NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

APPLICATION OF AN ONTOLOGY-DRIVEN FRAMEWORK TO A MARINE CORPS ACQUISITION PROGRAM

by

Raymond J. Stone

June 2023

Thesis Advisor:	Warren Vaneman
Second Reader:	Ronald R. Carlson

THIS PAGE INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE				*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.				
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2023	**3. REPORT TYPE AND DATES COVERED** Master's thesis		
4. TITLE AND SUBTITLE APPLICATION OF AN ONTOLOGY-DRIVEN FRAMEWORK TO A MARINE CORPS ACQUISITION PROGRAM				**5. FUNDING NUMBERS**
6. AUTHOR(S) Raymond J. Stone				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000				**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A				**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.				**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

System development involves the integration of different data types and modeling tools that were developed independently to address specific engineering challenges. These tools use different modeling languages, data formats, structures, and processes to represent data related to the system model. Currently, data exchange and combination are not possible due to the absence of adequate exchange standards. However, the Department of Defense Digital Engineering Strategy set goals to enable data exchange and usage. In 2022, Vaneman, Carlson, White, and Stone developed the Marine Corps Land Domain (MCLD) Ontology and conceptual data model (CDM) to facilitate this data exchange. This research evaluated the MCLD Ontology and CDM to determine their completeness. The data contained in the acquisition documentation was extracted and mapped to the entities defined in the MCLD Ontology. The research confirmed that MCLD Ontology and CDM could fully decompose the entire MCLD and identified several benefits, including containing critical acquisition details in one location, identifying the authoritative source of truth for each data element, and providing real-time status for all stakeholders. The MCLD Ontology and CDM can be used by all services on any type of acquisition program, from large ACAT I systems entering the acquisition process to small ACAT III programs that are close to the end of their program lifecycle.

14. SUBJECT TERMS ontology, conceptual data model, CDM, model-based systems engineering, framework, acquisition category, ACAT			**15. NUMBER OF PAGES** 111
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

THIS PAGE INTENTIONALLY LEFT BLANK

Approved for public release. Distribution is unlimited.

APPLICATION OF AN ONTOLOGY-DRIVEN FRAMEWORK TO A MARINE CORPS ACQUISITION PROGRAM

Raymond J. Stone
Civilian, Department of the Navy
BS, SUNY College of Environmental Science & Forestry, 1998

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS ENGINEERING MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
June 2023

Approved by: Warren Vaneman
Advisor

Ronald R. Carlson
Second Reader

Oleg A. Yakimenko
Chair, Department of Systems Engineering

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

System development involves the integration of different data types and modeling tools that were developed independently to address specific engineering challenges. These tools use different modeling languages, data formats, structures, and processes to represent data related to the system model. Currently, data exchange and combination are not possible due to the absence of adequate exchange standards. However, the Department of Defense Digital Engineering Strategy set goals to enable data exchange and usage. In 2022, Vaneman, Carlson, White, and Stone developed the Marine Corps Land Domain (MCLD) Ontology and conceptual data model (CDM) to facilitate this data exchange. This research evaluated the MCLD Ontology and CDM to determine their completeness. The data contained in the acquisition documentation was extracted and mapped to the entities defined in the MCLD Ontology. The research confirmed that MCLD Ontology and CDM could fully decompose the entire MCLD and identified several benefits, including containing critical acquisition details in one location, identifying the authoritative source of truth for each data element, and providing real-time status for all stakeholders. The MCLD Ontology and CDM can be used by all services on any type of acquisition program, from large ACAT I systems entering the acquisition process to small ACAT III programs that are close to the end of their program lifecycle.

THIS PAGE INTENTIONALLY LEFT BLANK

TABLE OF CONTENTS

LIST OF FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

LIST OF ACRONYMS AND ABBREVIATIONS

ACAT	acquisition category
AS	acquisition strategy
CD&I	Combat Development and Integration
CDD	capability development document
CDM	conceptual data model
CLB	combat logistics battalion
CPG	Commandant's Planning Guidance
DOD	Department of Defense
DON	Department of the Navy
EABO	expeditionary advanced base operations
EO-IR	electro-optical-infrared
EW	electronic warfare
FD2030	United States Marine Corps Force Design 2030
FoS	family of systems
GBAD	ground based air defense
GPS	global positioning system
HSI	human system integration
INCOSE	International Council on Systems Engineering
ISR	intelligence, surveillance, and reconnaissance
JCA	joint capabilities areas document
JLTV	Joint Light Tactical Vehicle
KPP	key performance parameter
KSA	knowledge, skills, and abilities

LAAB	littoral anti-air battalion
LCES	Logistics Combat Element Systems
LCSP	life cycle sustainment plan
LML	Lifecycle Modeling Language
MADIS	Marine Corps Air Defense Integrated System
MBSE	model-based system engineering
MCAS	Marine Corps Air Station
MCLD	Marine Corps Land Domain
MCSC	Marine Corps Systems Command
METL	mission essentials task list
MLR	marine littoral regiment
MOA	memorandum of agreement
MOE	measure of effectiveness
MOP	measure of performance
MOU	memorandum of understanding
OEM	original equipment manufacturer
PEO LS	program executive office land systems
RMP	risk management plan
RR/T	radar receiver and transmitter
SAR	selected acquisition report
SEP	systems engineering plan
SoS	system of systems
SPS	systems performance specification
TEMP	test evaluation master plan

TPM	technical performance measures
TTA	target tracking algorithm
TTP	tactics, techniques, and procedures
USMC	United States Marine Corps

THIS PAGE INTENTIONALLY LEFT BLANK

EXECUTIVE SUMMARY

Modern system development is a complex process requiring the integration of various data types, which were developed by using several different modeling tools. These digital tools were developed independently to address specific engineering challenges during system development. The digital tools use various modeling languages, data format and structure, and modeling processes and rules to represent thematic data related to the system model (Vaneman et al. 2022). In a model-based system engineering (MBSE) environment, this data should be combined to form a comprehensive virtual representation of the system in a model form. Currently, that exchange and combination of data are not possible, partly because adequate data exchange standards need to be defined. However, the exchange and usage of this data are stated goals in both the *Department of Defense Digital Engineering Strategy* (Department of Defense 2018) and the *United States Navy and Marine Corps Digital Engineering Transformation Strategy* (Department of the Navy 2020).

The research team, led by Vaneman, Carlson, White and Stone (2022), developed the Marine Corps Land Domain (MCLD) Ontology and conceptual data model (CDM) to facilitate this data exchange. They were presented in the technical report, *Developing an MBSE Land Domain Construct for Marine Corps Systems Command* (Vaneman et al. 2022).

While the MCLD Ontology and CDM appear to be promising, questions remain about how Marine Corps Systems Command (MCSC) programs would benefit from utilizing these tools. This research evaluated the recently developed MCLD Ontology and CDM against a MCSC program and *Force Design 2030* (FD2030) to determine the completeness of the MCLD Ontology and CDM. This research addressed the following specific questions:

- Did the MCLD Ontology and CDM accurately and completely represent the MCSC program?

- What program insights emerged that would not otherwise be gleaned when using the MCLD Ontology and CDM?
- How did the MCLD Ontology and CDM help demonstrate the alignment of the MCSC program to FD2030?
- How can the MCLD Ontology and CDM be used to correlate data between different models and modeling tools used by the MCSC program office?

An analysis of United States Marine Corps (USMC) specific artifacts and documentation was completed to ensure they were authoritative, current, relevant, and related to the system of interest. The pertinent data contained in the documentation was extracted, using the definitions provided in the artifacts. Subsequently, the data was mapped to the Data Type entities defined in the MCLD Ontology and CDM.

The research confirmed that the MCLD Ontology and CDM could be used to fully decompose the entire MCLD. The decomposition that was completed on one single capability would need to occur on every mission associated with the MCLD. Additionally, the research revealed several benefits that MCSC program offices would experience, using the MCLD Ontology and CDM: all the critical acquisition details would be contained in the system model rather than in multiple acquisition documents housed in various locations; the overarching guidance that led to the development of the system would be easily identifiable and accessible to all stakeholders. The MCLD Ontology and CDM clearly depicts the "authoritative source of truth" for each data element; consequently, the acquisition professional would know which organization is responsible for the data element. Finally, the system model would contain real-time status for every aspect of an acquisition program accessible to all stakeholders.

References

Department of Defense. 2018. *Department of Defense Digital Engineering Strategy.* Washington, DC: Office of the Deputy Assistant Secretary of Defense for Systems Engineering. https://ac.cto.mil/wp-content/uploads/2019/06/2018-Digital-Engineering-Strategy_Approved_PrintVersion.pdf.

Department of the Navy. 2020. *United States Navy and Marine Corps Digital Engineering Transformation Strategy*. Washington, DC: Department of the Navy. https://go.usa.gov/xfQpx.

Vaneman, Warren K., Ron. R. Carlson, Corina White, and Raymond J. Stone. 2022. *Developing an MBSE Land Domain Construct for Marine Corps Systems Command*. Report No. NPS-SE-22-004. Monterey, CA: Naval Postgraduate School, https://apps.dtic.mil/sti/pdfs/AD1184547.pdf

THIS PAGE INTENTIONALLY LEFT BLANK

ACKNOWLEDGMENTS

I would like to express my deepest gratitude to my advisor, Dr. Warren K. Vaneman, for his time, advice, patience, and encouragement throughout this process. I am deeply appreciative of my second reader, Professor Ronald R. Carlson, for his valuable insight and comments.

I am grateful to have served as a student researcher for the NPS NRP research team, including Dr. Vaneman, Professor Carlson, and Lecturer Corina White. I learned an incredible amount in the five months we worked together on the project.

I want to express my sincere gratitude to Wally Owens, Kristin Giammarco, and Heather Hahn, who supported me throughout this academic adventure and were able to knock down any barrier that stood in my way. I am also thankful for the staff members in the Graduate Writing Center. I benefitted greatly from their professional advice and support.

Lastly, I would like to recognize the support from my family, especially my wife, Kirsten. She encouraged me every day with her faithful camaraderie, her generous gift of time and talent, and her constant belief in my ability to undertake this valuable endeavor.

THIS PAGE INTENTIONALLY LEFT BLANK

I. INTRODUCTION

A. BACKGROUND

Model-based systems engineering (MBSE) has yet to be universally adopted, partially due to the complex nature of Department of Defense (DOD) acquisition management. MBSE has evolved at a different rate than DOD's system complexity. Systems engineering plays a crucial role during the early stages of the program life cycle. However, once a system has been fielded, the focus shifts from design and development to sustainment efforts. Unfortunately, this transition prevents the program office from fully taking advantage of MBSE's comprehensive approach, which provides a real-time virtual model of the system to help provide program leadership with greater situational awareness to promote better decision-making.

Marine Corps Systems Command (MCSC) is transitioning from a traditional document-based systems engineering environment to an MBSE environment (Vaneman et al. 2022). The Department of the Navy (DON) tasked the USMC to define an MBSE environment for the land domain, which requires a mission-oriented system design and development approach (Vaneman et al. 2022). This will necessitate adopting a System of Systems (SoS) perspective among several Marine Corps Commands to ensure the completeness of the system model created for the land domain. Additionally, the DON has tasked other entities to model specific domains that encompass all systems and activities within Naval Warfare (Vaneman et al. 2022). The ultimate goal of this modeling initiative is to provide decision-makers with more comprehensive insights to facilitate better programmatic decisions regarding systems development and to increase integration throughout the Naval Warfare domain.

B. MBSE MINDSET

To fully benefit from the potential of MBSE, the systems engineering community must adopt a new mindset (Vaneman 2019). This shift in mindset required for MBSE involves recognizing the model as the core element of the system development process, rather than seeing it as a byproduct of traditional engineering documentation (Vaneman

2019). This shift in focus encourages better model development and usage, which can result in better decision-making (Vaneman 2019).

In other words, with MBSE, the model is seen as the primary deliverable, rather than documents or other traditional artifacts (Vaneman 2019). This allows the model to be more flexible and dynamic, enabling it to be updated and refined throughout the system development process. By prioritizing the model, MBSE can help ensure that all stakeholders have a shared understanding of the system being developed and can make informed decisions based on the model's information (Vaneman 2019).

Vaneman (2022) presents the "multi-dimensional" polyhedron, which portrays multiple viewpoints from all stakeholders, each offering unique details from their respective vantage points (6). The polyhedron is shown in Figure 1. The program management viewpoint, for instance, provides information related to cost, schedule, and performance, while the maintenance viewpoint offers insights into the maintenance strategy and personnel requirements needed to maintain and sustain the system, as well as train the users. Rather than sifting through numerous artifacts to uncover critical details, all necessary data will be available in a single, comprehensive model.

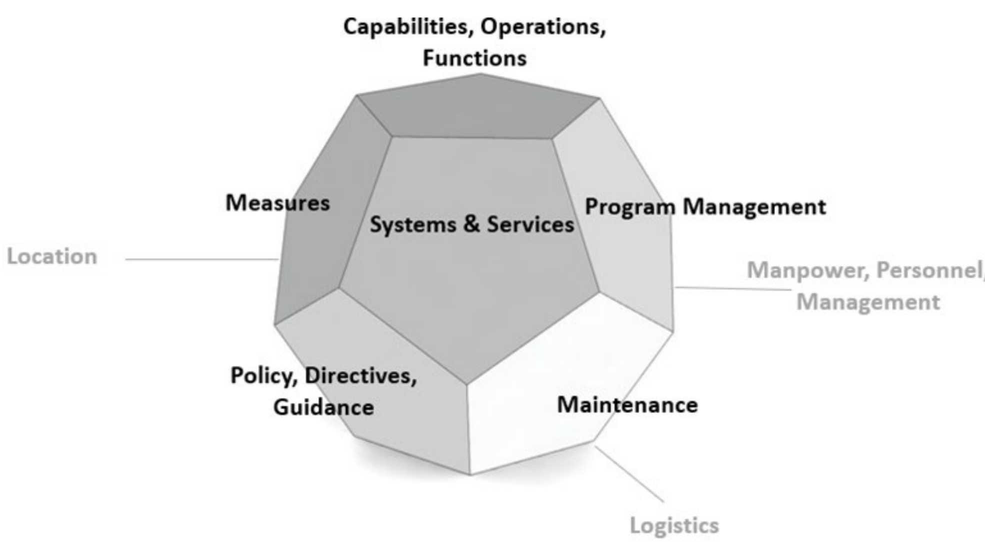


Figure 1. Ontology Dimensions. Source: Vaneman (2022).

