduction and underproduction. Studies noted, "the problem of forecasting distorted demand is of significant importance to businesses, especially those operating towards the upstream end of the extended supply chain." (Carbonneau et al., 2008, p. 1141).

Most recently, AI/ML has come to be prominently recognized by the general public with the unveiling of ChatGPT integration with Bing by Microsoft. In Microsoft's initial public unveiling of the technology, they demonstrated the AI/ML ability to immediately extract the essential earnings data from a company's quarterly financial results and then compare matching data points to another company's quarterly earnings report in table form. In addition, Microsoft demonstrated AI/ML answering fitment questions regarding an Ikea furniture item in a specific vehicle. Microsoft even showed the market research potential of shopping for a TV with iterative refinements to the initial question, successively narrowing results (Microsoft, 2023). AI/ML is valuable in supply chain management and market research. With access to broad enough data sets, the boundaries of what AI/ML might accomplish are left only to the human imagination. AI/ML might identify the most cost-effective parts available to make scheduled weapon system repairs with items of identical FFF by searching a comprehensive 4IR IDE of the DOD supply chain.

2. Data Lake and the Cloud

Data lakes store data in their raw format for later use in advanced analysis unforeseen at the onset of storage. Different data lakes include "on-premises," "cloud," "hybrid," and "multi-cloud" architectures, which are each chosen for varying business needs. The "on-premises" data lake includes local physical infrastructure and software requiring engineers, engineering resources, and high sunk infrastructure startup costs. The scalable "cloud" architecture stores data in offsite 3rd-party services that are typically paid over time as a subscription service and include companies such as Microsoft Azure, Amazon Web Services, and Google Cloud. A "hybrid" data lake is a blended data storage solution comprised of both "on-premises" and offsite "cloud" systems. As with "on-premises" solutions, this architecture requires costly experts to integrate and maintain both environments. Finally, a "multi-cloud" method involves integrating data storage across multiple 3rd-party service providers. This approach also requires expertise (Zagan & Danubianu, 2021).

"Cloud" data lake advantages include unlimited storage capacity, scalable costs commensurate with service needs, accessibility of data from any user's location, data security, and user-friendly interfaces. The primary advantage of a data lake for storage is the ability to "transform, organize, and combine different data sources" and "most cloud providers offer advanced analysis solutions" (Zagan & Danubianu, 2021, p. 3). Disadvantages and challenges of "on-premises" data lakes include higher cost, challenges to forming an entire team of reliable experts locally, scalability constraints, poor performance, data quality, governance, and management difficulties. For these reasons, the trend is to move towards "Cloud" data lakes for end-to-end management of data ingestion, storage, processing, analysis, and security, which 3rd-party service providers constantly improve (Zagan & Danubianu, 2021).

3. Edge Computing

Consider that “Cloud” data lakes tend to be central, core nodes that remotely compute information for users geographically dispersed at the “edge” of the internet. While “Cloud” computing layers consist of multiple high-performance servers and storage devices, “Edge” computing applications take place closer to the data source and bring computational resources to the proximity of end devices. Given the exceptional processing power of “cloud” data lakes to surpass the computing power of “edge” devices, a push and pull of data between the core nodes and edge devices consume bandwidth between the two ends of the spectrum. Data generated at the “edge” grows, but the bandwidth between these remote devices and the core “Cloud” data lake may be bottlenecked like a pipe that can only transmit so many gallons of water per hour. For example, a Boeing 787 generates 5 gigabytes of data per second but lacks bandwidth between satellites and ground stations to transmit this volume. In a few years, the number of “edge” devices will exceed billions, and most electric devices, such as air quality sensors, streetlights, and vehicles, will be part of the IoT. Approximately 80 billion devices will connect to the internet by 2025. The massive increase in raw data produced by “edge” devices will be too voluminous, constrained by bandwidth and computing resources for transmission to the “cloud.” Some data filtering and processing must be done at the “IoT” or “edge” sources to offset the increased data generated. At the same time, the “cloud” nodes analyze more complex tasks (Taheri & Deng, 2020). See Figure 7 depicting the conceptual framework for data lake, fog, edge, and IoT layers of information as it is communicated and processed across a broad network.

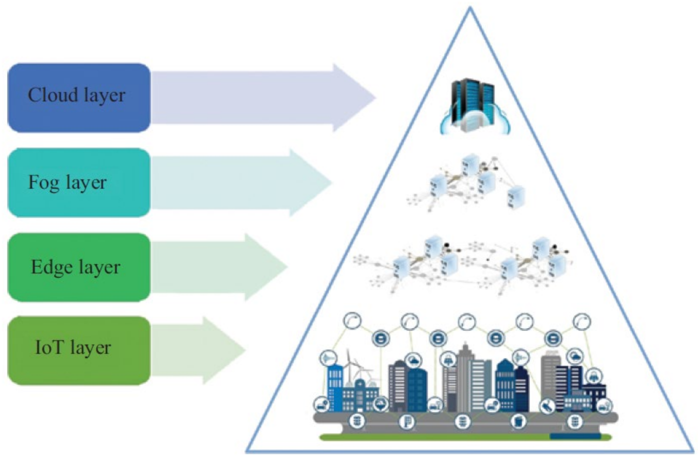

Figure 7. Edge Computing Architecture. Source: Taheri and Deng (2020, p. 9).

Any future 4IR IDE between DOD and OEMs must balance processing information across all data layers because while cloud computing resources may be vast, bandwidth and latency are a factor, and edge/fog computing is limited in computing, communication, and storage resources. Furthermore, as AI/ML increases, data generation and bandwidth growth may not be proportional. This is because AI/ML exists practically in the cloud, not the edge. For example, with Nvidia's H100 Graphic Processor Unit enabling generative AI and multiples faster AI than the prior-generation A100, data consumption in cloud server farms powered by these units has an increased draw on bandwidth (Allie, 2023).

4. Internet of Things (IoT)

Cloud and edge computing solutions enable data analytics through sensors embedded within intelligent IoT devices. For example, a vehicle may have onboard telematics and sensors capable of interfacing with the "Cloud" through "Edge" devices on the IoT (Bruce, n.d.). "Edge" or "IoT" devices may locally process complex analytics while filtering critical raw data to the "Cloud" for complex analysis. Sensors may prevent faults and critical failures before they occur. For example, imagine never realizing a dead battery or failed alternator because a vehicle's sensors detect unusually low voltage as components begin to degrade. If vehicle computers see such a scenario, data could transmit to the

"Edge" network to determine if local supplies exist to replace the faulty component and then automatically signal anticipated reorders to supply chain vendors. In addition, the cloud might perform more intensive analytics, such as idealized global positioning of wholesale inventory to meet demand.

Various subassemblies and components powered on a system, such as communications electronics, engines, or batteries of a Joint Light Tactical Vehicle (JLTV), may operate on the "edge" and work within the broader cloud-edge-IoT ecosystem. Looking at the electronics in the JLTV pictured in Figure 8, such a possibility is nearing reality.

Figure 8. JLTV Interior Electronics. Source: Kimmons (2019).

IoT sensors within vehicles can enable over-the-air updates and predictive maintenance from actively monitoring components across a fleet of vehicles. Consider when Tesla used the IoT to deliver a software fix for around 30,000 cars after a notice from the National Highway Traffic Safety Administration informed vehicle owners that a "charger plug" had triggered fires (Rastogi, 2022). Had this been a fleet of conventional government vehicles, organizations worldwide would have mechanics who would spend countless thousands of hours performing and documenting maintenance efforts. For those risk-averse communications officers, end-users could toggle an off-switch might for signature management during wartime conflict. The logistics benefits of IoT-embedded systems are too great to ignore, and the reward is more significant than any cyber-security risk. Competent cybersecurity professionals could offset risks through encryption and blockchain instead of using residual risk as a reason to stop revolutionary improvements.

5. Supply Chain Control Tower (SCCT)

Throughout commercial industries, SCCTs exist to coordinate between business partners. IBM advertises its Supply Chain Intelligence Suite as providing the ability to "orchestrate your end-to-end supply chain with AI-powered visibility and actionable workflows" (International Business Machines, 2021a). "Conceptually, a SCCT is a shared-service center that, like the digital twin of a traffic control tower, offers real-time monitoring of the status and performance of [end-to-end] activities in SCs that extend beyond the boundaries of the nucleus organization. Supply chain control tower can therefore constitute a 4IR digital information hub serving as the 'single access point of truth' for all decision makers, planners, buying teams and cross-organizational SC partners. Such SCCT hubs aggregate, correlate and distribute information for early detection of risks and opportunities" (Patsavellas et al., 2021, p. 291). SCCTs connect siloed data into an encompassing, collaborative network that serves as a "digital twin" of product and information flow across participating supply chain stakeholders. "Visibility can positively affect manufacturing, transaction activities, planning, supplying, and evaluation on both operational and strategic choice levels. On an operational level, it can impact forecasting, planning, and scheduling efficiency, along with execution accuracy and speed" (Patsavellas et al., 2021, p. 294). SCCTs are increasingly relevant due to supply chain globalization, where 94% of Fortune 1000 companies have disruptions (Patsavellas et al., 2021). Recall again the weapon system IDE concept and how valuable the information might be if integrated into the extended prime and subcontractor parts management data systems.