C. INCREASING COMPLEXITY IN SYSTEMS ENGINEERING

Modern system development is a complex process requiring the integration of various data types, which were developed by using several different modeling tools. These digital tools were developed independently to address specific engineering challenges during system development. The digital tools use various modeling languages, data format and structure, and modeling processes and rules to represent thematic data related to the system model. In an MBSE environment, this data should be combined to form a comprehensive virtual representation of the system in a model form. Currently, that exchange and combination of data are not possible, partly because adequate data exchange standards need to be defined. However, the exchange and usage of this data are stated goals in both the DOD Digital Engineering Strategy (Department of Defense 2018a) and the United States Navy and Marine Corps Digital Engineering Transformation Strategy (Department of the Navy 2020).

The research team, led by Vaneman, Carlson, White and Stone (2022), developed the Marine Corps Land Domain (MCLD) Ontology and conceptual data model (CDM) to facilitate this data exchange. They were presented in a technical report, *Developing an MBSE Land Domain Construct for Marine Corps Systems Command* (Vaneman et al. 2022).

While the MCLD Ontology and CDM appear to be promising, questions remain about how MCSC programs would benefit from utilizing these tools. This thesis research evaluated how the MCLD Ontology and CDM were applied to an MCSC program. The Marine Corps Air Defense Integrated System (MADIS) was selected for this evaluation, given its prominence within United States Marine Corps *Force Design 2030* (FD2030).

D. RESEARCH QUESTIONS

This research evaluated the recently developed MCLD Ontology and CDM against an MCSC program and FD2030 to determine the completeness of the MCLD Ontology and CDM. The following specific questions this research addressed include:

- Did the MCLD Ontology and CDM accurately and completely represent the MCSC program?
- What program insights emerged that would not otherwise be gleaned when using the MCLD Ontology and CDM?
- How did the MCLD Ontology and CDM help demonstrate that the MCSC program aligns with FD2030?
- How can the MCLD Ontology and CDM be used to correlate data between different models and modeling tools used by the MCSC program office?

E. DOCUMENT LAYOUT

This chapter gave an overview of MBSE, the challenges associated with its adoption, and introduced the research questions. Chapter II presents a literature review outlining the development of MBSE and emphasizes the importance of having a comprehensive ontology and CDM. Chapter III details the research methodology used to exercise the MCLD Ontology and CDM, while Chapter IV thoroughly analyzes the results. Chapter V documents the findings, lessons learned from the study, and potential opportunities for future research.

II. LITERATURE REVIEW

A. BACKGROUND

The concept of MBSE was introduced to take advantage of technology to manage complex systems engineering problems. This literature review provides an overview of the DOD and DON strategic documents published, to promote the widespread use of MBSE throughout the DOD and the DON. The importance of these documents is presented to illuminate how the strategies tie directly to this thesis research. There are many sources that confirm the need for a comprehensive ontology and CDM to facilitate the data exchange between model entities.

B. DEPARTMENT OF DEFENSE AND DEPARTMENT OF THE NAVY STRATEGIC GUIDANCE

In 2018, the DOD published its *Digital Engineering Strategy*. This document was created to serve as a roadmap for the DOD to follow, to harness the full potential of MBSE. In 2021, the DON published the Naval *Digital Engineering Transformation Strategy*, noting five important goals.

> 1. Formalize the development, integration, and use of models.
> 2. Provide an enduring authoritative knowledge source.
> 3. Incorporate technological innovation to improve the engineering practice.
> 4. Establish the supporting infrastructure and environments for the Digital Engineering practice.
> 5. Transform the culture and workforce to adopt and support Digital Engineering across the life cycle. (Department of the Navy 2020, 6–7)

This thesis research supports the achievement of all five goals.

The MCLD Ontology and CDM support achieving Goal 1 by developing the road map that will allow data exchange from one modeling tool to the next, thereby enhancing the integration and data exchange between different models and modeling tools.

The MCLD Ontology and CDM support the achievement of Goal 2 since each element of the system model needs to contain truth from each entity in the system development process. If the model is related to capabilities the warfighter needs, the warfighter must be the source of that data. Referring to the manufacturing model, the original equipment manufacturer (OEM) must be involved since they can provide the production details required. To use the MCLD Ontology and CDM effectively, all stakeholders need to be identified upfront and need to be in constant communication with each other. The MCLD Ontology and CDM can be used to ensure that all disciplines use common terminology and definitions.

As stated in the report from Vaneman et al. (2022), the MCLD Ontology and CDM were motivated by Goal 2 in three ways.

> 1. A parsimonious ontology is defined which allows entities defined within various data dictionaries to be reduced to an "atomic level" which allows like entity classes to be defined and treated the same way regardless of modeling language, MBSE tools, or presentation frameworks.
> 2. From the ontology, the relationships between entity classes can be defined. These relationships allow for commonality – a key ingredient when exchanging data.
> 3. A numbering schema facilitates the data type, where (which level) the data resides within the system model and identifies the organization that is the authoritative source of the data. (13)

The MCLD Ontology and CDM are tied to Goal 3 by defining the terminology used throughout the project from conception to disposal. The modelers will use the common terminology defined in the Ontology to ensure the models can fit together and exchange data.

To promote the achievement of Goal 4, the MCLD Ontology and CDM were developed to support the establishment of the Digital Engineering infrastructure. The best tools can be used to solve the problem affecting that view. The MCLD Ontology and CDM can be used as a "Rosetta stone" providing a roadmap to exchange data and link various modeling tools.

The MCLD Ontology and CDM support Goal 5 by providing definitions in a clear and concise manner that professionals can understand across the system acquisition spectrum. Each model viewpoint is expressed in terms of the stakeholder's language, and the MCLD Ontology and CDM define common terminology to provide clarity to all parties involved.

C. MODEL-BASED SYSTEMS ENGINEERING

There are many different definitions of MBSE throughout the DOD and industry. A few are presented here for a brief comparison. Holt (2019) states that the definition provided by the International Council on Systems Engineering (INCOSE) is one of the most widely accepted definitions: "Model-based systems engineering (MBSE) is the formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases" (6). This definition, while widely accepted, does not encompass all aspects of a system including traditional program management aspects of a system such as cost, schedule, or risk management (Vaneman 2019). Long and Scott (2011) provide the following definition of MBSE in *A Primer for Model-Based Systems Engineering*:

> Model-based systems engineering (MBSE) is fundamentally a thought process. It provides the framework to allow the systems engineering team to be effective and consistent right from the start of any project. At the same time, it is flexible enough to allow the "thought" process to adapt to special constraints or circumstances present in the problem. (65)

This definition provides a different view of MBSE that is strictly geared toward the engineering team. The definition appears to be a promising first step, but to fully harness the potential of MBSE, it needs to be adopted across all aspects of acquisition to include all stakeholders, not just the engineering team.

Holt (2019) provides the following definition: "Model-based Systems Engineering is an approach to realizing successful systems that is driven by a model that comprises a coherent and consistent set of views that reflect multiple viewpoints of the system" (8). This definition proposed can apply to any system including, technical, management, financial, and enterprise systems (Holt 2019). This definition casts a broader net to encompass many different disciplines.

Vaneman (2019) proposed a definition of MBSE that further enhances the context of MBSE:

> Model-Based Systems Engineering (MBSE) is the formalized application of modeling (static and dynamic) to support systems design and analysis, throughout all phases of the system life cycle, through the collection of modeling languages, structure, model-based processes, and presentation frameworks used to support the discipline of systems engineering in a "model-based" or "model-driven" context. (1)

Giachetti and Vaneman (2021) provided a detailed explanation of the five elements contained in the definition:

- Modeling Languages – serve as the basis of tools and enable the development of system models. Modeling languages are based on a logical construct (visual representation) and/or an ontology (meta-model).
- Structure – defines the relationships between the system entities, establishes concordance within the model, and allows for the emergence of system behaviors and performance characterizations within the model.
- Model-Based Processes – provide the analytical framework to conduct the analysis of the system virtually defined in the model. The model-based processes may be traditional systems engineering processes such as requirements management, risk management, or analytical methods such as discrete event simulation, systems dynamics modeling, and dynamic programming.
- Presentation Framework – provides the framework for the logical constructs of the system data in visualization models that are appropriate for the given stakeholders. These visualization models typically take the form of traditional systems engineering models. These individual models are often grouped into frameworks that provide the standard views and descriptions of the models, and the standard data structure of architecture models.
- Modeling Tool – the software application the engineering team uses to generate, modify, and manage the system model. (2)

The MCLD Ontology and CDM can be used to help bridge many elements discussed in the definition. The MCLD Ontology and CDM are modeling-tool and modeling-language agnostic. The best tool can be employed to solve the specific aspect of the problem. The MCLD Ontology and CDM can help facilitate the exchange of data from one tool to another.

D. WHY AN ONTOLOGY IS NEEDED

A comprehensive ontology is needed to define the relationships between each entity in the model (Vaneman 2019). Lu et al. (2022) states, "An ontology, which supports MBSE formalisms, enables combining systems engineering processes and AI tools for enterprise knowledge management and decision making" (5467). The MCLD Ontology and CDM were developed to utilize common terminology and a single frame of reference all stakeholders can agree upon.

In the past, one approach to developing a common ontology has been to combine each program's data dictionary to create a common ontology. Unfortunately, such an approach is ineffective, partly because the same term can have multiple definitions, if not clearly articulated upfront (Vaneman 2019). The MCLD Ontology and CDM have clear definitions for all terms that will be adopted by all stakeholders.

Smith (2018) proposed several reasons for ontology failure, two of which include:

- an ontology is built for a single community/enterprise; the ontology becomes unusable when a second community joins (silo syndrome)
- the ontology is built for data we already have; as soon as data, or data formats, change, the ontology very quickly loses its value leaving no one with the incentive to maintain it (short half-life syndrome) (17)

The MCLD Ontology and CDM were designed to be adopted by the entire DOD, preventing Smith's silo syndrome. The MCLD Ontology and CDM were also designed to be used throughout the entire acquisition life cycle of a program or enterprise. New capabilities may require development of innovative technology or data. Since the MCLD Ontology and CDM were designed to accommodate development activities, Smith's short half-life syndrome does not apply.

In his video titled, *Schema and Metamodels and Ontologies, Oh My*!, Long (2020), suggested a further explanation of why the changes are needed as we move toward an MBSE environment. Traditional systems engineering has been implicit, which is manageable for humans. As we move toward automation, *implicit* needs to become *explicit* because well-defined rules must exist when employing automation. This is where an ontology would be beneficial. The terminology used in an ontology provides the ability to move from implicit to explicit. The explicit rules will allow the technology to manage highly complex problems in new and innovative ways.

E. IMPLEMENTATION CHALLENGES

The universal adoption of MBSE across the DOD is gaining traction based on the DOD strategy although there are still significant hurdles that need to be overcome. Vaneman and Carlson (2019) identified five MBSE implementation challenges.

1. a comprehensive understanding or the organization's vision and goals for the MBSE environment;
2. establishing a comprehensive model – the proverbial "single source of technical truth";
3. the governance and management of the MBSE environment;
4. establishing an infrastructure and support environment that allows for collaboration and communication across stakeholders;
5. realizing the need, and establishing a plan, for organizational culture change (1).

This research may alleviate two of the roadblocks identified. The MCLD Ontology and CDM may help identify the "single source of truth" attributed to each entity in the model. The MCLD Ontology and CDM may be used as the common language increasing communication across all stakeholders, aiding in the universal adoption of MBSE throughout the DOD.

F. SUMMARY

The literature in this chapter provided an overview of how this research directly supports each of the five goals stated in the *Naval Digital Engineering Transformation Strategy*. Several definitions of MBSE were analyzed and discussed. The need for a comprehensive ontology and CDM to facilitate the data exchange between model entities was affirmed by multiple sources. Finally, the chapter described MBSE implementation challenges that this research will alleviate.

III. METHODOLOGY

A. OVERVIEW

The purpose of this research was to evaluate the effectiveness of the MCLD Ontology and CDM. This chapter will comprehensively explain each section of the MCLD Ontology, and the seven viewpoints offered in the CDM. Additionally, it will outline the method used to populate the MCLD Ontology and CDM. A discussion of the approach used to gather and refine the data and what adjustments were necessary, based on the sensitive nature of the data, to share this research outside of the DOD. Finally, this chapter will discuss how to use the MCLD Ontology and CDM to address the research questions posed in Chapter I, to evaluate the effectiveness of the MCLD Ontology and CDM.

B. DETAILS OF THE MCLD ONTOLOGY

Chapter II introduced the three challenges of exchanging data between different model elements. Figure 2 presents these challenges.

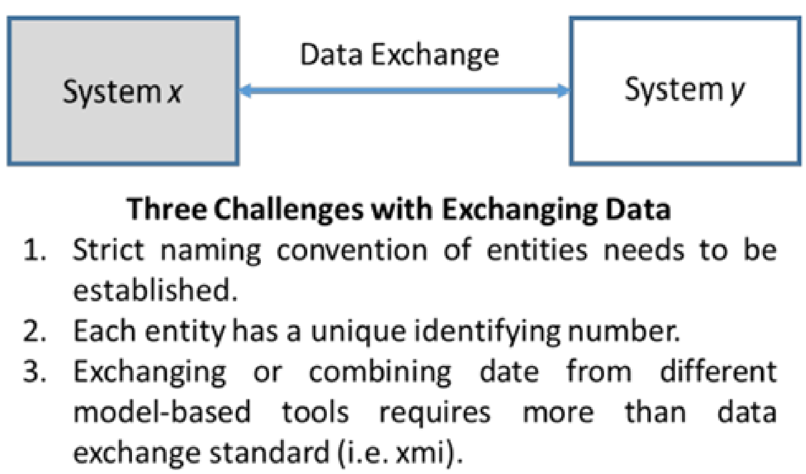


Figure 2. Data Exchange Challenges. Source: Vaneman et al. (2022).

The MCLD Ontology and CDM were developed to address the third challenge. Using a common language and terminology is necessary to communicate needs effectively in any large organization with multiple teams and programs. Thus, the MCLD Ontology and CDM were developed to facilitate use by all stakeholders, allowing them to use a common language and terminology.

The Entity Class in the MCLD Ontology is the broadest category. The definitions of each Entity Class are presented in Table 1.

Table 1. Entity Class Definitions. Source: Vaneman et al. (2022).