Naval Supply Systems Command (NAVSUP) has already initiated a pilot program that used an integrated SCCT to improve end-to-end visibility of supply chain data OEMs, Naval Air Systems Command (NAVAIR), maintenance organizations, PMs, and others. Upon connecting data sources, AI/ML was able to improve predictive analytics by integrating previously disparate data siloes. Even with imperfect data, aggregating information smoothed the impacts of inaccurate data from a given source. NAVSUP suffered from excesses of some supplies and shortfalls in other areas, or what the Japanese would call "mura" (i.e., unevenness) in the Kanban model (Serbu, 2020). Using an integrated SCCT helps to remove unevenness caused by the improper allocation of material parts. An SCCT provides end-to-end supply chain visibility for all business stakeholders while overcoming fears of asymmetrical power in relationships and proprietary information leaks. "Supply chain collaboration can reduce bullwhip effect costs, inventory, and administrative costs for the whole chain" (Patsavellas et al., 2021, p. 291).

6. Blockchain for Trust

Suppliers may rightly be concerned about protecting their intellectual property when collaboratively sharing information in an SCCT or IDE. A form of encryption must safeguard their rights while still allowing access to a weapon system's TDP, BoM, and PBS information to support government supply and maintenance actions. Modern blockchain technologies may offer security solutions that permit collaboration throughout the supply chain. IBM's solution advertises the use of its services' ability to "Build your own blockchain ecosystem to share data with your supply chain partners" (International Business Machines, 2021b).

a. Blockchain Primer

To dispel any misconceptions up front, Bitcoin is not synonymous with blockchain. Bitcoin is one application of blockchain technology. Otherwise known as Distributed Ledger Technology (DLT), Blockchain enables peer-to-peer data exchanges without intermediaries through digital signatures, cryptographic hash, and distributed consensus algorithms. Blockchain networks may be public, private, or consortium. These may be permissioned or permissionless DLT networks. Each type of blockchain network offers different properties regarding the nature of centralization, control, openness, identification of participants, permissions to write transactions, efficiency, scalability, and energy consumption during information exchange. To differentiate blockchain from central databases, DLT has no central node ensuring ledgers on the distributed network are the same. Instead of a central database, protocols validate transactions using a form of consensus among participating nodes. As with the three taxonomies of blockchain network types, there are also different consensus algorithm protocols used to validate information, including Proof of Work, Proof of Stake, Delegated Proof of Stakes, Practical Byzantine Fault Tolerance, and Tendermint. Like with different network types, different algorithms also have advantages and disadvantages. Blockchain implementation has tradeoffs and must be determined suitable before adopting any proposed network type, consensus protocol, or solution. Interoperability is a concern while numerous industries are adopting siloed blockchain solutions. No standard protocol exists for collaboration and interoperability between thousands of separate blockchain networks. Besides cryptocurrencies, experts in the field of blockchain see many potential use cases, including but not limited to identity management, cyber security, stock exchanges, supply chains, etc. (Monrat & Anderson, 2019).

In contrast to a centralized network database, many machines store blockchain where changes are reflected simultaneously for all ledger holders. Furthermore, cryptographic signatures authenticate information to provide transparent and verifiable transaction records. Key DLT features include immutable records, disintermediation (where nodes may interact directly), a lack of central control (through consensus changes to ledger data), and opportunities for management and sharing of data (through decentralized, distributed storage and varied access for ledger participants) (Gunashekar & McGarr, 2017).

In a business-to-business environment, there is no centralized network. When OEMs like Toyota and BMW partner to build a "Supra" sports car, companies likely collaborate through a secure internet system. It is unlikely that either BMW or Toyota made wholly separate supply chain systems for one niche product's development. More likely, they found interoperable communication practices between each company's business systems and teams. Likewise, in a government-to-business environment, no central intranet would dominate all contractors, but more realistically, 4IR technologies would enable data integration across internetworked systems. Even with a government-designed IDE, many businesses would still have unique business networks and systems. OEMs in business with the DOD also have commercial customers. Any government 4IR IDE must acknowledge that companies will likely retain their organic software systems as the DOD may not even be the largest revenue source for some suppliers. The question becomes how DOD can respect a business's autonomy while achieving access to pertinent information related to weapon systems supported by a company's native business systems. As the "Distributed" Ledger Technology name implies, it is a practical, decentralized internet tool across organizations. Collaboration in the supply chain requires data to cross an organization's networks. DLT may offer a secure bridge for supply chain data to flow between DOD and industrial base partner systems where the DOD has blocked access to some domains, services, and networked enterprise logistics systems.

b. DLT Permissions

In contrast with the public, permissionless ledgers such as those used by Bitcoin, permissioned (private) ledgers restrict transparency by disclosing ledger participants who are known to each other and subject to approval from other members. Permissioned DLT may be most suitable for collaboration throughout the DOD industrial base, acquisition, and logistics participants. Permissioned ledgers suffer fewer energy costs since they may be planned and managed. Furthermore, they do not require "Proof of Work" (Gunashekar & McGarr, 2017). Permissioned, private ledgers have transactional rules making potential malpractice visible in the blockchain's cryptographic audit trail between network participants with commercial and legal relationships. Private, permissioned ledgers are also quicker and more scalable, given the smaller number of identifiable participants. One may more easily modify permissioned ledgers to suit business needs with changes to the blockchain layer and applications built on top of it (Office for Product Safety & Standards, 2020).

c. Blockchain Supply Chain

Numerous potential benefits of blockchain technology lend to tracing products. U.S. law and acquisition regulations are very keen on avoiding supply chain risks, as pointed out in Defense Federal Acquisition Regulations (FAR) 252.239-7018 "Supply Chain Risk" and FAR 52.222-50 "Combating Trafficking in Persons." Given the weapon system acquisition pipeline's particular sensitivity to ensuring the origin of all supplies and services, blockchain advantages are an excellent solution if adopted throughout suppliers under unilateral, government-wide contract clauses (i.e., government regulatory or statutory actions). In 2022, the Defense Contract Management Agency received a report from Lockheed Martin's F-35 subcontractor informing them that a fifth-tier subcontractor used alloy sourced from the People's Republic of China, violating U.S. law and acquisition regulations. DOD found the part in every F-35, and an investigation ensued (Capaccio, 2022). The British government's Department for Business, Energy & Industrial Strategy published a report detailing the use of DLT/blockchain technology to verify the provenance of goods. The British report emphasized how blockchain application in supply chain shows particular promise and offers benefits including: "increased trust, transparency, and accountability between disparate entities in complex supply chains; real-time tracking and monitoring of products; immutable audit trails, full transaction history; proof of certification, identity, authenticity, or compliance; process automation through smart contracts; and ultimately, improved product safety and standards" (Office for Product Safety & Standards, 2020, p. 6). Blockchain must couple with other technologies such as seals, tags, and sensors to mitigate incorrect inputs and maximize supply chain data quality. In a 2017 survey of 408 organizations from 64 countries, 69% did not have complete visibility of their supply chain, 65% experienced one or more supply chain disruptions per year, and only 37% used technology to analyze, track, or monitor potential supply chain issues with the most widely used software being Microsoft Excel. Siloed, non-interoperable, and fragmented data across supply chain participants create technological barriers to sharing and transparency between partners. Attempts to defragment data through centralized aggregation create data integrity risks from collusion, data tampering, and cyber-attacks such as the 2017 NotPetya ransomware attack that cost Maersk $300 million

(Office for Product Safety & Standards, 2020). So, while consolidating information creates risks, aggregating supply chain data is necessary for improved collaboration, and this is where DLT mitigates cyber security risks upon connecting business system networks.

The importance of blockchain is its decentralized nature, allowing for trust in an increasingly trustless cyber domain. Intellectual property concerns and data protection are now more paramount than ever. While DOD supply chain participants must agree upon DLT standards, the technology is an opportunity to create trust and end-to-end visibility from the OEM to warfighting customers. With an effectively designed 4IR IDE across blockchain networks, the permissioned DLT could share any inventory, distribution, demand, usage, or maintenance data to all members in a trusted environment without worry of electronic spillage. "Blockchain technology safeguards the integrity of the data without the need of a central authority… [and] allows companies to participate in a network while protecting their commercial interests by retaining control over who accesses their data" (Office for Product Safety & Standards, 2020, p. 21).

In the context of supply chains, Blockchain offers limitless potential sharing of electronic records and data in a secure, traceable, auditable peer-to-peer network. Decentralized networks are less prone to crashing or hacking. All blockchain network members maintain block ledgers, which prevent fraud and make manipulation detectable. Network members keep the information as blocks connected with timestamps and cryptographic hash values while validating access and legitimacy through consensus protocols. Tracking technologies such as Radio Frequency Identification (RFID) and the IoT allows physical products to be integrated with the virtual blockchain network to prevent counterfeits, supply chain poisoning, and shrinkage (Kouhizadeh & Sarkis, 2018). To address the "garbage in garbage out conundrum," coupling DLT with other secure tags, seals, or sensor technologies links the physical and virtual worlds to overcome incorrect or fraudulent data inputs (Office for Product Safety & Standards, 2020, p. 28).

d. Smart Contracts

Blockchain may enable smart contracts that automatically self-execute mutual agreements to reduce administrative costs and transaction risks without the need for human involvement after coding deals onto the distributed ledger. The removal of human judgment by financial, legal, and contract professionals is possible with blockchain smart contracts (Kouhizadeh & Sarkis, 2018). "Smart contracts check the pre-determined conditions, including rules and penalties that are agreed to by parties and trigger the related action to those conditions" (Kouhizadeh & Sarkis, 2018, p. 4). Naturally, purchasing, speed, and logistics efficiency grow with fewer humans slowing decision-making processes down. Smart contracts could be crucial for the future machine-to-machine (M2M) economy (Gunashekar & McGarr, 2017). In an M2M economy, sensor data may automate the reorder of products running low in inventory and is crucial to warehouse management systems and supply chain management (Shea, 2019). With blockchain-enabled intelligent contracts, machines may automatically replenish the inventory to manufacture or refurbish a system based on its BoM and PBS specifications. Smart Contracts via Blockchain may allow contract invoices to be automatically disbursed following receiving operations of material integrated within the blockchain network through either RFID tracking, M2M, or IoT technologies. Sensor technologies, when coupled with blockchain, may add significant value to monitoring supply chain and product usage data such as temperature, humidity, power consumption, product location, hours, mileage, etc. (Office for Product Safety & Standards, 2020).

Furthermore, blockchain might automate the sharing of TDP parts information between suppliers and the government in the IDE through smart contracts. Government weapon systems' subassembly and component item data could automatically synch with the IDE through AI/ML-enabled, cloud-based, DLT-secured, SCCT networks. Then, trusted members in the permissioned DLT environment would have access to parts data essential to sustaining weapon systems while still safeguarding that information from access by other members of the DLT who do not have permission to know, such as competing suppliers.

D. ANALYSIS, TPS, AND 4IR REVIEW

The Marine Corps weapon systems analyzed showed poor accuracy and incomplete records for electronic BoM data between TDM-CATALYST, WSIT, SMU demand-based parts stocked, and technical publications. The analysis results demonstrate questionable management effectiveness for parts, standardization, SCRM, SCI, and O&S activities dependent on BoM information. Toyota has deep SCI practices that mitigate waste, partly through an understanding of BoM and computerized applications to manage inventory related to end product systems in demand or use. The Marine Corps electronic BoM data and computerized systems appear behind what Toyota's SCI and parts management capabilities were in the '90s based on Dr. Monden's study of Toyota's business practices. The Service should learn lessons from Toyota's business continuity plan in identifying essential BoM items before future disasters or pandemics strike that may disrupt supply chains. In looking at Toyota's practices, and considering an IDE, 4IR technologies such as AI/ML, Data Lakes, Edge Computing, the IoT, SCCT, and DLT should also be thoroughly studied to achieve SCI practices for weapon system acquisition.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. BOM ANALYSIS AND MANAGEMENT PRACTICES REVIEWED

The Marine Corps must improve its electronic BoM data and systems to achieve better SCI, SCRM, and general acquisition practices so that actions in the O&S phase are supportable. Toyota offers insights into commercial SCI business practices and computerized production approaches that the DOD may apply to weapon system acquisition. Additionally, standardization is necessary across the DOD to achieve collaborative partnerships that benefit industry and government Program Office participants in a 4IR IDE.

A. BOM CHALLENGES AND 4IR IDE SOLUTIONS

From the data analysis between government TDM-CATALYST and WSIT BoM parts systems, the Marine Corps is not well positioned to manage the extensive supply chains across numerous weapon systems. For the 17 systems analyzed in Appendix A, WSIT BoMs had 48,385 of 71,234 items of supply that were missing in TDM-CATALYST BoMs, making for accuracy levels of 32 percent. Appendix B shows that the end-user customers of these 17 weapon systems are ordering items of supply not found in either TDM-CATALYST or WSIT BoM electronic data. For the 17 systems analyzed, TDM-CATALYST BoM data only matched 40% of the NSNs stocked by the SMU as informed by the corresponding system's user parts demands. Similarly, the SMU's weapon system demand-based inventory for these systems only matched WSIT BoM data for 60% of items held on hand. Such gross mismanagement of weapon system BoM and PBS information makes data-informed decisions unreliable, undermines supply chain management, and negatively affects total life cycle management in the O&S phase.

In contrast with commercial manufacturers, such as Toyota, government BoM systems lack vital data, such as the quantity of each NSN needed for an overall system and wherein those items fall within a PBS. Furthermore, unlike Toyota's MRP, the Marine Corps depot-level MWS repair production schedule for systems does not extend to computer-generated parts requirement forecasts using BoM data. This gap in an MRP-like part forecasting capability is evident by the need to manually transpose parts data from publications into a Microsoft Excel list using the Georgia Tech-made "BoM Scraper." To achieve SCI and JIT logistics practices similar to Toyota and the 21st-century commercial manufacturing industry, the Marine Corps needs modernized IT systems, accurate data for all weapon systems' BoM, and PBS with quantities of child-systems, subassemblies, components, and parts. Without adopting contemporary 4IR IT solutions, the Service's logistics efforts throughout O&S actions will continue to be overburdened, suffering from wasteful practices that lend no production value, such as waiting, excess inventory, and unevenness that can cause work stoppages and production spikes. In addition, continued reliance on print-publication style documents instead of digitized BoM, PBS, and TDP information impedes accuracy, as seen in the systems analyzed. For example, Appendix C shows that 1,319 BoM items found in official Technical Publications and MDMC's BoM lists had only 818 items (62%) that matched those weapon systems' corresponding TDM-CATALYST BoM data. To compile electronic lists of weapon systems parts, logisticians should not need to resort to tools such as a "BoM scraper" made by local colleges and "webpage scraper" tools such as those used during this study.

Numerous 4IR technologies may combine to improve the management of weapon system data, depot-repair production scheduling, and life cycle sustainment during the O&S phase. AI/ML can improve supply chain forecasting. The Cloud, Edge, and IoT can connect digital logistics systems to material products in the physical world through sensors and networks. SCCTs connect business-business databases. DLT-enabled security build trust. The Service should not continue to rely on manual, human cataloging and parts management practices that have remained unsuccessful. Mismatched electronic BoM data between DOD and USMC websites reflect a lack of intragovernmental unity and synchronization. 4IR technology could link e-publications directly to supplier systems to synchronize weapon system designs and parts changes and resolve the mismatches in traditional printed technical publications and online electronic BoM data.

While 4IR technologies present new opportunities, Toyota's business practices evidence computerized approaches to SCI in the 20th century. The Marine Corps and DOD should exercise prudence in evolving modern weapon system management efforts by carefully studying and adopting the TPS's logistics manufacturing, SCI, and JIT techniques. With effective implementation of 4IR technologies, the DOD and Marine Corps might better apply conventional manufacturing practices such as those demonstrated by Toyota. Depot maintenance can gain efficiency from accurately understanding BoM parts requirements corresponding to a weapon systems PBS. Accurate parts requirements support inventory control systems to replenish material as needed and mitigate Muda (Unnecessary Effort), Mura (Unevenness), and Muri (Overburden) when repairing military weapon systems. An accurate understanding of parts needs further enables practices like Toyota's five "S" Kaizen "Improvement" principles. Through "Seiri," DOD actors may identify unneeded items and carry out "red-label" disposal projects. With "Seiton," DOD actors may optimize the organization and positioning of their inventory across Services. While humans struggle to perform inventory management actions at the scale of the DOD's collective inventories, this is where 4IR technologies, such as AI/ML, offer solutions to make constant improvements. 4IR technologies must be applied with conventional principles, such as Kaizen's "Seketsu," to constantly carry out Seiri, Seiton, and Seiso for weapon system management. Hybrid logistics must apply tried and true logistics models, such as the TPS with contemporary 4IR technologies, to optimize O&S weapon system actions.

The DOD should establish a 21st-century IDE that adopts 4IR technologies, including AI/ML, Data Lakes, SCCTs, and DLT. The IDE must blend government and industry information systems into a functioning or unified whole to provide product life cycle sustainment analytic capabilities with the latest, accurate supply chain, BoM, PBS, and TDP information related to military weapon systems. The IDE should incorporate all Program Offices, warfighting units, and contracted suppliers of weapon systems and BoM parts. The IDE should include establishing 4IR standardization across core logistics systems for all acquisition, procurement, contracting, property accounting, finance, supply, distribution, and maintenance systems. Upon achieving interservice-wide adoption of the 4IR IDE, contract suppliers must next integrate their systems. Commercial business data systems should be networked and fused directly into the IDE with SCCTs, AI/ML, and blockchain security. To embrace these contemporary technologies, governance is needed.

Do not trust the executive branch to self-govern emerging technologies such as AI/ML, cloud, and DLT, as each Service adopts an overly liberal use of U.S. Code Title 10 authorities to the detriment of unity or jointness. The Goldwater-Nichols Act of 1986 allows military Services to "Organize, Train, and Equip" subject to the authority, direction, and control of the Secretary of Defense (SECDEF) (Goldwater-Nichols Department of Defense Reorganization Act, 1986). Practically, each Service has gone in different directions with its 20th-century enterprise IT and logistics strategies. Before the Services repeat mistakes with new tools, Congress should compel governance of 21st-century solutions by introducing legislation to force the adoption of standardized 4IR technologies by DOD and its supply chain business partners. In their study for the British Standards Institution, RAND Europe aptly pointed out that "to realize the full benefits of DLT/Blockchain, it will be critical for ledgers to be able to exchange information with other ledgers and with legacy IT systems" and "there are at least dozens of fragmented DLT/Blockchain systems competing, each with their proprietary, non-interoperable standards and protocols, which raises challenges for interoperability" (Gunashekar & McGarr, 2017, p. 9). Since 4IR technologies are only solutions when they can fuse and integrate otherwise siloed data, achieving unity through legislation is paramount. New statutes are needed to overcome the natural resistance to transparency. Some actors in the supply chain may defend their opaque business models, which may cut corners or costs through unscrupulous means. Not limited to DLT/Blockchain, standards must be carefully studied in further technical detail across all collaborative 4IR technologies related to supply chain management.