Entity Class	Definition
Artifact	An Artifact entity specifies a document or other source of information that is referenced by or generated in the knowledgebase.
Action	An Action entity specifies the mechanism by which inputs are transformed into outputs.
Asset	An Asset entity specifies an object, person, or organization that performs Actions, such as a system, subsystem, component, or element.
Resource	A Resource entity specifies a consumable or producible Asset (e.g., fuel, bullets, missiles, people).
Characteristic	A Characteristic entity specifies the properties of an entity (e.g., power, size, weight, role).
Measure	A Measure entity specifies properties of measurements and measuring methodologies, including metrics (e.g., Key Performance Parameter (KPP), Measure of Effectiveness (MOE), Measure of Performance (MOP), Metric).
Cost	A Cost entity specifies the outlay or expenditure (as of effort or sacrifice) made to achieve an objective associated with another entity (e.g., Earned Value, Work Breakdown Structure, Actual Cost, Planned Cost).
Location	A Location entity specifies where an entity resides.
Statement	A Statement entity specifies text referenced by the knowledgebase and is usually contained in an Artifact (e.g., Need, Goal, Objective, Assumption).
Requirement	A Requirement entity identifies a capability, characteristic, or quality factor of a system that must exist for the system to have value and utility to the user.
Risk	A Risk entity specifies the combined probability and consequence of achieving objectives (e.g., cost risk, technical risk, schedule risk).
Time	A Time entity specifies a point or period when something occurs or during which an action, asset, process, or condition exists or continues (e.g., Milestone, phase, date-time group).

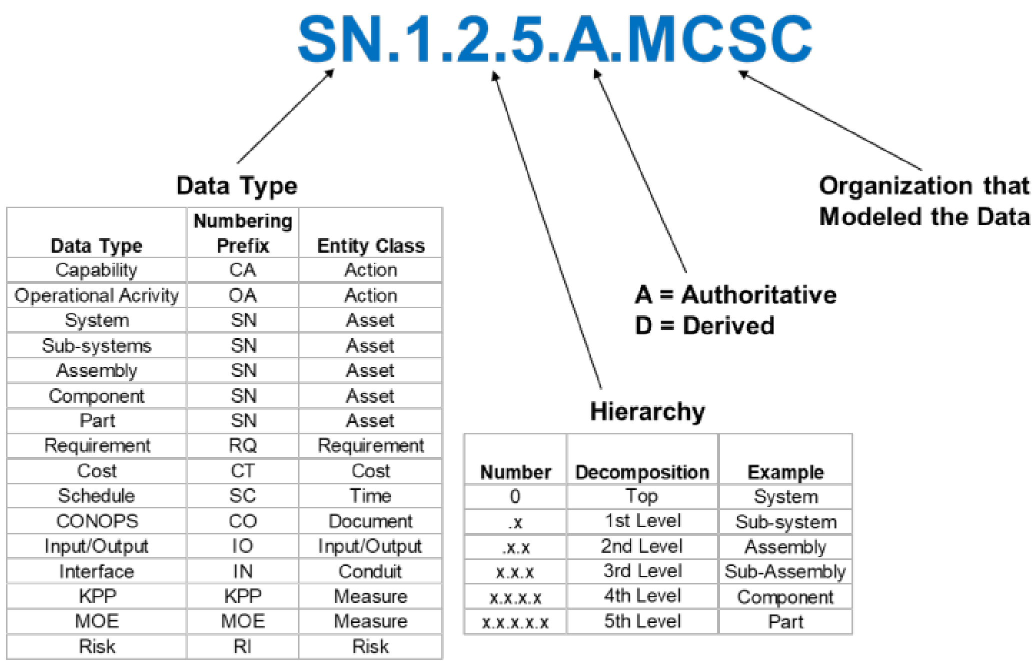
An Entity Subclass was created to divide the data into smaller categories. The Entity Subclass terms are defined in Appendix A. A further division was made to align with a program's data dictionary more closely. Therefore, the Data Type is the smallest category in the MCLD Ontology. The Data Type terms are defined in Appendix B.

The MCLD Ontology adopted a portion of the Lifecycle Modeling Language (LML) since there was an existing ontology detailing the relationships between various entities (Vaneman et al. 2022). Those relationships are summarized in Figure 3.

	Action	Artifact	Asset (Resource)	Characteristic (Measure)	Connection (Conduit, Logical)	Cost	Decision	Input/Output	Location (Orbital, Physical, Virtual)	Risk	Statement (Requirement)	Time
Action	decomposed by* related to*	references	(consumes) performed by (produces) (seizes)	specified by	-	incurs	enables results in	generates receives	located at	causes mitigates resolves	(satisfies) traced from (verifies)	occurs
Artifact	referenced by	decomposed by* related to*	referenced by	referenced by specified by	defines protocol for referenced by	incurs referenced by	enables referenced by results in	referenced by	located at	causes mitigates referenced by resolves	referenced by (satisfies) source of traced from (verifies)	occurs
Asset (Resource)	(consumed by) performs (produced by) (seized by)	references	decomposed by* orbited by* related to*	specified by	connected by	incurs	enables made responds to results in	-	located at	causes mitigates resolves	(satisfies) traced from (verifies)	occurs
Characteristic (Measure)	specifies	references specifies	specifies	decomposed by* related to* specified by*	specifies	incurs specifies	enables results in specifies	specifies	located at specifies	causes mitigates resolves specifies	(satisfies) spacifies traced from (verifies)	occurs specifies
Connection (Conduit, Logical)	-	defined protocol by references	connects to	specified by	decomposed by* joined by* related to*	incurs	enables results in	transfers	located at	causes mitigates resolves	(satisfies) traced from (verifies)	occurs
Cost	incurred by	incurred by references	incurred by	incurred by specified by	incurred by	decomposed by* related to*	enables incurred by results in	incurred by	located at	causes incurred by mitigates resolves	incurred by (satisfies) traced from (verifies)	occurs
Decision	enabled by result of	enabled by references result of	enabled by made by responded by result of	enabled by result of specified by	enabled by result of	enabled by incurs result of	decomposed by* related to*	enabled by result of	located at	causes enabled by mitigated by result of resolves	alternative enabled by traced from result of	date resolved by decision due occurs
Input/Output	generated by received by	references	-	specified by	transferred by	incurs	enables results in	decomposed by* related to*	located at	causes mitigates resolves	(satisfies) traced from (verifies)	occurs
Location (Orbital, Physical, Logical)	locates	locates	locates	locates specified by	locates	locates	locates	locates	decomposed by* related to*	locates mitigates	locates (satisfies) traced from (verifies)	occurs
Risk	caused by mitigated by resolved by	caused by mitigated by references resolved by	caused by mitigated by resolved by	caused by mitigated by resolved by specified by	caused by mitigated by resolved by	caused by incurs mitigated by resolved by	caused by enables mitigated by results in resolved by	caused by mitigated by resolved by	located at mitigated by	caused by* decomposed by* related to* resolved by*	caused by mitigated by resolved by	occurs mitigated by
Statement (Requirement)	(satisfied by) traced to (verified by)	references (satisified by) sourced by traced to (verified by)	(satisified by) traced to (verified by)	(satisified by) specified by traced to (verified by)	(satisified by) traced to (verified by)	incurs (satisified by) traced to (verified by)	alternative of enables traced to results in	(satisified by) traced to (verified by)	located at (satisfied by) traced to (verified by)	causes mitigates resolves	decomposed by* traced to* related to*	occurs (satisified by) (verified by)
Time	occurred by	occurred by	occurred by	occurred by specified by	occurred by	occurred by	date resolves decided by occurred by	occurred by	occurred by	occurred by mitigates	occurred by (satisfies) (verifies)	decomposed by* related to*

Figure 3. LML Relationship Summary. Source: Lifecycle Modeling Language Steering Committee (2022).

The Numbering Schema provides a location where the data element will reside in the model and helps determine the authoritative source of truth for each entity. Thereby helping to achieve Goal 2 from the DON *Digital Engineering Strategy*. The Numbering Schema is shown in Figure 4.



Data Type	Numbering Prefix	Entity Class
Capability	CA	Action
Operational Acrivity	OA	Action
System	SN	Asset
Sub-systems	SN	Asset
Assembly	SN	Asset
Component	SN	Asset
Part	SN	Asset
Requirement	RQ	Requirement
Cost	CT	Cost
Schedule	SC	Time
CONOPS	CO	Document
Input/Output	IO	Input/Output
Interface	IN	Conduit
KPP	KPP	Measure
MOE	MOE	Measure
Risk	RI	Risk

Number	Decomposition	Example
0	Top	System
.x	1st Level	Sub-system
.x.x	2nd Level	Assembly
x.x.x	3rd Level	Sub-Assembly
x.x.x.x	4th Level	Component
x.x.x.x.x	5th Level	Part

Figure 4. Ontology Numbering Schema. Source: Vaneman et al. (2022).

There are four elements in the numbering schema. The first element is the prefix corresponding to the data type defined in the Ontology. The second element specifies the hierarchy of where the data resides in the model. The top-level whole number is the system. This would decompose down to the *n*th level of decomposition, wherever that data resides in the model.

The third element identifies whether the data element is authoritative or derived. For example, one organization may be responsible for modeling the Systems and Services viewpoint. Modeling the Systems and Services viewpoint may require data from the Measures viewpoint. Since this data is derived, the modeling organization is not the authoritative source of the Measures data and therefore is not free to alter the data (Vaneman et al. 2022).

The fourth element highlights the organization responsible for the data. This would be the "authoritative source of truth" or "knowledge source." The responsible organization is the one that updates the data and can answer questions about the data.

Currently, the MCLD Ontology only includes the first two elements of the numbering schema. The complete MCLD Ontology, including all the categories defined previously, is shown in Table 2.

Table 2. MCLD Ontology. Adapted from Vaneman et al. (2022).

Entity Class	Entity Subclass	Data Type	Number
Artifact	**Guidance**	Strategic Objectives and Policies	STRT.x
		Directives	Dir.x
		Defense Planning Guidance	DPG.x
		Plans	PLAN.x
		Tactics, Techniques, and Procedures (TTP)	TTP.x
		Doctrine	Doc.x
		Program of Record	POR.x
	Governance	Regulations	REG.x
		Policy	POL.x
	Agreement	Memorandum of Understanding (MOU)	MOU.x
		Memorandum of Agreement (MOA)	MOA.x
	Standard	Joint Capabilities Areas Document (JCA)	JCA.x
		Mission Essential Task List (METL)	METL.x
		Required Operational Capabilities/Projected Operational Environment	ROC/POE.x
		Technical Standard	TS.x
Action	**Activity**	Operational Activity	OA.x
		Training	TRA.x
		Maintenance	MNT.X
	Capabilities	Capabilities	CA.x
	Function	Function	F.x
		System Function	SF.x
		Service Function	SVC.x
		SOA Function	SOA.x
		Test Process	TP.x
		Test and Diagnostic	TD.x
	Program	Program Activity	PM.x

Entity Class	Entity Subclass	Data Type	Number
Asset	**System**	Enterprise	ES.x
		System of Systems (SoS)	SOS.x
		Family of Systems (FoS)	FOS.x
		Platform	S.x
		System	SN.x
		Sub-System	SN.x.x
		Assembly	SN.x.x.x
		Sub-Assembly	SN.x.x.x.x
		Component	SN.x.x.x.x.x
		Hardware	SN.x.x.x.x.x.x
		Software	SW.x
	Service	Service	SER.x
Resource	**Organization**	Organization	ORG.x
	Performer	User/Person	PER.x
	Installation	Facility	FAC.x
		Property	IN.x
		Site	IN.x.x
	Logistics	Consumables	LOG.x
		Support Equipment	LSE.x
		Test and Diagnostic Equipment	TDE.x
		Training Devices and Simulators	TDS.x
	Information	Data	IN.x
Characteristic	**Condition**	Environmental State	CE.x
		Operational Condition	CC.x
		Quality of Service	CQ.x
	Skill	Skill	CS.x
Measure	**MOE**	Measures of Effectiveness (MOE)	MOE.x
	KPP	Key Performance Parameters (KPP)	KPP.x
	MOP	Measures of Performance (MOP)	MOP.x
	TPM	Technical Performance Measures (TPM)	MOP.x
Cost	**Cost**	Cost	C.x

Entity Class	Entity Subclass	Data Type	Number
Location	**Location**	Location	L.x
	Orbital	Orbital	LO.x
	Physical	Address, Geolocation	LP.x
	Virtual	IP Address	LV.x
Statement	**Guidance**	Scenario Steps	SC.x
		Mission	MI..x
	Standard	Joint Capabilities	JC.x
		Task	MT.x
Requirement	**Requirement**	Requirement	R.x
	Originating	Performance Requirement	RP.x
		Operational Requirements	RO.x
	Derived	Functional Requirements	RF.x
		System (Physical) Requirements	RS.x
		Interface Requirements	RI.x
Risk	**Risks**	Risk	R.x
Time	**Time**	Event	T.x
		Milestone	T.x
		Phasing/Evolution/Forecast	T.x

C. CONCEPTUAL DATA MODEL

The CDM visually depicts the relationships that were defined in the MCLD Ontology. Figure 5 portrays how the relationships between the entities are conveyed in the CDM. The relationships are indicated by the labeled line connecting the elements.

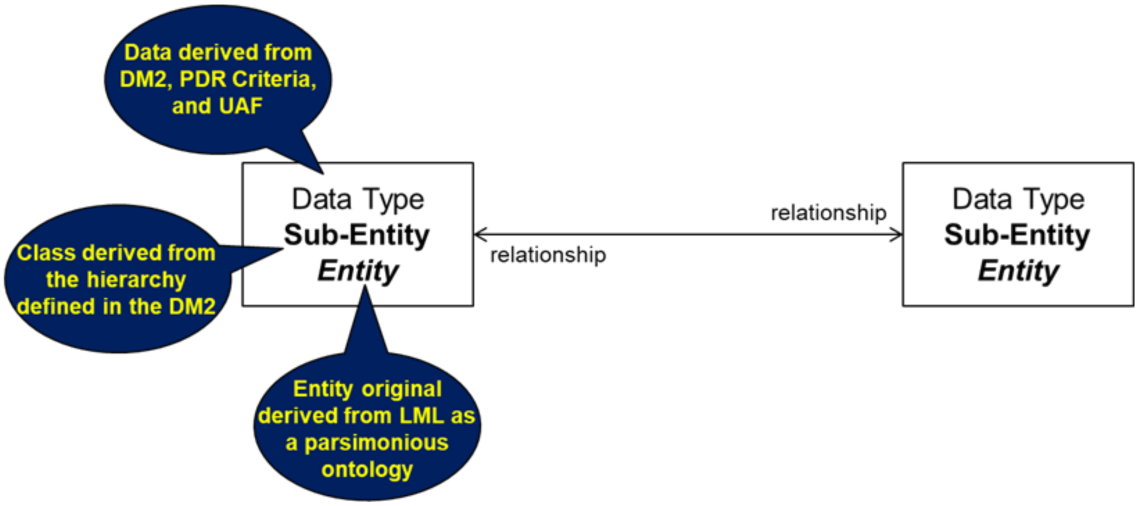


Figure 5. Conceptual Data Model Format. Source: Vaneman et al. (2022).