Governance, standardization, and supply chain management of weapon systems parts are essential to sustain warfighting functions in the O&S acquisition phase. The DSPO chartered PSMC should take action, leveraging 4IR technologies, to better comply with the Defense Cataloging and Standardization Act and ultimately improve readiness in support of all Combatant Command forces. Establishing a mandated DOD-wide 4IR IDE should achieve horizontal integration of business practices across the military Service's disparate acquisition commands that will benefit SCI within the DOD and industry participants. Standardizing collaborative TDP, BoM, and PBS information management practices across the Services and contract industry base is an essential foundation for weapon systems logistics actions throughout the life cycle, especially in the O&S phase.

B. WHAT'S IN IT FOR INDUSTRY?

In the 4IR IDE, government and contractors stand to gain from collaborative partnerships. Either voluntarily or as compelled in acquisition legislation, OEMs' would receive never-before-seen insights into the U.S. military's daily operations to aid their production planning in exchange for participating in a government-industry IDE. Such insights would meaningfully reduce the bullwhip effect suppliers suffer from in attempting to forecast demand. Since forecasting demand is significantly vital to business, and the DOD creates numerous intermediaries between companies and their ultimate customers, transparency is of value to suppliers. Contractors today may not know how much of their product exists in DOD inventory, while parts may span across wholesale (DLA), retail-level (military Services), and user-level (unit) stocks. As a result, contractors might be uncertain of when DOD customers will take action to replenish supplies. However, if participating in a future government-contractor IDE, suppliers would smooth their production operations in anticipation of Government demand by leveraging all government inventory data in the 4IR IDE. Once the defense industrial base can see real-time usage and sense equipment operating conditions, they will be better able to plan efficient supply chain actions proactively. Rather than reacting to the bullwhip of distorted DOD demand signals, OEMs and their participating suppliers can identify demand from the point of inception worldwide. Supplier contractors would receive government demand consumption usage, distribution, supply, and maintenance data to smooth production and eliminate waste.

C. WHAT'S IN IT FOR PROGRAM OFFICES?

Should they consolidate business practices in a core group of standardized acquisition and logistics systems, Government Program Offices across the Services would benefit from insights into the extended supplier network, i.e., the defense industrial base, to better plan and manage risk. In addition, government participants would receive valuable OEM TDPs and parts information that would enable SCRM.

4IR can improve SEP by better organizing TDP and PBS information to support O&S actions. As systems of systems make for ever-increasing complexities and depth of a PBS with parent-systems and child-systems, effective BoM, PBS, and TDP management is critical for an enterprise-level understanding of parts requirements and the DOD supply chain health. A standardized government-industry-wide 4IR IDE would support a PM's parts management responsibilities "for the selection of parts during design to consider the life cycle application stresses, standardization, technology (e.g., new and aging), reliability, maintainability, supportability, life cycle cost, and diminishing manufacturing sources and material shortages" (Department of Defense [DOD], 2020d, p. 25). A 4 IR IDE would make TDP management across all portfolios standardized and simplified across the DOD. A central repository of TDP information organized with BoM and PBS information will help plan and execute downstream life cycle functions in the O&S phase. As manufacturing techniques have evolved to include Additive Manufacturing and 3D models, organizing massive parts data at the scale of the DOD's portfolio of weapon systems is not within the ability of any individual Program Office or Military Service. Furthermore, having lasting knowledge management of weapon system data will empower the government to recompete new acquisitions and weapon system upgrades. The lack of TDP information effectively shared across the enterprise increases the government's total ownership costs. Adopting 4IR IDE will extend knowledge across government departments where the government already has unlimited rights to FFF, OMIT, and item data funded 100 percent by the government (Department of Defense [DOD], 2020a).

In contrast, without a 4IR IDE, TDP information stored in isolation across varied Program Office siloes makes aggregating and sourcing data critical to O&S actions challenging. As OEMs eventually retool or move on to other projects where it may not be in their lasting business interests to maintain supply chain support for the life cycle of a weapon system, DOD may find it challenging to find a substitute, alternative part supplier for weapon system life cycle extension projects. Maintaining TDP rights and effectively managing that information in a 4IR IDE will help Program Offices to continue weapon support in the O&S phase and better adapt to changes in the business environment. Using 4IR technologies such as AI/ML to manage and organize FFF, OMIT, BoM, and PBS data within an overall IDE will further increase the tempo of logistics actions faster than human decision-makers could otherwise make suitable recommendations.

D. BOM ANALYSIS AND MANAGEMENT PRACTICES OVERVIEW

With TDM-CATALYST BoMs accuracy of only 32 percent compared to DOD WSIT BoM data sets, the Service’s independent approach to cataloging material is ineffective. Considering past precedents of the central cataloging organization in the Office of the Assistant Secretary of Defense supporting all Services, rather than each military department taking this effort on independently, one may question the wisdom of independent logistics practices given to each Service by Title 10 authorities (McGuire, 1957) (Goldwater-Nichols Department of Defense Reorganization Act, 1986). To achieve standardization, interoperability, and SCI between industry and all military departments, the DSPO PSMC should reconsider what liberties SECDEF affords each Service concerning their unique stand-alone logistics IT systems that may be unconducive to an IDE. Service’s discretion over logistics practices can always be limited since it is subject to the authority, direction, and control of the SECDEF (McGuire, 1957).

THIS PAGE INTENTIONALLY LEFT BLANK

V. CONCLUSION

Upon recognizing inaccurate, incomplete electronic BoM data for weapon systems, I offer the following findings and recommendations. Hopefully, these will achieve SCI, improved SCRM, collaboration with contract suppliers, government-wide coordination, life cycle weapon system management, and ultimately improved readiness of our Combatant Command forces' equipment in the O&S phase.

A. 4IR IDE FOR WEAPON SYSTEM SUSTAINMENT

Existing Marine Corps and DOD websites lack critical BoM data, and leveraging 4IR technologies to automate supply chain data across organizational boundaries and partner networks may improve weapon system sustainment. Such conceptual 4IR IDE networks should permeate all DOD acquisition activities, program offices, logistics units, warfighting forces, industrial base manufacturers, and contract suppliers.

1. Finding

Based on the study of the data available, the Marine Corps TDM-CATALYST system lacks standard WBS elements (Department of Defense [DOD], 2020c). TDM-CATALYST has no apparent PBS organization, items of supply component quantities, subassemblies, or tiered child-system parts data within the overarching parent-system's BoM. WSIT similarly lacks this information. Industry OEMs, such as Toyota, use computer information systems containing BoM data integrated with dealer customer demand, production plants, and parts suppliers to inform a master production schedule and forecast MRP of parts needed (Monden, 1994). From the BoM analysis in this study, significant data gaps may prevent the DOD from performing enterprise-wide SCRM, parts management, and DMSMS screening of critical items of supply across a vast portfolio of weapon systems that share common items. While Toyota was able to develop a continuity plan identifying 500 priority items for their end products that cushioned it from threats, the Marine Corps is likely incapable of effectively doing the same due to its crude BoM data (Norihiko, 2021). For the weapon systems studied herein, the Service lacks electronic, accurate, and complete BoM, PBS, and component quantity requirement data which would inform supply chain risks and priority parts identification.

2. Recommendation

Implement 4IR technologies and build a 21st-century IDE to fuse government-wide weapon system data with parts and supply chain data from industrial base partners. Use standardized 4IR technologies such as the IoT, AI/ML, DLT/Blockchain, and SCCT in the IDE to capture BoM, PBS, TDP, FFF, OMIT, and all weapon system design and sustainment data across the entire breadth and depth of supply chain contractors and program offices. Study and apply lessons learned from conventional JIT, SCI, and SCRM logistics practices as found in the TPS.

a. Internet of Things

Some parts within a weapon system's BoM should have sensors embedded that integrate with the IDE to make the DOD's IoT. Sensors should be capable of monitoring the health of cataloged items of supply to automatically inform recommended maintenance and supply replenishment orders for repair parts, components, secondary reparables, subassemblies, and overall systems. Sensors might then automatically interface with the 4IR IDE to reorder replenishment parts or notify maintenance personnel of actions required. Such an IoT would enable modernized logistics surveillance and supply chain management practices. To create a true digital twin, weapon systems, high-value, sensitive, and controlled parts must be affixed with sensors that are interoperable with the 4IR IDE. Contract manufacturers and parts suppliers should attach sensors, electronic seals, or RFID tags upon initial build. Associating electronic records in the IDE with affixed sensors' unique data by contractors at the point of manufacture for critical parts would allow for a true digital twin of physical components. Integrating virtual records with physical parts may provide blockchain-immutable audit trails with transaction histories, smart contracts with automatic reorder points, counterfeit goods detection, and mitigation of supply chain risks. CPS efforts such as this could have reasonably prevented scenarios such as the metal alloy part from the Peoples Republic of China found in F-35s (Capaccio, 2022).

b. AI/ML Applications

AI/ML-demand forecasting methods reduce the “bullwhip” effect and are valuable to mitigate over/underproduction challenges from distorted demand found upstream with OEMs and the extended supply chain of OEMs and subcontractors. AI/ML is better for distorted demand signals in the extended supply chain. Collaboration through the Internet or other technologies to coordinate decisions with various partners may tangibly benefit forecasting (Carbonneau et al., 2008).