Although the CDM is one large and complex interwoven system model, it is divided into seven viewpoints for ease of readability and discussion. The CDM can be initialized from any viewpoint depending on where the system is in the acquisition life cycle when MBSE is adopted. Typically, traditional system acquisition programs start with the strategic guidance that outlines the mission requirements. The following sections describe each viewpoint, and an example MCSC acquisition program is mapped to the MCLD Ontology and CDM in Chapter IV.

1. Capabilities, Operations, and Requirements Viewpoint

The Capabilities, Operations, and Requirements viewpoint offers a visual representation of the system's objectives. The mission is driven by strategic guidance, which outlines the necessary capabilities. These capabilities are fulfilled by operational activities, from which system functions can be derived. The functions and activities can then be broken down into requirements to guide the system's design.

It is important to note that the same entities can appear in multiple viewpoints, as this is just a snapshot of the interconnected model. The entities enclosed in dashed boxes are introduced in a different viewpoint, while those in solid boxes are introduced in the current viewpoint (Vaneman et al. 2022). The Capabilities, Operations, and Requirements viewpoint is shown in Figure 6.

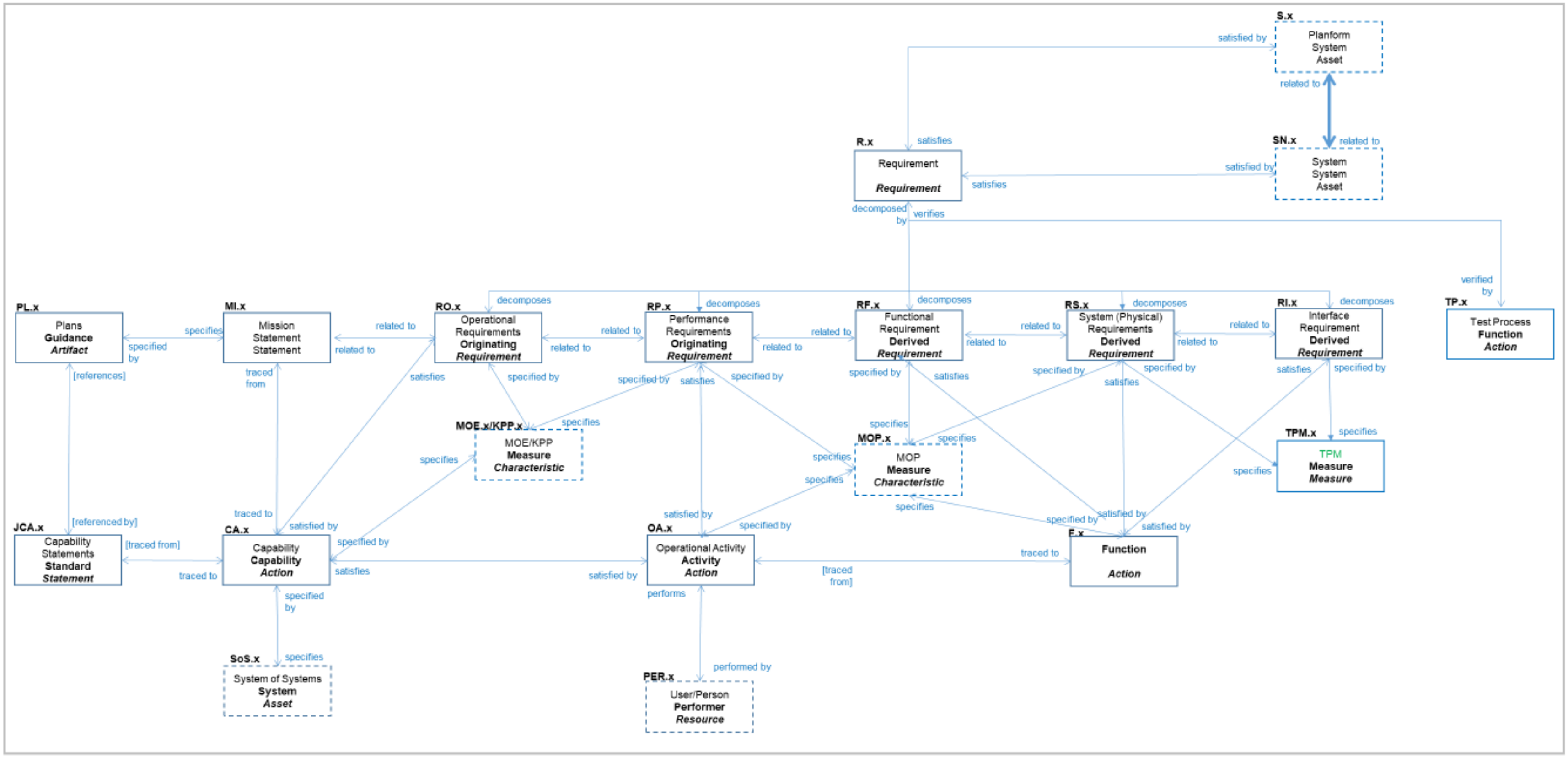


Figure 6. Capabilities, Operations, and Requirements Viewpoint. Source: Vaneman et al. (2022).

2. Systems and Services Viewpoint

The Systems and Services viewpoint is a vital viewpoint of the CDM. The Enterprise/Portfolio entity satisfies the mission and capability entities introduced in the Capabilities, Operations, and Requirements viewpoint. The Enterprise entity is related to the organization, which is related to the program activity. The Enterprise entity can be decomposed into a System of Systems or a Family of Systems, which can be further decomposed to the hardware and software components. Those hardware and software components undergo testing to verify their required functionality (Vaneman et al. 2022). The Systems and Services viewpoint is shown in Figure 7.

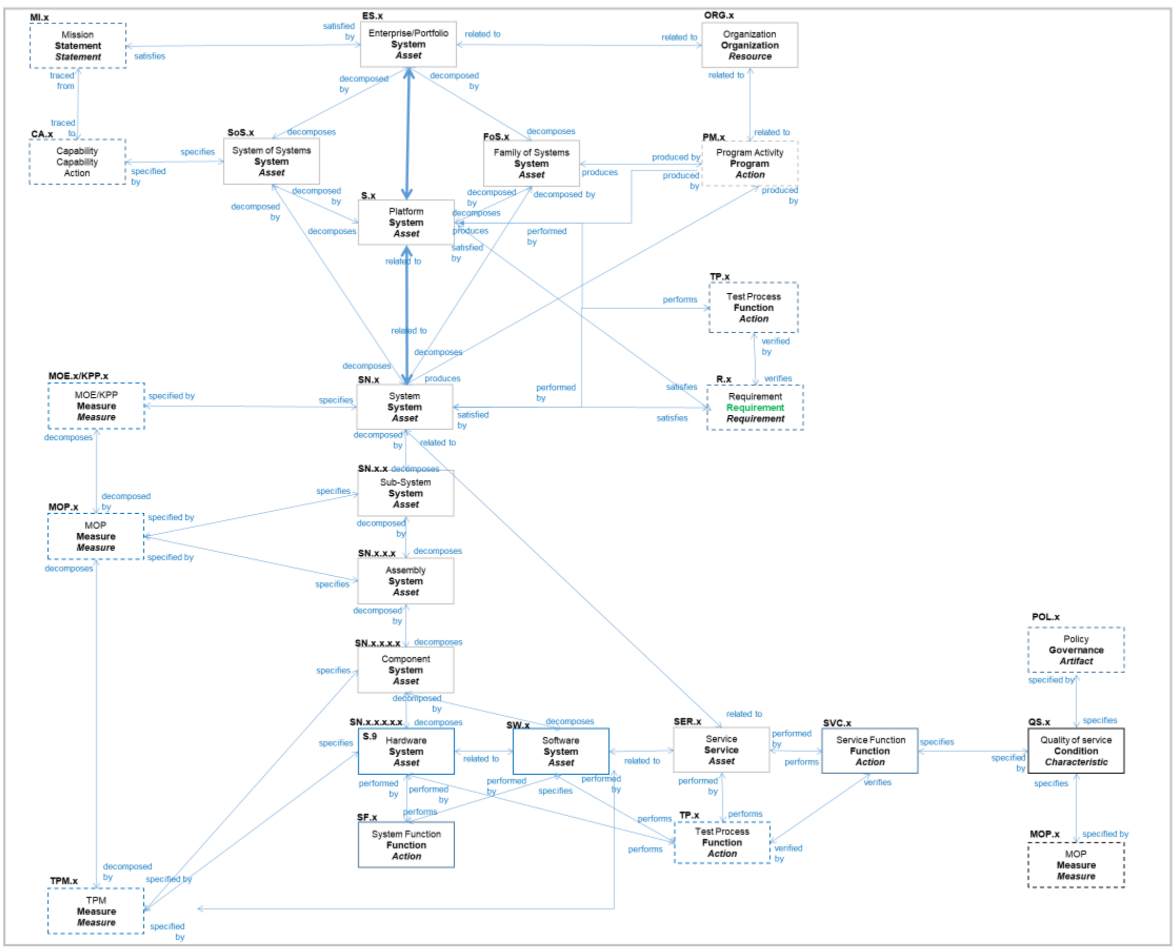


Figure 7. Systems and Services Viewpoint. Source: Vaneman et al. (2022).

3. Program Management Viewpoint

The Program Management viewpoint is associated with the program management aspect of acquisition. It offers valuable insights into the program's status by including traditional program management elements such as cost, schedule, performance, and risks (Vaneman et al. 2022). The Program Management viewpoint is shown in Figure 8.

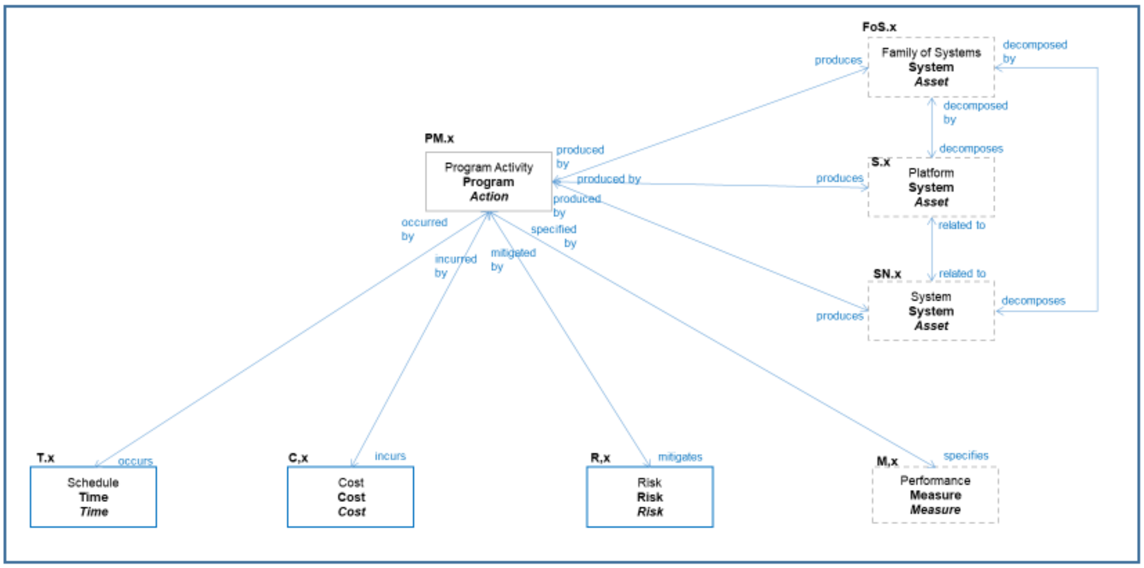


Figure 8. Program Management Viewpoint. Source: Vaneman et al. (2022).

4. Measures Viewpoint

The Measures viewpoint focuses on the measurements within the system. As the CDM represents the entire system, all measurements are included in this model. However, to maintain clarity, only three levels are depicted in this CDM. This viewpoint could contain hundreds or even thousands of measures in a complete system.

At the highest level, this viewpoint includes the high-level capabilities and operational requirements defining the Measures of Effectiveness (MOEs) and Key Performance Parameters (KPPs) that the system must meet. If the MOEs and KPPs are not achieved, the system may not fulfill the user's high-level needs, and the project may be terminated.

The second tier of measures comprises performance and functional requirements, which specify the Measure of Performance (MOP) that have been decomposed from the MOEs and KPPs. The MOP specifies what the system and the subsystem must do.

The third tier of measures includes system and interface requirements, which specify the Technical Performance Measures (TPMs) decomposed from the MOPs. The TPM specifies what the components must accomplish (Vaneman et al. 2022). The Measures viewpoint is shown in Figure 9.

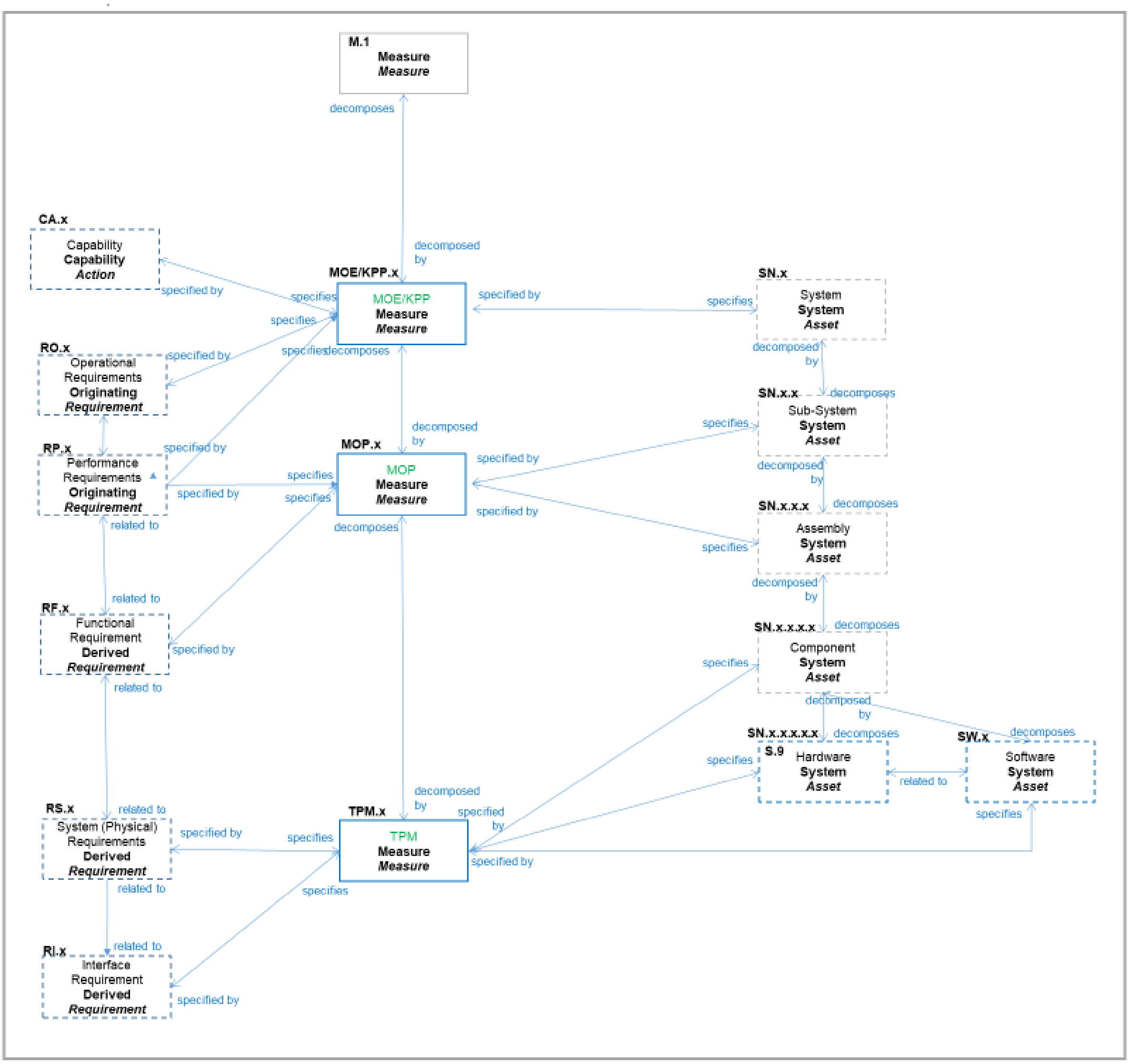


Figure 9. Measures Viewpoint. Source: Vaneman et al. (2022).

5. Maintenance and Logistics Viewpoint

The Maintenance and Logistics viewpoint emphasizes elements related to system maintenance across the life cycle. Currently, logistics planning is often separated from system design and development. The goal of MBSE is to provide a comprehensive picture of the system of interest and maintenance considerations that must be included throughout the entire life cycle of the program. This viewpoint covers not only the System of Interest but also any Support Equipment or Special Test and Diagnostic Equipment that may need to be designed (Vaneman et al. 2022). The Maintenance and Logistics viewpoint is shown in Figure 10.

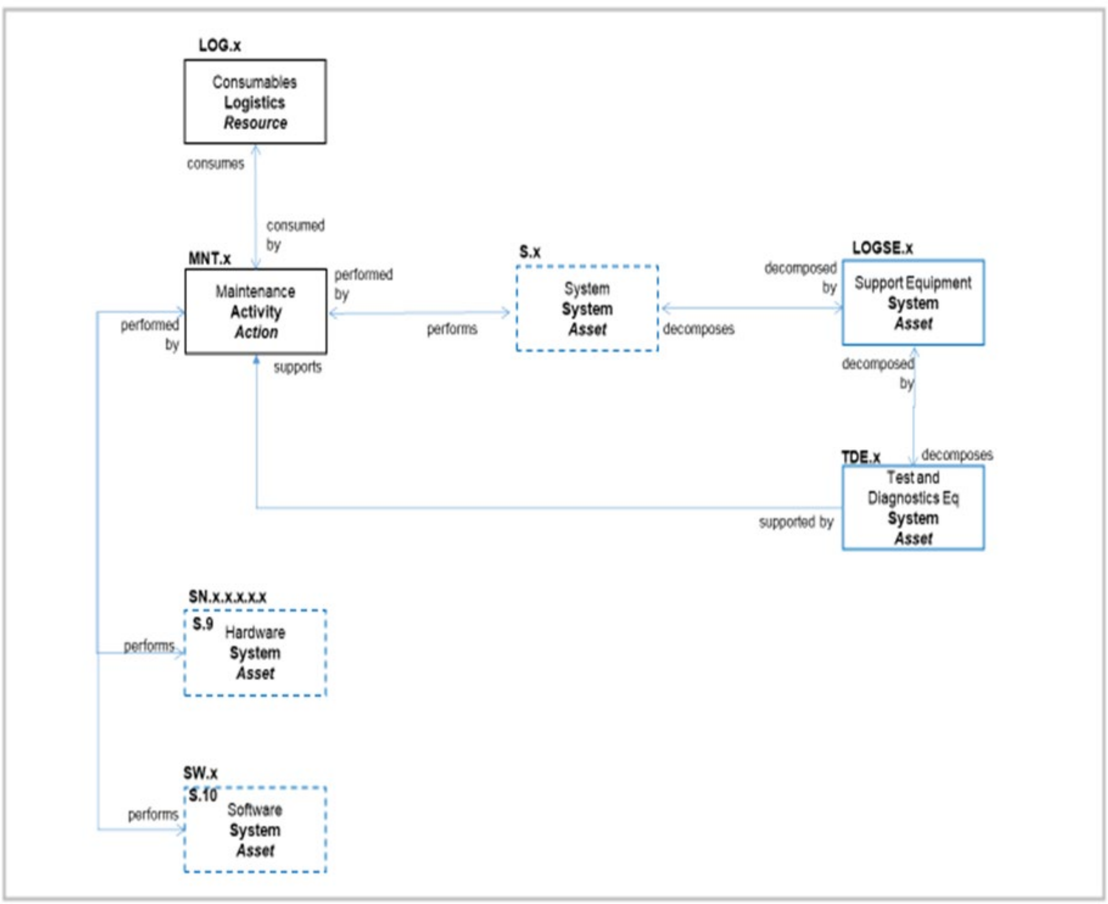


Figure 10. Maintenance and Logistics Viewpoint. Source: Vaneman et al. (2022).

6. Manpower, Personnel, and Training Viewpoint

The Manpower, Personnel, and Training viewpoint underscores the significance of incorporating Human System Integration (HSI) into the design and development phase of a project at the onset. Often, the "human" element is overlooked until the detailed design stage, resulting in time constraints that prevent the incorporation of HSI feedback into the design. This viewpoint identifies required knowledge, skills, and abilities (KSAs) for both system operators and maintainers. Additionally, it accounts for the development of training devices, simulators, and training materials (Vaneman et al. 2022). The Manpower, Personnel, and Training viewpoint is shown in Figure 11.

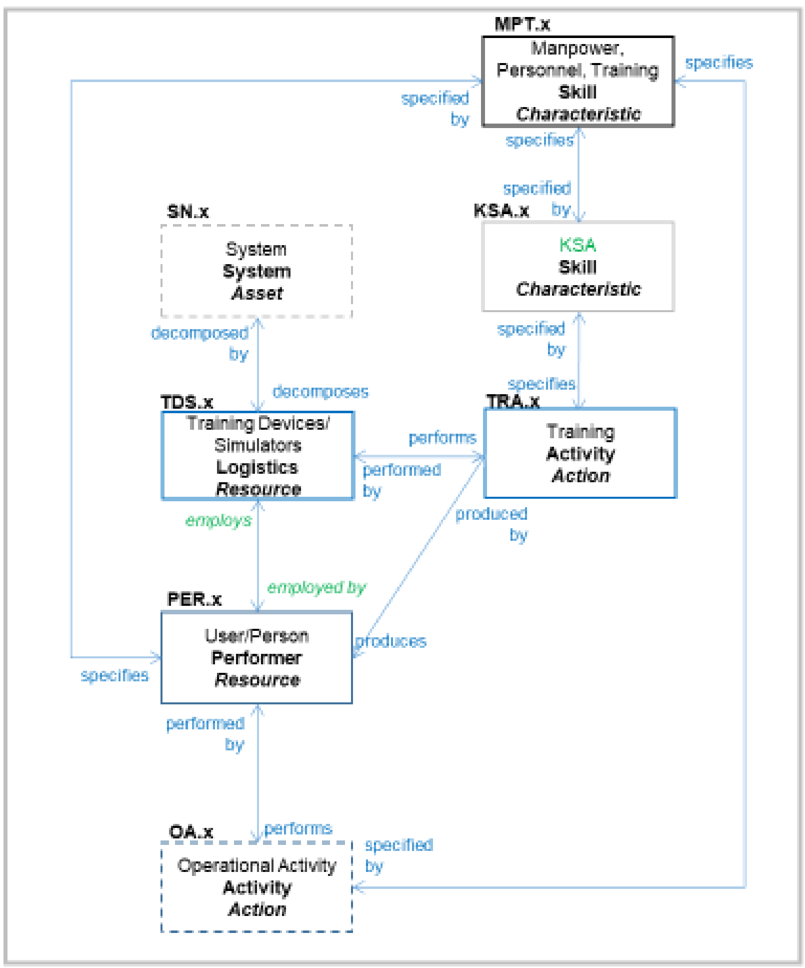


Figure 11. Manpower, Personnel, and Training Viewpoint.
Source: Vaneman et al. (2022).

7. Location Viewpoint

The Location viewpoint streamlines the initial development of a system by specifying its usage, storage, maintenance, and potential overhaul locations. This information helps identify the environmental conditions the system may face, which is crucial to its design and development. Furthermore, this viewpoint includes information about the location of the virtual data associated with the system (Vaneman et al. 2022). The Location viewpoint is shown in Figure 12.

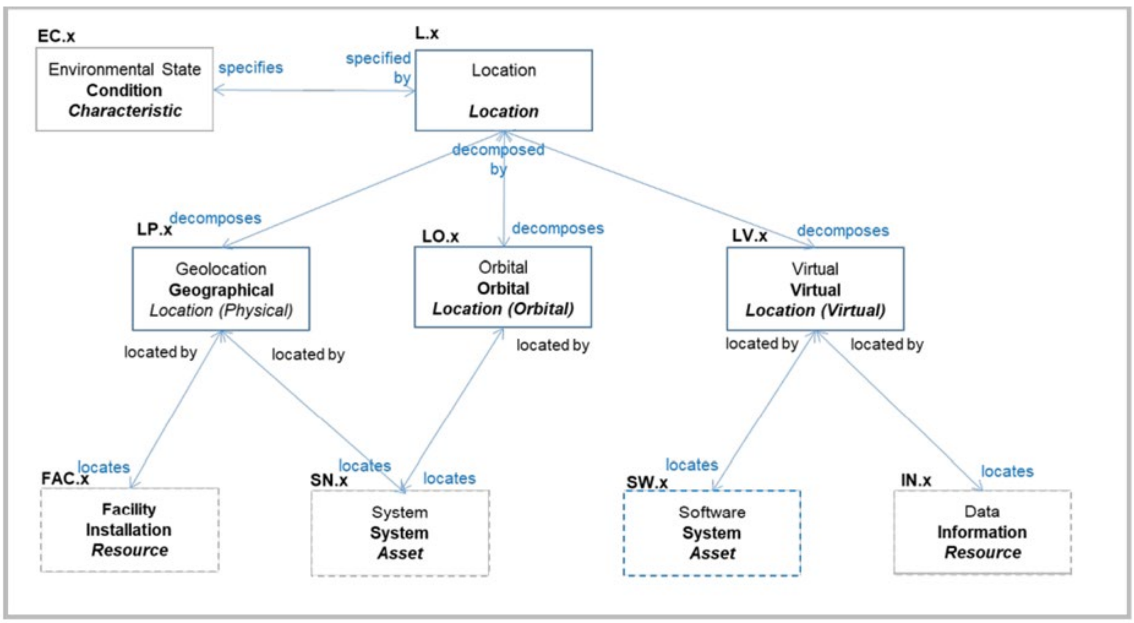


Figure 12. Location Viewpoint. Source: Vaneman et al. (2022).

D. DATA COLLECTION AND REFINEMENT

The first step in exercising the MCLD Ontology and CDM was to determine what documentation would be needed to populate the MCLD Ontology and CDM fully. To accomplish this task, a set of selection criteria was established. These criteria determined the relevant documentation required for populating the MCLD Ontology. The following is a summary of the selection criteria.

- Authoritative: The documents selected were signed and approved by the relevant body, ensuring authenticity and validity. There is no need to expend limited resources on efforts that are not fully validated or when a genuine need has not been fully articulated.

- Current: The chosen documents were carefully selected to ensure they were current and relevant. It was essential to exclude outdated, canceled, or superseded documents, especially in the current era of rapid technological advancements and changes in executive administration. An authoritative document published several years ago may no longer align with the current strategy and goals, making it irrelevant to the MCLD Ontology and CDM.

- Relevant: Only documents relevant to the system of interest were selected to ensure consistency and avoid contradictions or opposing viewpoints.

- Related: The selected documents either had a direct relationship or were cross-referenced with each other. This interrelatedness ensured that the information contained in the documents was cohesive and complemented each other, providing a complete and comprehensive understanding of the system of interest.

After the selection criteria were applied, the following acquisition documentation was requested from the MADIS program office: the acquisition strategy (AS), the capability development document (CDD), the systems performance specification (SPS), the test evaluation master plan (TEMP), the systems engineering plan (SEP), the life cycle sustainment plan (LCSP), and finally the risk management plan (RMP).

A comprehensive review of the acquisition data revealed that certain documents had distribution statements that restricted sharing results across the DOD and industry. Therefore, it was necessary to adopt a different approach to populate the MCLD Ontology and CDM fully. To ensure the unrestricted sharing of results, no actual program data was used in populating the MCLD Ontology and CDM. Instead, publicly available information was used as a representative data set to showcase the utility of the MCLD Ontology and CDM.

Two additional selection criteria were introduced during the process. Firstly, the documents selected had to be approved for public release, which means their contents could be shared in an open environment across the DOD and industry. Secondly, engineering judgment was used to derive some lower-level entities through a logical systems engineering process from higher-level guidance documents. This was necessary if the authoritative source documents were not approved for public release.

E. DATA APPLICATION

To populate the MCLD Ontology, refined documentation was utilized, and the data necessary for each data element in the MCLD Ontology was extracted. This process was carried out for all data elements. A few examples are provided in the following sections.