At the earliest opportunities in the acquisition life cycle, Program Offices should ensure items of supply are cataloged in FLIS and the Technical Data Management System (e.g., TDM-CATALYST) BoM to support weapon system sustainment operations and TPS-like JIT manufacturing techniques. To that end, AI/ML can solve inaccurate BoM weapon system problems that are a barrier to effective supply chain management by wholly replacing manual government PSM cataloging practices. In the 4IR-enabled government-and-contractor-wide IDE, contractor parts management systems should directly interface with data exchanges using government FLIS standards applied. To decentralize work and mitigate duplication of effort, AI/ML can smartly reference manufacturers’ BoMs across numerous contractor systems to automatically incorporate data into the government IDE based on a weapon system’s PBS. AI/ML would keep the PBS current through iterative version refinement of system components. AI/ML management of BoM and PBS data would eliminate swivel-chair updates of government-only records that have customarily relied upon government users manually cataloging data provided in varied forms by manufacturers. Manual government cataloging practices are onerous, time-consuming, and unlikely to be kept current at the same pace of change as prime and subcontractors’ information systems. Integrating supplier’s parts data management systems with a government IDE would inherently improve the quality of the government’s understanding of its BoMs across many systems and where they may overlap. Since AI/ML solutions train on data sets, they are more effective with standardized inputs. Given the DOD’s many standards, such as FLIS, AI/ML should be adept at integrating supply chain data into a cohesive picture related to weapon systems. The NSN, a 13-digit number, is one example data attribute that AI/ML should easily be able to source and reference across government and contractor systems to fuse information.

c. DLT/Blockchain Security

The IDE should use DLT, blockchain technology, to create trust in sharing information across a standard operating environment. Where many competitors may have their data absorbed into the IDE by AI/ML, DLT security measures should help supplier participants overcome adoption concerns. Contractors will have a "fear of unfettered access to easily shareable digital information [that] remains the dominant cause of collaboration inertia" (Patsavellas et al., 2021, p. 294). Permissioned blockchain ledgers within the IDE should be explored for adoption throughout the DOD industrial base, acquisition, and logistics participants' systems to improve collaboration while balancing security and information access concerns. Safe DLT/blockchain-enabled IDE approaches should ease weapon system contractors' and suppliers' security concerns while allowing DOD to access essential BoM data directly from their systems.

d. SCCT Data Lakes

Leverage consortium, SCCT-data lake environments to improve Financial Improvement and Audit Readiness practices and account for the inventory of all DOD-owned assets, including inventory/operating materials and supplies managed by and furnished to a contractor. Such a collaborative approach to end-to-end business processes will include contractor business activities and support auditable inventory processes to account for DOD-owned assets with complete reconciliation to the financial records. Audit results will benefit from capturing government material records stored in contractor inventory systems with the location, quantity, and current condition of all unconsumed DOD-owned assets furnished to contractors. In addition, 4IR IDE legislation should improve DOD's ability to analyze contractor property management systems when accounting for the government-furnished property. Property in possession of contractors should be visible within the government-industry IDE for compliance with future FAR standards resulting from such legislation.

B. UPDATE DEFENSE CATALOGING AND STANDARDIZATION ACT TO ENABLE DOD-WIDE 4IR IDE

Congress should modernize public law to prescribe the adoption of the 4IR IDE across all military Services. Congressionally mandated technology standards and progress reports from DOD heads would bring about meaningful change, as has historically been done.

1. Finding

Congress enacted the Defense Cataloging and Standardization Act 70 years ago. Technology has radically changed since Congress and DOD made initial investments to modernize and centralize management of all DOD items of supply at the Office of the Assistant Secretary of Defense (Supply and Logistics) for the Army, Navy, Marine Corps, and Air Force (McGuire, 1957). Emerging 21st-century 4IR technology includes SCCT, AI/ML, DLT, and Cloud/Edge/IoT solutions (Patsavellas et al., 2021). Congress required biennial reports to demonstrate progress in achieving goals set in the Defense Cataloging and Standardization Act (Defense Cataloging and Standardization Act, 1952)

2. Recommendation

Legislative action is necessary to achieve horizontal SCI across the Service's many weapons system program offices. First, all military departments, including DLA, should conform to a set of IT data standards and enforce interoperability of systems through such standards as leveraged by 4IR technology. Congress should compel DOD to unify the Service's supply chain systems, cataloging AIS databases, military equipment property record books, maintenance, distribution, contracting, and invoicing systems through standardized 4IR solutions to interlink disparate DOD IT systems together. While implementing unifying data standards and accompanying DOD-wide 4IR tools would initially cause many ripples and disruptions, such horizontal integration of supply chain systems and practices would pay dividends in the long run. Standardization and unification may seem a tall feat, as the Army, Navy, Marine Corps, Air Force, and DLA are heavily invested in their legacy and current technology systems. Still, historical efforts made by Congress and DOD to modernize computer systems and parts management data systems show it to be achievable and of great significance. Just as centralizing the cataloging office within the Office of the Assistant Secretary of Defense (Supply and Logistics) was crucial in establishing a Federal Supply Catalog, achieving unified Acquisition and Logistics systems is pivotal to establishing a proper IDE. (McGuire, 1957). Unifying program office IT systems through data standards and 4IR interoperability is the first step towards making a DOD business environment where suppliers may subsequently integrate their system-to-system IT efforts. So long as hundreds of DOD program offices are allowed autonomy concerning their IT solutions, the government's business landscape will remain too fractured for any practical means of incorporating contractor systems. Effectively replicating business models across program offices through a standardized software operating system should improve situational awareness of supply chain vulnerabilities while building resilience in the civil-service and military workforce's knowledge of routine practices. Congress should require biennial reports from DOD to implement a military-department-wide 4IR IDE and eliminate redundant, service-peculiar acquisition and logistics systems.

C. EXTEND LEGISLATION TO INTEGRATE CONTRACTOR SUPPLY CHAIN SYSTEMS IN THE 4IR IDE

Upon achieving standardized intragovernmental adoption by key logistics activities, Congress should pass public law mandating an extension of the 4IR IDE across all contractor's business systems so long as they provide defense materiel items of supply for use in weapon systems. As the volume of suppliers and items of supply continues to grow, only 4IR-enabled automation and direct system-system data will keep pace with weapon system parts management needs. Weapon systems continue to grow more complex with a greater number of components and suppliers. Rather than relying on manual, rote, "swivel chair" human entry across various systems, the U.S. should implement contemporary, collaborative business systems like those used in OEMs to achieve realistic LCSPs and IPS element management.

1. Finding

In the Defense Cataloging and Standardization Act, Congress sought to involve industry best practices, cooperation, and participation in managing supply system parts. (Defense Cataloging and Standardization Act, 1952). With technology matured and the cost of computing power significantly reduced since the days of IBM 407 EAM card devices and IBM 705 magnetic tape mainframe computers, most contractors in business with the DOD today should be equipped with microprocessor-enabled computers, the internet, and cloud data lakes. As the Defense Cataloging and Standardization Act was published in 1952, before the invention of the microchip or internet, legislators at the time had only thought to incorporate industry through liaison advisory groups. Change in technology across the business environment now presents a significantly greater potential for government integration with industry participants through a contemporary supply catalog and standardization program.

2. Recommendation

Once the military departments have achieved a standardized 4IR IDE business IT environment, Congress should enact an acquisition law mandating prime contractors integrate their parts management data systems into the government 4IR IDE. Contractors would have to share data therein for all weapon systems and corresponding items of supply awarded for design and production. Contractors would be required to adopt the same data standards and 4IR technology solutions as DOD to achieve SCI. This sequential IT data integration strategy would build upon the government-wide IDE with defense industrial base suppliers. Additionally, legislation should require prime contractors to furnish and maintain subcontractors-supplied parts data for the duration of the systems in service. Extending a standardized 4IR IDE across all program offices to their countless contractors would achieve total supply chain visibility for all weapon system components. Such an extended IDE is necessary to detect material risks such as sole source parts providers who may rely on rare earth minerals mined by Chinese corporations. Without such an IDE, material risks may be siloed and unknown to senior DOD leaders or create false assumptions on the sustainment of core weapon system capabilities needed by Combatant

Commander's forces. Subcontractors may go out of business or discontinue parts with no alternative sources of supply. DMSMS problems may go unidentified until too late, and readiness could suffer in combat.

Life cycle Sustainment calls for planning for obsolescence beginning in the EMD phase, and "the [weapon system's] contract should require the design delivery data package including a complete bill of materials to support the PSM's obsolescence tracking and management responsibilities" (Defense Standardization Program Office [DSPO], 2021, p. 18). Should DOD PSMs have collaborative access to their supplier's BoM data directly using 21st-century technologies, they could smartly meet sustainment responsibilities. With the right 4IR IDE approach and standards, technology could enable the automatic acquisition of TDP across program offices and contractor systems. Rather than manually transposing supplier BoM data into government systems, 4IR technologies such as AI/ML can refer directly to a contractor's source data while surveilling global inventories for part sustainment risks. Future contracts for all weapon systems should include a mandatory clause for contractors to integrate their parts systems with the IDE. In addition, legislation with a mandatory FAR clause should require weapon system suppliers to comply with specified technical data standards and 4IR systems. Parts standards in a BoM should be universal, such as how MIL-STD-881E defines WBS standards (Department of Defense [DOD], 2020c).

D. AREAS FOR FUTURE STUDY

Should further analysis be needed on DMSMS from GIDEP, ad-hoc relational databases become necessary. Such a study to compare data sources besides WSIT, TDM-CATALYST, and SMU retail-level inventory was prohibitively tedious and not conducted as part of this research but may offer insights into answering questions on supply chain risks buried hidden across weapon systems BoM data. Should DOD realize 4IR IDE technologies, analysts could answer DMSMS and supply chain risk questions more quickly without such slow and manual Microsoft Excel analysis techniques as used for this study.

E. CALL TO ACTION

Congress or SECDEF are likely the only levels at which change will occur to bring about the "fourth industrial revolution" in DOD acquisition business practices. Without a change agent driving action from the top, far too much bureaucracy exists to realize transformation across the breadth of DOD program offices and the depth of supply chain participants. The DSPO PSMC should champion a revolutionary 4IR IDE initiative and make proposals to Congress where necessary to implement laws that bring about supplier participation. Without effective SCI across all DOD Program Offices and contract suppliers, Combatant Command forces may carry unknown risks of critical replenishment part shortages due to obsolescence and DMSMS. DOD must proactively begin SCRM practices across all weapon system component items with complete, accurate, electronic BoM and PBS information. The DOD can realize a strategic acquisition environment only by demonstrating brilliance in the basics, as shown by Toyota's computer-integrated JIT and SCI manufacturing practices. Achieving such simple logistics brilliance in this era of increased complexity and big data requires standardized 4IR IDE solutions.

THIS PAGE INTENTIONALLY LEFT BLANK

VI. SUPPLEMENTALS

Supplemental number 1 is the MDMC MWS, which I used to select weapon systems from for the analysis in this thesis. Supplementals 2 through 18 are weapon systems analyzed in Appendices A and B. Supplementals 19 through 21 are weapon systems data analyzed in Appendix C. Supplementals 19 and 20 compared weapon system Technical Publication BoM data to TDM-CATALYST BoM data. Supplemental 21 compared MDMC BoM data used for depot-repair against TDM-CATALYST BoM data.

1. Supplemental 1 of 21_MWSFY22.xlsx
2. Supplemental 2 of 21_A00317G.xlsx
3. Supplemental 3 of 21_A00327G.xlsx
4. Supplemental 4 of 21_A02577G.xlsx
5. Supplemental 5 of 21_A21797G.xlsx
6. Supplemental 6 of 21_A26007G.xlsx
7. Supplemental 7 of 21_B00667B.xlsx
8. Supplemental 8 of 21_B00717B.xlsx
9. Supplemental 9 of 21_B12987B.xlsx
10. Supplemental_10 of 21_B15837Bxlsx
11. Supplemental_11 of 21_B17857B.xlsx
12. Supplemental_12 of 21_B19227B.xlsx
13. Supplemental_13 of 21_B20857B.xlsx
14. Supplemental_14 of 21_B21277B.xlsx
15. Supplemental_15 of 21_B24837B.xlsx
16. Supplemental_16 of 21_B25667B.xlsx
17. Supplemental_17 of 21_D00037K_MTVR-2AMK23.xlsx

18. Supplemental_18 of 21_E09947M.xlsx

19. Supplemental_19 of 21_A23352B.xlsx

20. Supplemental_20 of 21_A23372B.xlsx

21. Supplemental 21 of 21_D00037K_MTVR-2AMK25.xlsx

APPENDIX A: ANALYSIS OF TDM-CATALYST VS. WSIT BOM

WSIT provided the ability to look up weapon system BoM by NSN. Only weapon systems were compared that had one unique variant identified by a WSC/WSDC to ensure data consistency and relevance. TDM-CATALYST returned multiple BoMs for parent systems and only a single variant would appear in WSIT. BoM data did not match.

System	TDM-CATALYST Items	WSIT Items	WSIT NSN in TDM	TDM Items in WSIT
A00317G 5895016285884 AN/TSQ-297(V)1 Operations Facility	BoM Items: 741 Items not in WSIT: 42	Total NSNs: 8,496 NSNs not in TDM: 7,822	1-(7,822/8,496) = 8%	1-(42/741) = 94%
Note: A00317G TDM-CATALYST BoM lists only one of two authorized HMMWV variants found in the SL-3 publication (PCN 123 114020 00); WSIT lists both and a third variant.				
A00327G 5895015928791 AN/MRQ-13(V)1 Communications System	BoM Items: 869 Items not in WSIT: 28	Total NSNs: 11,609 NSNs not in TDM: 10,770	1-(10,770/11,609) = 7%	1-(28/869) = 97%
Note: A00327G TDM-CATALYST BoM does not even list any of the HMMWV variants found in the SL-3 publication excerpt (PCN 123 120410 00); WSIT lists all three.				
A02577G 7010015524617 AN/MSQ-145 C2 System Section Leader Vehicle	BoM Items: 421 Items not in WSIT: 2	Total NSNs: 5,297 NSNs not in TDM: 4,878	1-(4,878/5,297) = 8%	1-(2/421) = 99%
A21797G 5895015602957 AN/TRC-170A(V)5 Radio Terminal Set	BoM Items: 2,757 Items not in WSIT: 18	Total NSNs: 12,124 NSNs not in TDM: 9,385	1-(9,385/12,124) = 23%	1-(18/2,757) = 99%
A26007G 5895016128832 AN/MSQ-143A(V)1 Tactical Command System, Composite Tracking Network (CTN)	BoM Items: 504 Items not in WSIT: 10	Total NSNs: 9,562 NSNs not in TDM: 9,068	1-(9,068/9,562) = 6%	1-(10/504) = 98%
B00667B 3510015498384 Containerized Batch Laundry	BoM Items: 276 Items not in WSIT: 7	Total NSNs: 381 NSNs not in TDM: 113	1-(113/381) = 70%	1-(7/276) = 97%
B00717B 4610015728283 Lightweight Water Purification System	BoM Items: 2 Items not in WSIT: 0	Total NSNs: 1,046 NSNs not in TDM: 1,044	1-(1,044/1,046) = 0.2%	1-(0/2) = 100%
B12987B 1055012035883 Launcher, Mine Clearance MK 155	BoM Items: 240 Items not in WSIT: 12	Total NSNs: 559 NSNs not in TDM: 332	1-(332/552) = 41%	1-(12/240) = 95%
B15837B 4320015889165	BoM Items: 192 Items not in WSIT: 0	Total NSNs: 908 NSNs not in TDM: 716	1-(716/908) = 21%	1-(0/192) = 100%

System	TDM-CATALYST Items	WSIT Items	WSIT NSN in TDM	TDM Items in WSIT
Centrifugal Fuel Pump, 600GPM				
B17857B 3895014538573 Self Propelled Vibratory Compactor	BoM Items: 1,610 Items not in WSIT: 3	Total NSNs: 2,504 NSNs not in TDM: 894	1-(894/2,504) = 64%	1-(3/1,610) = 99%
B19227B 3805015507164 Wheeled Tractor-Scraper, Model 621G	BoM Items: 3,300 Items not in WSIT: 0	Total NSNs: 3,388 NSNs not in TDM: 88	1-(88/3,300) = 97%	1-(0/3,300) = 100%
B20857B 5430012404578 Fuel Storage Tank Module (SIXCON)	BoM Items: 57 Items not in WSIT: 0	Total NSNs: 57 NSNs not in TDM: 0	1-(0/57) = 100%	1-(0/57) = 100%
B21277B 3830015867713 Rotary Sweeper Vehicle	BoM Items: 2,907 Items not in WSIT: 18	Total NSNs: 3,530 NSNs not in TDM: 623	1-(623/3,530) = 82%	1-(18/2,907) = 99%
B24837B 3805015574003 Backhoe Loader, Model 420E IT	BM Items: 2,519 Items not in WSIT: 0	Total NSNs: 4,172 NSNs not in TDM: 1,653	1-(1,653/4,172) = 60%	1-(0/2,519) = 100%
B25667B 3930016051984 Light Capability, Rough Terrain Forklift, RT-022	BoM Items: 1,777 Items not in WSIT: 2	Total NSNs: 1,809 NSNs not in TDM: 34	1-(34/1,809) = 98%	1-(2/1,777) = 99%
D00037K 2320015305676 Truck, Cargo, 7 Ton, Armored, AMK23/AMK23A1	BoM Items: 4,709 Items not in WSIT: 0	Total NSNs: 5,641 NSNs not in TDM: 932	1-(932/5,641) = 83%	1-(0/4,709) = 100%
E09947M Machine Gun, Grenade 1010014909697	BoM Items: 118 Items not in WSIT: 0	Total NSNs: 151 NSNs not in TDM: 33	1-(33/151) = 78%	1-(0/118) = 100%
17 Total Systems Analyzed from FY22 MWS	22,999 TDM-CATALYST Items 142 Items not in WSIT under respective BoMs	71,234 WSIT Items 48,385 Items not in TDM-CATALYST under respective BoMs	32% of WSIT NSNs found in respective TDM BoMs 1-(48,385/71,234)	99% of TDM Items found in respective WSIT BoMs 1-(142/22,999)

APPENDIX B: ANALYSIS OF MARINE CORPS RETAIL-LEVEL STOCKS VS. WSIT AND TDM-CATALYST BOMS

The Marine Corps retail-level inventory held at the SMU were compared against WSIT and TDM-CATALYST BoM data. Decisions to stock retail-level inventory items of supply by the Marine Corps are informed by a local BoM database of parts ordered by customers corresponding to Table of Authorized Material Control Number weapon systems. The local SMU database afforded the ability to reconcile real world inventory, based on customer demand versus the TDM-CATALYST and WSIT BoM data for matching weapon systems. BoM reconciliation yielded poor matches between data sets.