High-level strategic documentation was used to populate the Data Type entities in the Guidance and Governance subclass of the MCLD Ontology. The following are some examples of such documentation:

- The 2018 *National Defense Strategy* (Department of Defense 2018b) was used to populate the Strategic Objectives and Policies Data Types within the Artifact Entity Class.

- The *Commandant's Planning Guidance* (Berger 2019) was used to populate several entities, including the Directives, Defense Planning Guidance, and Plans Data Types in the Artifact Entity Class, and the Missions, Joint Capabilities, and Task Data Types found in the Statement Entity Class.

The MCLD Ontology could be populated using the acquisition documentation acquired from the program office. The following are examples of how some of the acquired documents could be used to populate the ontology:

- The AS could populate the Data Types found in the Cost, Risk, and Schedule Entity Class Elements.

- The CDD could populate the Data Types found in the Measures Entity Class, including the KPPs, MOEs, and TPMs associated with the system of interest.
- The SPS could populate the Data Types found in the Requirements Entity Class.
- The TEMP could populate the Test Process Data Type in the Action Entity Class and influence the Event or Milestone Data Type in the Time Entity.
- The SEP could populate the risk entities. The SEP may include the WBS, which could populate the Data Types found in the Asset Entity Class.
- The LCSP could populate several entities in the Logistics Subclass, including Consumables, Support Equipment, Test and Diagnostic Equipment, and Training Devices and Simulators. Additionally, it could be used to populate the Training and Maintenance Data Types within the Activity Subclass and the Test and Diagnostic Data Type found in the Function Subclass.
- The RMP could populate the entities within the Risk Entity Class.

An established DOD program designated an Acquisition Category (ACAT) I program must submit a Selected Acquisition Report (SAR) every year. The SAR could be used to populate several Data Type Entities in the Ontology, including:

- Program of Record entity in the Guidance Subclass
- Capabilities, Functions, System Function, Test Process, and Program Activity entities in the Action Entity Class
- Platform, System, and Service entities in the Asset Entity Class
- MOEs and KPPs in the Measures Entity Class
- Cost entities in the Cost Entity Class

- Risk entities in the Risk Entity Class
- Event and Milestone Entities in the Time Entity Class.

The CDM visually represents the relationships defined in the MCLD Ontology. Specifically, the data entities populated within the MCLD Ontology are visually depicted in the CDM.

F. DATA ANALYSIS

The population of the MCLD Ontology and CDM provided the framework necessary to address the research questions posed in Chapter I:

- Did the MCLD Ontology and CDM accurately and completely represent the MCSC program?
- What program insights emerged that would not otherwise be gleaned when using the MCLD Ontology and CDM?
- How did the MCLD Ontology and CDM help demonstrate the alignment of the MCSC program to FD2030?
- How can the MCLD Ontology and CDM be used to correlate data between different models and modeling tools used by the MCSC program office?

G. SUMMARY

This chapter introduced the methodology used to evaluate the effectiveness of the MCLD Ontology and CDM. Each section of the MCLD Ontology was thoroughly examined, as were the seven viewpoints offered in the CDM. Additionally, this chapter reviewed the analysis used to gather and refine the system documentation, the method used to extract the pertinent data, and how this data was used to populate the MCLD Ontology.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. APPLICATION AND ANALYSIS

A. OVERVIEW

During FY22, the MCLD Ontology and CDM were developed to share system data between different modeling languages, MBSE tools, and presentation frameworks. As stated in Chapter I, this research evaluated the MCLD Ontology and CDM. The research team, comprised of Vaneman, Carlson, White and Stone, populated and exercised the MCLD Ontology and CDM, using FD2030 as the overall principle guiding document. The first section of this chapter provides an overview of FD2030. Next, each section of the fully populated MCLD Ontology and CDM will be discussed and analyzed using the methodology defined in Chapter III. The research team presented the MCLD Ontology and CDM in the technical report, *Developing an MBSE Land Domain Construct for Marine Corps Systems Command*.

B. UNITED STATES MARINE CORPS *FORCE DESIGN 2030*

In 2020, the United States Marine Corps (USMC) published FD2030 in response to the *Commandant's Planning Guidance* published in 2020. *Force Design 2030* identified various gaps in USMC's capabilities, including "the need for long range precision fires, medium to long range air defense systems, short range air defense systems, high endurance unmanned systems with intelligence, surveillance, and reconnaissance (ISR), electronic warfare (EW), and lethal strike capabilities" (Berger 2020, 2). The redesign of FD2030 is based on a campaign of learning that allows the USMC to support updated threats and adapt to new warfighting concepts such as distributed maritime operations, littoral operations in a contested environment, expeditionary advanced base operations (EABO), stand-in forces, and reconnaissance and counter-reconnaissance (Berger 2020).

As addressed in FD2030, one of the significant changes to the force structure of the USMC is the establishment of a Marine Littoral Regiment (MLR). The MLR consists of lower-level entities, such as the Littoral Combat Team (LCT), Combat Logistics Battalion (CLB), and Littoral Anti-Air Battalion (LAAB).

The warfighting concept chosen for this research was EABO, which involves using mobile, low-visibility, persistent naval forces that can be easily maintained and sustained from "temporary locations ashore, or inshore within a contested or potentially contested maritime area" (Department of the Navy [DON] 2021, 1–3). Expeditionary advanced base operations is designed to deny the enemy control of the sea, support naval control, and sustain the fleet. Additionally, EABO is a critical part of projecting naval power and integrates with other naval campaigns (DON 2021).

Expeditionary operations involve working in challenging conditions, deploying forward, and projecting military strength (DON 2021). The reason that EABO is different from other expeditionary operations is that the forces involved must be able to persist despite enemy threats, both lethal and non-lethal (DON 2021). It is essential to carefully choose the "composition, distribution, and disposition of forces executing EABO limit the adversary's ability to target them, engage them with fires or other effects, and otherwise influence their activities" (DON 2021, 1–4).

The methodology described in Chapter III was used to decompose FD2030, using the single capability to "conduct short range ground-based air defense (GBAD)," decomposed from the EABO warfighting concept. Using this capability as a starting point, further decomposition was performed, which ultimately led to the Marine Air Defense Integrated System (MADIS) system. The MADIS system was designed to detect, track, and engage hostile forces in the area, thus fulfilling the capability of conducting short range GBAD.

C. MCLD ONTOLOGY MAPPING

The MCLD Ontology was introduced in Chapter III. The overall intent is to reduce any system to its atomic level to facilitate data exchange between different elements in the model. The Data Type element facilitated the mapping of program data to the MCLD Ontology. The following sections will provide a detailed analysis of the program data mapped to each Entity Class in the MCLD Ontology.

1. Artifacts

The Artifacts entity class elements are shown in Table 3. While Vaneman et al. (2022) described numerous data types and relationships in detail this study summarizes the key elements relevant to the current research. The *National Defense Strategy* and *Defense Planning Guidance* were both published in 2018. The 2018 *National Defense Strategy* shifted the focus from non-state actors in the Middle East to traditional peer-level competition (Vaneman et al. 2022). As a result of the *National Defense Strategy*, the USMC Commandant published his Planning Guidance in 2019 to lay out the vision of how the Marine Corps would evolve to meet the objectives. The *Commandant's Planning Guidance* (CPG) serves as the authoritative document for USMC planning (Vaneman et al. 2022).

FD2030, as mentioned earlier in the chapter, was published in 2020. The program of record selected for this research, the MADIS system, consists of two variants (Vaneman et al. 2022). The MADIS Mk1 includes several components such as a turret-launched Stinger missile, multi-functional electronic warfare capability, a direct-fire weapon, electro-optical-infrared (EO-IR) optics, and a shoulder-fired Stinger missile for dismounted operations. The MADIS Mk2 is a variant designed for counter-unmanned aerial system (C-UAS) operations and includes a multi-function electronic warfare capability, a 360-degree radar, a direct-fire weapon, EO-IR optics, and a supporting command and control communications suite.

Both the MADIS Mk1 and Mk2 are designed to work together as a complementary pair and are the basic building blocks of the LAAB GBAD capability. The MADIS Mk1 and Mk2 systems are integrated into the Joint Light Tactical Vehicle (JLTV) Platform, which provides a versatile and mobile platform for deploying these advanced defense systems in a variety of situations.

The standards used in this research are associated with the MADIS system and are directly linked to supporting the EABO mission. One such standard is the Subclass artifact that documents the tasks necessary for conducting short range GBAD. This artifact is included in the Marine Corps Task List for conducting GBAD to support semi-fixed or limited mobility critical assets within the Joint/Coalition Integrated Air Defense System.

Another standard selected for this effort is typically incorporated into systems that facilitate military data transfer (Vaneman et al. 2022). This standard, known as "TEMPEST" certification, is obtained through DOD and NATO and guarantees that the data is safeguarded against external threats.

Table 3. Artifact Entities. Adapted from Vaneman et al. (2022).

Entity Class	Entity Subclass	Data Type	Number
Artifact	**Guidance**	2018 National Defense Strategy	STRT.x
		Directives	Dir.x
		2018 Defense Planning Guidance	DPG.x
		Commandant's Planning Guidance (CPG)	PLAN.x
		Tactics, Techniques, and Procedures (TTP)	TTP.x
		Force Design 2030/CPG/DPG	Doc.x
		Marine Air Defense Integrated Weapons System (MADIS)	POR.x
	Governance	Regulations	REG.x
		Policy	POL.x
	Agreement	Memorandum of Understanding (MOU)	MOU.x
		Memorandum of Agreement (MOA)	MOA.x
	Standard	Conduct Defensive Operations	JCA.x
		MCT 6.1.1.8.3 Conduct short range ground based air defense in support of Expeditionary Bases (GBAD)	METL.x
		Required Operational Capabilities/ Projected Operational Environment	ROC/ POE.x
		The MADIS System will adhere to TEMPEST guidelines.	TS.x

2. Actions

The Actions Entity Class elements are shown in Table 4. Vaneman et al. (2022) provides a detailed description of several Data Types and their relationships. All action entities selected for this research are required to support the EABO mission. The operational activity chosen for this research, Coordinate Lethal Fires, is just one of the activities required to support the mission. Trained Marines will be needed to execute this operational activity, necessitating a training program to guarantee that the Marines are properly and adequately trained to carry out the mission and maintain the MADIS system.

The operational activity, Coordinate Lethal Fires, can be decomposed into several functions (Vaneman et al. 2022). One of which is to provide short range GBAD. This system function related to this activity is to destroy low-flying aircraft and helicopters. The system will require Global Positioning System (GPS) location services provided by a different acquisition entity to accomplish this.

The different functions necessary for the system to provide short range GBAD will be decomposed into requirements. These requirements will be documented and verified through a test process involving both developmental and operational testing to ensure that the requirements are met (Vaneman et al. 2022).

The actions of procuring, testing, and fielding all systems for the USMC warfighter lie with MCSC. The acquisition effort of the MADIS will be managed by the Program Executive Office Land Systems (PEO LS), while the acquisition of the JLTV will be managed by MCSC Logistics Combat Element Systems (LCES).

Table 4. Action Entities. Adapted from Vaneman et al. (2022).

Entity Class	Entity Subclass	Data Type	Number
Action	**Activity**	Coordinate Lethal Fires	OA.x
		Conduct Occupational Training	TRA.1
		Develop Training / Curriculum	TRA.2
		Conduct Maintenance on MADIS System	MNT.X
	Capabilities	Conduct Short Range Ground Based Air Defense (GBAD)	CA.x
	Function	Provide Short Range GBAD	F.x
		Destroy Low Flying Aircraft and Helicopters	SF.x
		Provide GPS Service to the MADIS System	SVC.x
		SOA Function	SOA.x
		Test Process (Perform DT / OT)	TP.x
		Test Process for "Service" (Service DT / Service OT)	TP.xx
		Perform Test & Diagnostics	TD.x
	Program	Program Executive Office Land Systems (PEO LS) – MADIS Logistics Combat Element Systems (LCES) – JLTV	PM.x

3. Assets

The Asset Entity Class elements are shown in Table 5. Vaneman et al. (2022) provides a detailed account of the Asset entity class. The MLR is the Enterprise that owns all assets needed to support the EABO Mission. The SoS for GBAD involves multiple crucial entities required to accomplish the mission. For this research, the entities selected include the JLTV which will host the MADIS system. It is important to note that the representative decomposition identified for the MADIS is only one subsystem from one of the two MADIS variants previously identified. The MADIS MK2, for instance, includes a radar and a command and control suite.

One subsystem, the radar, can be further decomposed into several assemblies. The radar receiver and radar transmitter (RR/T) can be further decomposed into sub-assemblies and components. The radar receiver, for example, will require operator observation, and this function will be fulfilled by a display panel consisting of a circuit board. Additionally, the radar subsystem will need software to track targets, accomplished through a target tracking algorithm (TTA).

It may be necessary to break down the system further, depending on the situation or need (Vaneman et al. 2022).

Table 5. Asset Entities. Adapted from Vaneman et al. (2022).

Entity Class	Entity Subclass	Data Type	Number
Asset	**System**	Enterprise (Marine Littoral Regiment)	ES.x
		System of Systems (SoS) – Ground Based Air Defense (GBAD)	SOS.x
		Family of Systems (FoS) – Joint Light Tactical Vehicle (JLTV)	FOS.x
		Platform (JLTV)	S.x
		System (MADIS)	SN.x
		Sub-System (MK2 Radar System)	SN.x.x
		Assembly (Radar Receiver/ Transmitter) (RR/T)	SN.x.x.x
		Sub-Assembly	SN.x.x.x.x
		Component (Display Panel)	SN.x.x.x.x.x
		Hardware (Circuit Board)	SN.x.x.x.x.x.x
		Software (Target Tracking Algorithm)	SW.x
	Service	Service (Global Positioning System Location)	SER.x

4. Resources

The Resource Entity Class elements are shown in Table 6. Vaneman et al. (2022) provides a detailed account of the Resource entity class. The USMC is responsible for providing the necessary resources to accomplish the mission, while the Marine is the warfighter performing the mission's associated tasks. The MADIS system is assigned to a unit within the Marine Littoral Regiment (MLR), stationed on a Marine Corps base or installation where the equipment is stored and maintained.

Vaneman et al. (2022) documents that the MCLD Ontology and CDM can map to each unit that receives the MADIS. One specific unit is the Third Littoral Anti-Air Battalion, which supports the Third Marine Littoral Regiment, stationed at the Marine Corps Air Station, Kaneohe Bay, Hawaii. Logistics resources are required to sustain the MADIS throughout the acquisition life cycle, while test and diagnostic equipment are used to maintain the system during operation.

Additionally, the Marines use the MADIS Visual Simulator (VS) during the operational training activity (Vaneman et al. 2022).

Table 6. Resource Entities. Adapted from Vaneman et al. (2022).

Entity Class	Entity Subclass	Data Type	Number
Resource	**Organization**	USMC	ORG.x
	Performer	US Marine	PER.x
	Installation	Assigned Facilities: XXX Building	FAC.x
		Property	IN.x
		Site: Marine Corps Air Station Kaneohe Bay	IN.x.x
	Logistics	Consumables	LOG.x
		Support Equipment	LSE.x
		Test & Diagnostic Equipment	TDE.x
		MADIS Virtual Simulator (MADIS VS)	TDS.x
	Information	Data	INFO.x

5. Characteristics and Measures

The Characteristics and Measures Entity Class elements are shown in Table 7. Vaneman et al. (2022) provides a detailed account of the Characteristics and Measures entity classes. The mission can occur anywhere in the world and in every temperate zone. The environmental conditions must be considered during the design phase to make appropriate design decisions.

The characteristics of the GPS signal including availability and update rate, need to be defined early in the development process. Availability refers to the percentage of time that GPS signals are available to a receiver, while update rate refers to how frequently the

GPS system provides new position, velocity, and timing information. Defining the required availability and update rate early in the development process will help guide the selection of hardware and software components, the positioning of GPS antennas, and the development of algorithms for processing and integrating GPS data with other sensors.

The Measures entities play a critical role in mission success, with the Measures of Effectiveness (MOE) and Key Performance Parameters (KPP) selected for this research directly tied to the ability to track multiple targets to secure the ground base. The Measure of Performance (MOP) is tied to how well the radar tracks targets in the area. Additionally, Technical Performance Measures (TPM) provide details on how the data is portrayed to the user (Vaneman et al. 2022).

Table 7. Characteristics and Measures Entities. Adapted from Vaneman et al. (2022).

Entity Class	Entity Subclass	Data Type	Number
Characteristic	**Condition**	Environmental State	CE.x
		Extreme Heat (+150ºF) to Very Low Operational Temperature (-45ºF)	CC.x
		The GPS Signal shall be available on a continuous basis and provide updates every second.	CQ.x
	Skill	Manpower, Personnel, Training	CS.x
		KSA	CS.x
Measure	**Measures of Effectiveness (MOE)**	The MADIS shall be capable of simultaneous Tracking of x targets	MOE.x
	Key Performance Parameters (KPP)	The MADIS shall be capable of simultaneous Tracking of x targets	KPP.x
	Measures of Performance (MOP)	Detect targets of x meter cross section area	MOP.x
	Technical Performance Measures (TPM)	The system display shall have a resolution of 1080p	MOP.x

6. Location

The Location Entity Class elements are shown in Table 8. Vaneman et al. (2022) provides a detailed account of the Location entity class. The location of deployment is a crucial factor in the effectiveness of the MADIS system. For this project, the location chosen is directly tied to the Third Littoral Anti-Air Battalion (LAAB) stationed in Hawaii. By selecting this location, the MADIS system is deployed in an area where it can effectively support the Third Marine Littoral Regiment and contribute to the overall mission success (Vaneman et al. 2022).

Table 8. Location Entity. Adapted from Vaneman et al. (2022).

Entity Class	Entity Subclass	Data Type	Number
Location	**Location**	Location	L.x
	Orbital	Orbital	LO.x
	Physical	Marine Corps Air Station Kaneohe Bay	LP.x
		GPS Coordinates: 21° 26’45”N 157o46’11”W	LP.xx
	Virtual	IP Address	LV.x

7. Statements and Requirements

The Statements and Requirements Entity Class elements are shown in Table 9. Vaneman et al. (2022) provides a detailed account of the Statements and Requirements entity classes. For this research, the selected mission is EABO. Expeditionary Advanced Base Operations, as discussed earlier, is a complex mission with several aspects supporting the Joint Capability of conducting defensive operations. One specific Marine Corps task that supports this mission is MCT 6.1.1.8.3, Conduct Short Range Ground Base Air Defense (GBAD) ISO Expeditionary Bases (Marine Corps Task List Branch, 2023). This task is critical for protecting expeditionary bases from airborne threats and ensuring the safety and security of deployed Marines. By focusing on this task and incorporating the MADIS system as part of the GBAD capability, the Marine Corps can effectively carry out its mission of supporting EABO and conducting defensive operations.

For this effort, the selected requirements have been carefully chosen to provide the necessary value and utility to the user. The first requirement is availability, which specifies how long the system will be functional. This is critical for ensuring the system is always ready to provide force protection and fulfill its mission.

Another functional requirement is the ability to detect low-flying aircraft and helicopters. This is essential for conducting effective GBAD and protecting the Marines on the ground.

The system also needs to be hosted by a platform, which means that the system's weight cannot exceed the payload capacity of the platform. This requirement ensures that the system can be easily transported and deployed to the necessary locations.

Finally, the system must integrate seamlessly with the Navy fleet and provide data to the AEGIS weapon system. This capability provides the commanders with additional firepower and protection, enhancing the overall effectiveness of the system and improving mission success. These requirements have been carefully selected to ensure that the system can effectively carry out its mission and provide maximum value to the user (Vaneman et al. 2022).

Table 9. Statements and Requirements Entities.
Adapted from Vaneman et al. (2022).

Entity Class	Entity Subclass	Data Type	Number
Statement	**Guidance**	Scenario Steps	SC.x
		Mission (Expeditionary Advanced Base Operations)	MI.x
	Standard	Joint Capabilities (Conduct Defensive Operations)	JC.x
		MCT 6.1.1.8.3 Conduct Short Range Ground Based Air Defense in support of Expeditionary Bases (GBAD).	MT.x
Requirement	**Requirement**	Requirement	R.x
	Originating	Performance Requirement The MADIS system shall Achieve an Ao ≥ of XX %	RP.x
		Operational Requirements The MADIS System shall provide Force Protection	RO.x
	Derived	Functional Requirements The MADIS system shall detect low flying aircraft and helicopters	RF.x
		System (Physical) Requirements The MADIS system weight shall not exceed the payload capacity of the host platform	RS.x
		Interface Requirements The MADIS system shall incorporate the equipment necessary to interact with the AEGIS Weapon System (AWS)	RI.x

The process of mapping the acquisition documentation to the MCLD Ontology identified terminology contradictions across various data sources. These contradictions highlight the need for a universal ontology to ensure that all stakeholders use common terminology to prevent confusion or ambiguity. A case in point is the acronym "SCI," which has two different definitions in two different artifacts. In the SPS artifact, "SCI" was defined as "Software Configuration Item," while in the security classification guide artifact, "SCI" was defined as "Sensitive Compartmented Information." This contradiction illustrates how the same acronym can have different meanings, leading to confusion and miscommunication.

D. MCLD CONCEPTUAL DATA MODEL

The next step in verifying the application of the MCLD Ontology is to examine how the relationships in the CDM represent the Land Domain, using the applied ontology from section C. As discussed in Chapter II, it should be noted that the CDM is one large and complex interwoven system model divided into seven different viewpoints for ease of readability and discussion. Each viewpoint is discussed in the following sections.

Vaneman et al. (2022) identifies the fact that the entities depicted in the MCLD Ontology and CDM only represent one single thread from one single mission out of many missions, capabilities, and systems that must be decomposed to fully populate the MCLD Ontology and CDM for the USMC Land Domain. The purpose of this chapter's example is to demonstrate that the MCLD Ontology and CDM, as developed, can facilitate the creation of all necessary missions and systems required to accurately represent the USMC Land Domain (Vaneman et al. 2022).

1. MCLD Capabilities, Operations, and Requirements Viewpoint

Figure 13 depicts the Capabilities, Operations, and Requirements viewpoint of the CDM that offers a visual representation of the system's objectives. The EABO mission is driven by strategic guidance stated in FD2030, which outlines the necessary capabilities, including Conduct Short Range GBAD. This capability is fulfilled by the operational activity, Conduct and Deliver Lethal Fires.

As mentioned in Chapter III, the same entities can appear in multiple viewpoints, as this is just a snapshot of the interconnected model. The entities enclosed in dashed boxes are introduced in a different viewpoint, while those in solid boxes are introduced in the current viewpoint (Vaneman et al. 2022).

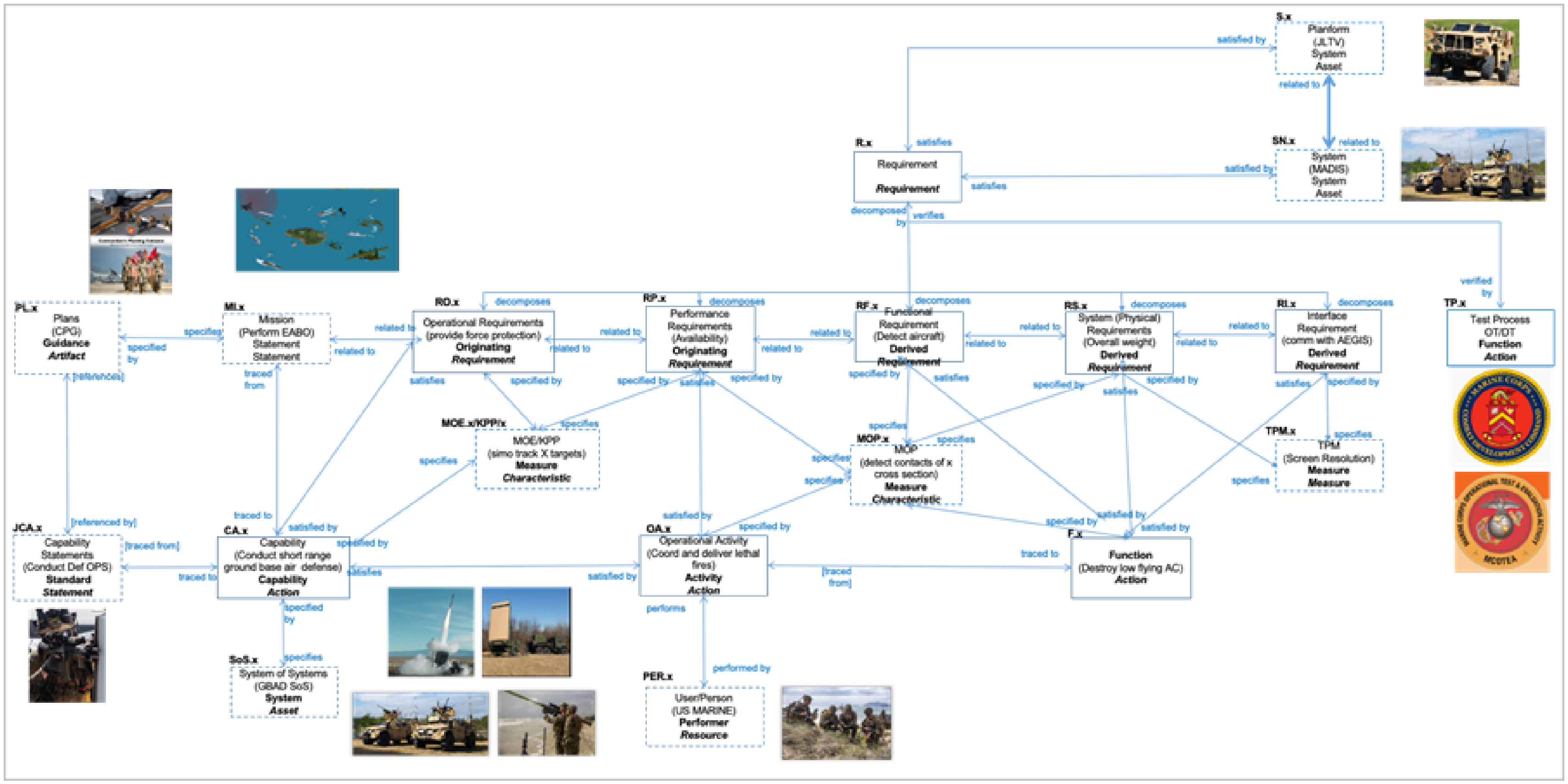


Figure 13. MCLD Capabilities, Operations, and Requirements Viewpoint. Source: Vaneman et al. (2022).

Vaneman et al. (2022) provides a detailed account of the Capabilities, Operations, and Requirements viewpoint. The diagram depicts the overall plans in the *Commandant's Planning Guidance* and can be broken down into the EABO mission and the joint capability to Perform Defensive Operations. The capability of Conduct Short Range GBAD is carried out by the GBAD SoS, which has associated MOEs such as the ability to Track Multiple Targets Simultaneously. The mission and associated MOEs lead to operational requirements, specifically Providing Force Protection. The Conduct Short Range GBAD capability can be further broken down into operational activities, such as Coordinating and Delivering Lethal Fires.

In the CDM, each operational activity and function has specific MOPs to ensure the tasks are performed effectively (Vaneman et al. 2022). For instance, one of the MOPs is to detect aircraft of X cross-section. Figure 13 illustrates the decomposition into functional, system, and interface requirements. For example, the requirements for detecting aircraft, overall system weight, and communicating with the AGEIS system are identified.

The MOPs, MOEs, and operational activities specify performance requirements such as availability. All these requirements are combined to define the system, MADIS, which is installed on the JLTV vehicle. The entire set of requirements is tested through Operational and Developmental test processes (Vaneman et al. 2022).

2. MCLD Systems and Services Viewpoint

Figure 14 depicts the Systems and Services viewpoint, a key CDM viewpoint (Vaneman et al. 2022). The Enterprise/Portfolio entity, in this research, the MLR, satisfies the EABO mission and the Conduct Short Range GBAD capability introduced in the Capabilities, Operations, and Requirements viewpoint. The MLR is decomposed into the GBAD SoS. This viewpoint provides the visualization of the decomposition of the SoS down to the individual hardware components and software modules.