System	SMU Stocks	TDM-CATALYST Items	WSIT Items	SMU NSNs in TDM	SMU NSNs in WSIT
A00317G 5895016285884 AN/TSQ-297(V)1 Operations Facility	43 Items Stocked	BoM Items: 741 SMU NSNs not in TDM: 32	BoM NSNs: 8,496 SMU NSNs not in WSIT: 15	1-(32/43) = 26%	1-(15/43) = 65%
A00327G 5895015928791 AN/MRQ-13(V)1 Communications System	138 Items Stocked	BoM Items: 869 SMU NSNs not in TDM: 107	BoM NSNs: 11,609 SMU NSNs not in WSIT: 41	1-(107/138) = 22%	1-(41/138) = 70%
A02577G 7010015524617 AN/MSQ-145 C2 System Section Leader Vehicle	47 Items Stocked	BoM Items: 421 SMU NSNs not in TDM: 41	BoM NSNs: 5,297 SMU NSNs not in WSIT: 9	1-(41/47) = 13%	1-(9/47) = 81%
A21797G 5895015602957 AN/TRC-170A(V)5 Radio Terminal Set	78 Items Stocked	BoM Items: 2,757 SMU NSNs not in TDM: 75	BoM NSNs: 12,124 SMU NSNs not in WSIT: 11	1-(75/78) = 4%	1-(11/78) = 86%
A26007G 5895016128832 AN/MSQ-143A(V)1 Tactical Command System, Composite Tracking Network (CTN)	35 Items Stocked	BoM Items: 504 SMU NSNs not in TDM: 25	BoM NSNs: 9,562 SMU NSNs not in WSIT: 9	1-(25/35) = 29%	1-(9/35) = 74%
B00667B 3510015498384 Containerized Batch Laundry	27 Items Stocked	BoM Items: 276 SMU NSNs not in TDM: 24	BoM NSNs: 381 SMU NSNs not in WSIT: 21	1-(24/27) = 11%	1-(21/27) = 78%
B00717B 4610015728283	51 Items Stocked	BoM Items: 2 SMU NSNs not in TDM: 51	BoM NSNs: 1,046	1-(51/51) = 0%	1-(51/51) = 0%

System	SMU Stocks	TDM-CATALYST Items	WSIT Items	SMU NSNs in TDM	SMU NSNs in WSIT
Lightweight Water Purification System			SMU NSNs not in WSIT: 51		
B12987B 1055012035883 Launcher, Mine Clearance MK 155	46 Items Stocked	BoM Items: 240 SMU NSNs not in TDM: 43	BoM NSNs: 559 SMU NSNs not in WSIT: 18	1-(43/46) = 7%	1-(18/46) = 61%
B15837B 4320015889165 Centrifugal Fuel Pump, 600GPM	86 Items Stocked	BoM Items: 192 SMU NSNs not in TDM: 82	BoM NSNs: 908 SMU NSNs not in WSIT: 74	1-(82/86) = 5%	1-(74/86) = 14%
B17857B 3895014538573 Self Propelled Vibratory Compactor	23 Items Stocked	BoM Items: 1,610 SMU NSNs not in TDM: 10	BoM NSNs: 2,504 SMU NSNs not in WSIT: 9	1-(10/23) = 57%	1-(9/23) = 61%
B19227B 3805015507164 Wheeled Tractor-Scraper, Model 621G	30 Items Stocked	BoM Items: 3,300 SMU NSNs not in TDM: 15	BoM NSNs: 3,388 SMU NSNs not in WSIT: 15	1-(15/30) = 50%	1-(15/30) = 50%
B20857B 5430012404578 Fuel Storage Tank Module (SIXCON)	53 Items Stocked	BoM Items: 57 SMU NSNs not in TDM: 46	BoM NSNs: 57 SMU NSNs not in WSIT: 46	1-(46/53) = 13%	1-(46/53) = 13%
B21277B 3830015867713 Rotary Sweeper Vehicle	8 Items Stocked	BoM Items: 2,907 SMU NSNs not in TDM: 3	BoM NSNs: 3,530 SMU NSNs not in WSIT: 2	1-(3/8) = 37%	1-(2/8) = 75%
B24837B 3805015574003 Backhoe Loader, Model 420E IT	35 Items Stocked	BoM Items: 2,519 SMU NSNs not in TDM: 22	BoM NSNs: 4,172 SMU NSNs not in WSIT: 22	1-(22/35) = 37%	1-(22/35) = 37%
B25667B 3930016051984 Light Capability, Rough Terrain Forklift, RT-022	65 Items Stocked	BoM Items: 1,777 SMU NSNs not in TDM: 43	BoM NSNs: 1,809 SMU NSNs not in WSIT: 43	1-(43/65) = 34%	1-(43/65) = 34%
D00037K 2320015305676 Truck, Cargo, 7 Ton, Armored, AMK23/AMK23A1	1,124 Items Stocked	BoM Items: 4,709 SMU NSNs not in TDM: 360	BoM NSNs: 5,641 SMU NSNs not in WSIT: 320	1-(360/1,120) = 68%	1-(320/1,120) = 72%
E09947M Machine Gun, Grenade 1010014909697	126 Items Stocked	BoM Items: 118 SMU NSNs not in TDM: 110	BoM NSNs: 151 SMU NSNs not in WSIT: 109	1-(110/126) = 13%	1-(109/126) = 13%
17 Total Systems Analyzed from FY22 MWS		22,999 TDM-CATALYST Items	71,234 WSIT Items 48,385 Items not in TDM-	32% of WSIT NSNs found in respective TDM BoMs	99% of TDM Items found in respective WSIT BoMs

System	SMU Stocks	TDM-CATALYST Items	WSIT Items	SMU NSNs in TDM	SMU NSNs in WSIT
		142 Items not in WSIT under respective BOMs	CATALYST under respective BOMs	1-(48,385/71,234)	1-(142/22,999)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX C: ANALYSIS OF TDM-CATALYST VS. TECHNICAL PUBLICATIONS

Two of the below systems, the Electronic Maintenance Shelters, were used to compare BoM data found on TDM-CATALYST versus soft-copy technical publication documents found on the sister-website TDM-PUBLICATION. The third system, an MTVR, was selected to compare TDM-CATALYST BoM data versus MDMC's BoM list used for depot repair of that exact vehicle. The BoM accuracy matches between data sets was poor.

System	TDM-CATALYST Items	Tech Pub Items	BoM Matches TDM-CATALYST
A23352B 10' Electronic Maintenance Complex 5441-01-304-6122 5411-01-623-1897	Total BOM NSNs 350 IDN 09272A: 96 IDN 0972B: 277	TM 09272b-14/1 Total NSNs: 277 NSNs not in TDM: 24	1-(24/277) = 86%
		SL-4-08998A Total NSNs: 136 NSNs not in TDM: 123	1-(123/136) = 9%
		TM 5411–14 Total NSNs: 166 NSNs not in TDM: 153	1-(153/166) = 7%
A23352B Roll-Up		Total Distinct NSNs: 499 Tech Pub NSNs not in TDM: 245	1-(245/499) = 51%
A23372B 20' Electronic Maintenance Complex Shelter 5411-01-305-7366 5411-01-623-1898	Total BOM NSNs 402 IDN 09281A: 152 IDN 09281B: 402	TM 09281B-14-1 Total NSNs: 296 NSNs not in TDM: 59	1-(59/296) = 80%
		SL-4-09902A Total NSNs: 184 NSNs not in TDM: 165	1-(165/184) = 10%
		SL-3-09281A Total NSNs: 9 NSNs not in TDM: 6	1-(6/15) = 60%
A23372B Roll-Up		Total Distinct NSNs: 477 Tech Pub NSNs not in TDM: 227	1-(227/477) = 52%
D00037K MTVR-2AMK25 2320-01-530-5677	Total BOM NSNs IDN 10629D: 4,137	MTVR MDMC BOM Master Usable Code 9D NSNs: 343 MDMC BOM NSNs not in TDM: 29	1-(29/343) = 92%

System	TDM-CATALYST Items	Tech Pub Items	BoM Matches TDM-CATALYST
3 Total Systems Analyzed from FY22 MWS	4,889 TDM-CATALYST Items	1,319 Tech Pub Items 501 Items not in TDM-CATALYST under respective BOMs	62% of WSIT NSNs found in respective TDM BOMs 1-(501/1,319)

LIST OF REFERENCES

Allie, C. (2023, March 21). *NVIDIA hopper GPUs expand reach as demand for AI grows*. NVIDIA Newsroom. http://nvidianews.nvidia.com/news/nvidia-hopper-gpus-expand-reach-as-demand-for-ai-grows

Bruce, D. (n.d.). *Telematics and the internet of things to better manage your fleet*. Knowledgenile. Retrieved March 26, 2023, from https://www.knowledgenile.com/blogs/telematics-and-the-internet-of-things-to-better-manage-your-fleet/

Capaccio, A. (2022, September 8). F-35 deliveries halted over a chinese alloy, pentagon says. *Bloomberg.Com*. https://www.bloomberg.com/news/articles/2022-09-07/f-35-deliveries-halted-over-use-of-chinese-alloy-pentagon-says-l7rsjt36

Carbonneau, R., Laframboise, K., & Vahidov, R. (2008). Application of machine learning techniques for supply chain demand forecasting. *European Journal of Operational Research*, *184*(3), 1140–1154. https://doi.org/10.1016/j.ejor.2006.12.004

Core logistics capabilities, 10 U.S.C § § 2464.

Creative Safety Supply. (n.d.). *Kanban training and research*. Creative Safety Supply. Retrieved September 27, 2021, from https://www.creativesafetysupply.com/articles/kanban/

Cruz, F. (2022, August 12). *The IBM 407 accounting machine*. http://www.columbia.edu/cu/computinghistory/407.html

Defense Acquisition University [DAU]. (n.d.-a). *DAU acquipedia: Product support manager*. Retrieved March 25, 2023, from https://www.dau.edu/acquipedia/pages/ArticleContent.aspx?itemid=389

Defense Acquisition University [DAU]. (n.d.-b). *Provisioning*. Retrieved August 22, 2021, from https://www.dau.edu/acquipedia/pages/articledetails.aspx#!382

Defense Cataloging and Standardization Act of 1952, Pub. L. No. 82–436, 10 U.S.C. (1952). https://www.govinfo.gov/content/pkg/STATUTE-66/pdf/STATUTE-66-Pg318.pdf

Defense Standardization Program Office [DSPO]. (n.d.). *Parts standardization and management committee*. Retrieved January 24, 2022, from https://www.dla.mil/Land-and-Maritime/Offers/Services/TechnicalSupport/DocStandDiv/PartsMgmtPgrm/PartsStdMgmtComm/#dmsms

Defense Standardization Program Office [DSPO]. (2013). *Parts management guide* (SD-19). https://www.dla.mil/Portals/104/Documents/LandAndMaritime/V/VA/PSMC/Documents/LM_SD19FINAL_151030.pdf

Defense Standardization Program Office [DSPO]. (2021). *Diminishing manufacturing sources and material shortages: A guidebook of best practices for implementing a robust DMSMS management program* (SD-22). https://www.dau.edu/tools/Lists/DAUTools/Attachments/139/Diminishing-Manufacturing-Sources-and-Material-Shortages-(DMSMS)-Guidebook-(SD-22).pdf

Department of Defense. (n.d.). *Defense acquisition guidebook* [DAG]. Retrieved August 21, 2021, from https://www.dau.edu/tools/dag

Department of Defense. (2015). *Parts management* (MIL-STD-3018). Department of Defense.

Department of Defense. (2019). *Product support manager guidebook*.

Department of Defense. (2020a). *Configuration management guidance* (MIL-HDBK-61B).

Department of Defense. (2020b). *Major capability acquisition* (DoDI 5000.85). Office of the Under Secretary of Defense for Acquisition and Sustainment.

Department of Defense. (2020c). *Work breakdown structures for defense materiel items* (MIL-STD-881E). Department of Defense.

Department of Defense. (2020d). *Engineering of defense systems* (DoDI 5000.88). Department of Defense. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500088p.PDF

Department of Defense. (2021). *Weapon System Impact Tool* [Data set]. Weapon System Impact Tool. https://wsit.xsb.com/start.do

DFARS 252.227-7013 Rights in technical data—Other than commercial products and commercial services. (2023, March 22). https://www.acquisition.gov/dfars/252.227-7013-rights-technical-data%E2%80%94other-commercial-products-and-commercial-services.

Erboz, G., Hüseyinoglu, I., & Szegedi, Z. (2021). The partial mediating role of supply chain integration between Industry 4.0 and supply chain performance. *Supply Chain Management: An International Journal*, 538–559. https://doi.org/10.1108/SCM-09-2020-0485

Goldwater-Nichols Department of Defense Reorganization Act of 1986, Pub. L. No. 99–433, 10 U.S.C. (1986). http://www.congress.gov/

Gunashekar, S., & McGarr, T. (2017). *Distributed ledger technologies/blockchain: Challenges, opportunities and the prospects for standards*. RAND Europe.

International Business Machines. (n.d.). *What is industry 4.0 and how does it work?* Retrieved January 16, 2023, from https://www.ibm.com/topics/industry-4-0

International Business Machines. (2003, January 23). *IBM archives: 705 data processing system* [TS200]. https://www.ibm.com/ibm/history/exhibits/mainframe/ mainframe_PP705.html

International Business Machines. (2021a, December 7). *Supply chain intelligence suite*. https://www.ibm.com/products/supply-chain-intelligence-suite/control-tower

International Business Machines. (2021b, December 7). *Supply chain intelligence suite: Blockchain transparent supply*. https://www.ibm.com/products/supply-chain-intelligence-suite/blockchain-transparent-supply

Kanban Tool. (n.d.). *History of kanban*. Retrieved September 27, 2021, from https://kanbantool.com/kanban-guide/kanban-history

Kimmons, S. (2019, March 15). *Soldiers learn cutting-edge features on first shipment of JLTVs*. Www.Army.Mil. https://www.army.mil/article/217823/ soldiers_learn_cutting_edge_features_on_first_shipment_of_jltvs

Kouhizadeh, M., & Sarkis, J. (2018). Blockchain practices, potentials, and perspectives in greening supply chains. *MDPI*.

Life-cycle management and product support, Pub. L. No. 111–84, 10 U.S.C. https://uscode.house.gov/view.xhtml?req=granuleid:USC-2012-title10-section2337&num=0&edition=2012

McGuire, P. (1957). *Ninth report to Congress of the DOD in accordance with section 8 of the Defense Cataloging and Standardization Act of 1952*. https://books.google.co.jp/ books?id=jFWk2f7fdoQC&printsec=frontcover&hl=ja&source=gbs_ge_summar y_r&cad=0#v=onepage&q&f=false

Microsoft (Director). (2023, February 8). *Introducing your copilot for the web: AI-powered Bing and Microsoft Edge*. https://www.youtube.com/ watch?v=rOeRWRJ16yY

Monden, Y. (1994). *Toyota production system: An integrated approach to just-in-time* (2nd ed.). Chpman & Hall.

Monrat, A., & Anderson, K. (2019). A survey of blockchain from the perspectives of applications, challenges, and opportunities. *IEEE Access*.

Norihiko, S. (2021, March 9). How Toyota thrives when the chips are down. *Reuters*. https://www.reuters.com/article/us-japan-fukushima-anniversary-toyota-in-idUSKBN2B1005

Office for Product Safety & Standards. (2020). *The use of distributed ledgers to verify the provenance of goods*. Department for Business, Energy & Industrial Strategy. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/923608/use-distributed-ledgers-verify-provenance-goods.pdf

Patsavellas, J., Kaur, R., & Salonitis, K. (2021). Supply chain control towers: Technology push or market pull—An assessment tool. *IET Collaborative Intelligent Manufacturing*, *3*(3), 290–302. https://doi.org/10.1049/cim2.12040

Rastogi, H. (2022, May 5). *IoT in Tesla: Applications, benefits and potential risks*. https://www.analyticssteps.com/blogs/iot-tesla-applications-benefits-and-potential-risks

Rendon, R., & Snider, K. (2008). *Management of defense acquisition projects*. American Institute of Aeronautics, Inc.

Rodrigue, J.-P. (2017, November 26). *The geography of transport systems*. https://transportgeography.org/contents/chapter7/freight-transportation-value-chains/corporation-expansion/

Serbu, J. (2020, March 11). *Navy turns to machine learning to help spot supply chain gaps*. Federal News Network. https://federalnewsnetwork.com/navy/2020/03/navy-turns-to-machine-learning-to-help-spot-supply-chain-gaps/

Shea, S. (2019, August). *Machine-to-machine*. IoT Agenda. https://www.techtarget.com/iotagenda/definition/machine-to-machine-M2M

Taheri, J., & Deng, S. (2020). *Edge computing models, technologies and applications*. The Institution of Engineering and Technology,.

Toyota. (n.d.). *Toyota production system*. Toyota Motor Corporation Official Global website. Retrieved September 27, 2021, from https://global.toyota/en/company/vision-and-philosophy/production-system/index.html

Toyota. (2018, July 23). *Toyota lean management and 5S*. Toyota Material Handling. https://www.toyotaforklift.com/blog/toyota-lean-management-and-5s

U.S. Marine Corps. (n.d.). *Marine Corps Systems Command*. Retrieved March 25, 2023, from https://www.marcorsyscom.marines.mil/

U.S. Marine Corps. (2021). *TDM-CATALYST* [Data set]. TDM-CATALYST. https://app.mcboss.usmc.mil/suite/

Work Breakdown Structures for Defense Materiel Items. (2020). Department of Defense. http://everyspec.com/MIL-STD/MIL-STD-0800-0899/download.php?spec=MIL-STD-881E.056929.pdf

Zagan, E., & Danubianu, M. (2021). *Cloud data lake: The new trend of data storage*. International Congress on Human-Computer Interaction. https://doi.org/10.1109/HORA52670.2021.9461293

Acquisition Research Program
Naval Postgraduate School
555 Dyer Road, Ingersoll Hall
Monterey, CA 93943

www.acquisitionresearch.net