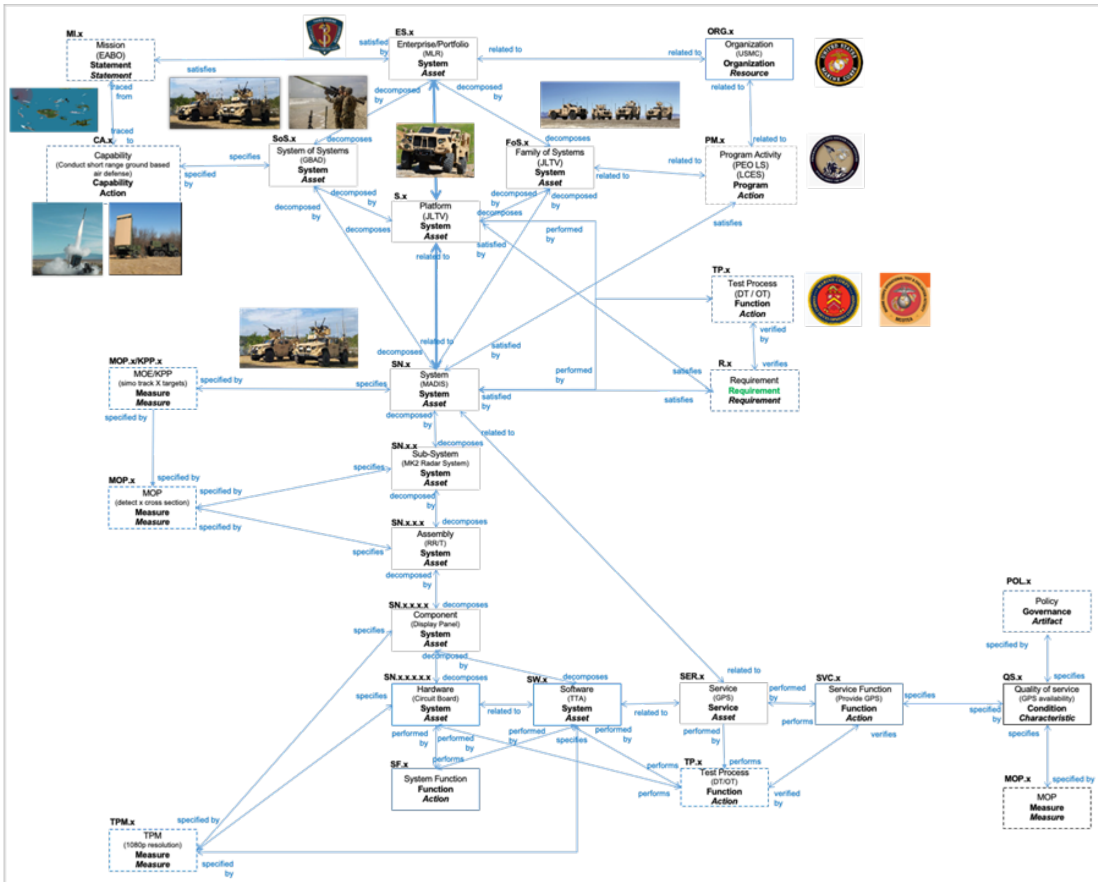


Figure 14. MCLD System and Services Viewpoint. Source: Vaneman et al. (2022).

Vaneman et al. (2022) provides a detailed account of the Systems and Services viewpoint. The Ground Based Air Defense system which includes the JLTV and the MADIS system, functions as a system of systems for performing short range GBAD. The systems are assigned to the MLR portfolio. The JLTV and MADIS systems are procured by LCES and PEO LS, respectively.

In the previous section, the requirements for the MADIS system, the MOEs/KPPs, and the MOPs were established. The MOP, detect targets with x cross section area, is related to the MK2 radar system and the RR/T assemblies, which were decomposed from the MADIS system. Further decomposition of the system reveals its components. The display panel consists of both hardware items and software modules. The hardware includes circuit boards, and the software modules include a TTA. These subsystems and assemblies perform the necessary functions to meet the system requirements.

These components have TPMs to ensure compliance with the MOPs and MOEs. As described in the MCLD Ontology, the decomposition of the system reveals that the MADIS system requires services and service functions to operate, such as GPS, to target aircraft accurately. To ensure the quality of its performance, the GPS has established its own policy and MOP. Finally, the entire system and its components must undergo extensive developmental and operational testing to verify system functionality (Vaneman et al. 2022).

3. MCLD Program Management Viewpoint

Figure 15 depicts the Program Management viewpoint of the CDM, which is associated with the program management aspect of systems acquisition. It offers valuable insights into the program's status by including traditional program management elements such as cost, schedule, performance, and risks (Vaneman et al. 2022).

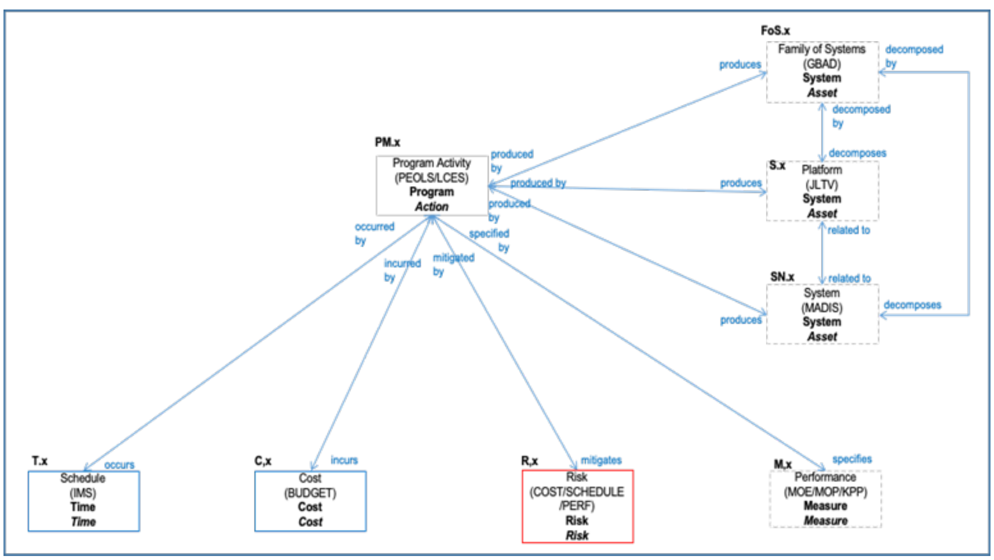


Figure 15. MCLD Program Management Viewpoint. Source: Vaneman et al. (2022).

Vaneman et al. (2022) provides a detailed account of the Program Management viewpoint. Program Executive Office Land Systems (PEO LS) undertake the necessary program activities to develop the MADIS system described in earlier viewpoints. This system enables the USMC to meet its capability and mission requirements. The program ensures adherence to the prescribed performance metrics, including MOEs, KPPs, MOP, and TPMs.

The program manager has the ultimate responsibility of ensuring that the necessary capabilities are provided within the given timeframe and budget. The CDM provides a visual representation of the entire system, including schedule dependencies and cost elements.

Program risks are typically managed through a comprehensive risk management plan. As shown, the MCLD Ontology and CDM provide a framework that interconnects all aspects of the system. By utilizing the MCLD Ontology and CDM, program leadership can obtain early awareness of areas that might encounter cost, schedule, or performance risks, which may not be detected through traditional risk management approaches.

4. MCLD Measures Viewpoint

Figure 16 depicts the Measures viewpoint of the CDM, which is crucial to the system, program management, and test and evaluation. All Measures originate in this viewpoint; however, they have all been defined in the previous views (Vaneman et al. 2022).

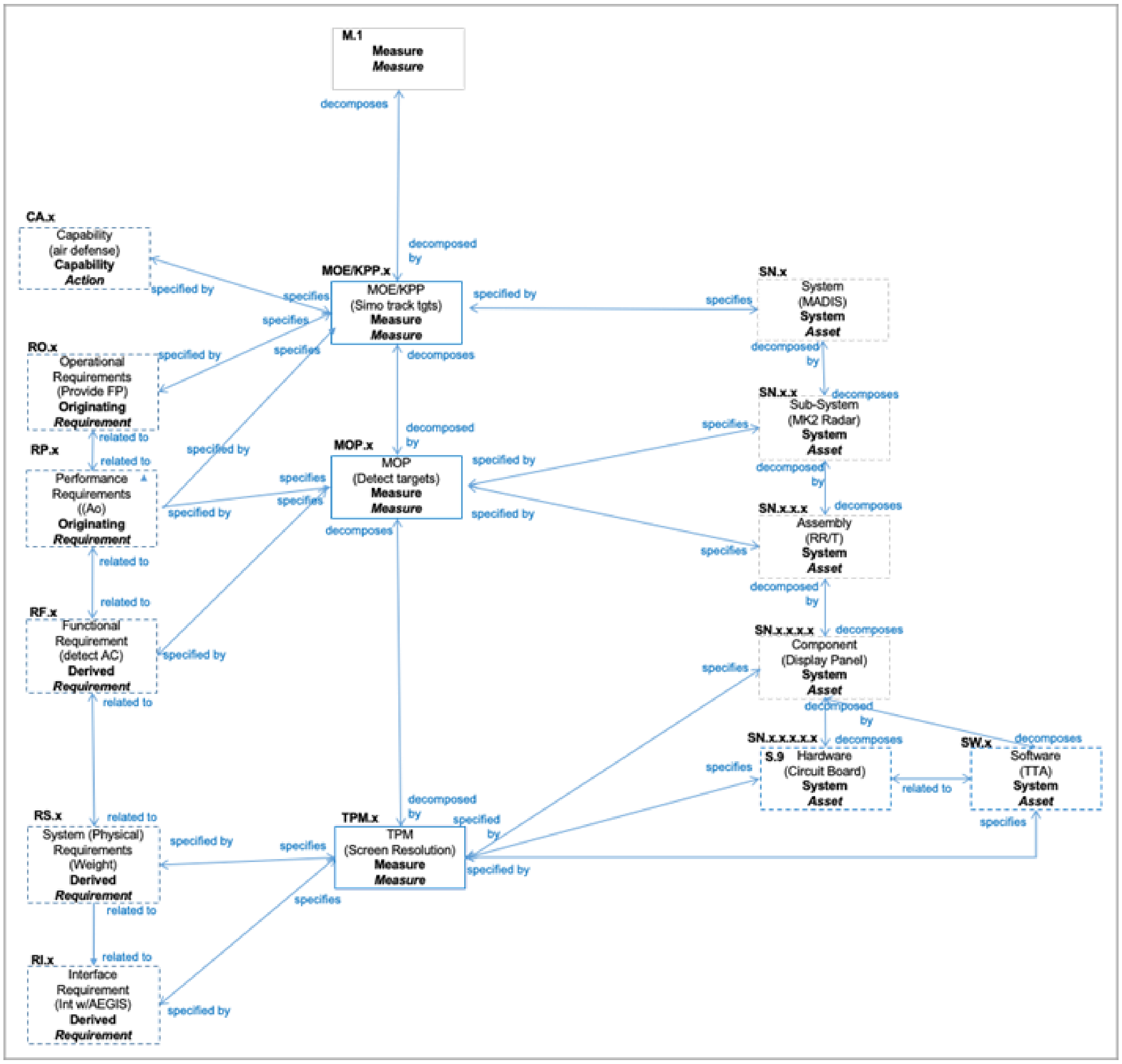


Figure 16. MCLD Measures Viewpoint. Source: Vaneman et al. (2022).

Vaneman et al. (2022) summarizes the Measures viewpoint. In Chapter III, it is mentioned that the CDM includes all measures for the entire system, but for clarity purposes, only three levels are depicted in this exercise. If the complete MADIS system were to be modeled, this single viewpoint would contain thousands of measures.

The KPP, simultaneously track X targets, is specified by the capability discussed previously, conduct short range GBAD, and the operational requirement, provide force protection. Failing to achieve this KPP could result in the system not meeting the user's high-level needs, leading to project termination.

The second tier of measures includes availability requirements (Ao), and the functional requirement, to detect low-flying aircraft and helicopters. These specify the MOP, detect aircraft of X cross-section, that has been decomposed from the previously discussed KPP. The MOP specifies the necessary functionality of the MK2 radar system and RR/T assembly.

The third tier of measures includes the TPM, screen resolution, which was decomposed from the MOP. The components selected or developed to support the MADIS system must meet the resolution requirement stated in the TPM (Vaneman et al. 2022).

5. MCLD Maintenance and Logistics Viewpoint

Figure 17 depicts the Maintenance and Logistics viewpoint of the CDM, which focuses on the maintenance of the MADIS system. The MADIS system requires scheduled maintenance tasks that require consumable resources (Vaneman et al. 2022). Additionally, specific support equipment and test and diagnostics equipment are utilized to facilitate the required maintenance actions for the MADIS system.

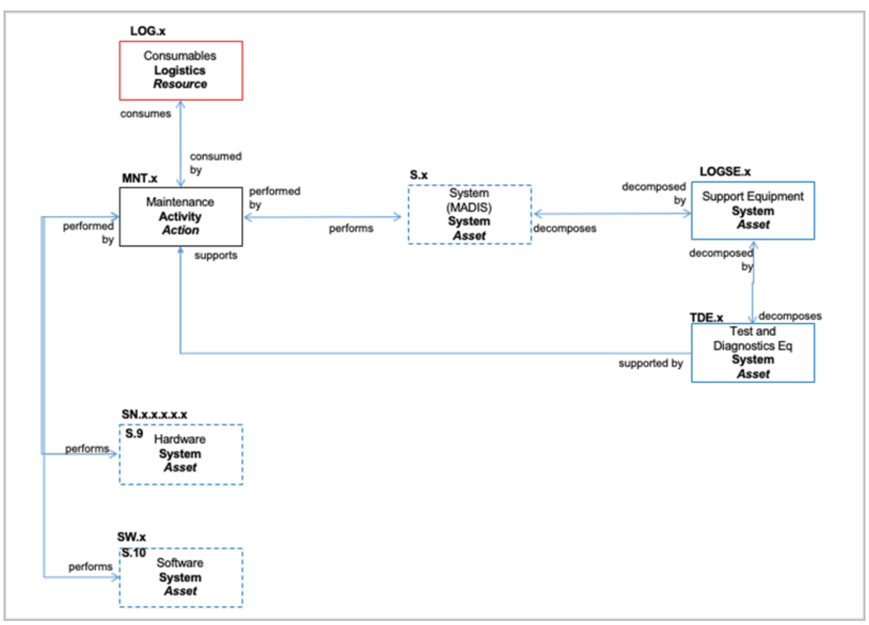


Figure 17. MCLD Maintenance and Logistics Viewpoint. Source: Vaneman et al. (2022).

6. MCLD Manpower and Personnel Viewpoint

Figure 18 depicts the Manpower and Personnel viewpoint of the CDM, which focuses on the operational activities required to use the system, and the specific KSAs necessary for the individual who performs them. This viewpoint shows that a U.S. Marine, the User, performs both operational activities and maintenance tasks for the MADIS system (Vaneman et al. 2022). A training curriculum is required utilizing training devices and simulators to acquire and maintain the required skills. It is worth noting that this training is intended for both operators and maintainers of the MADIS system.

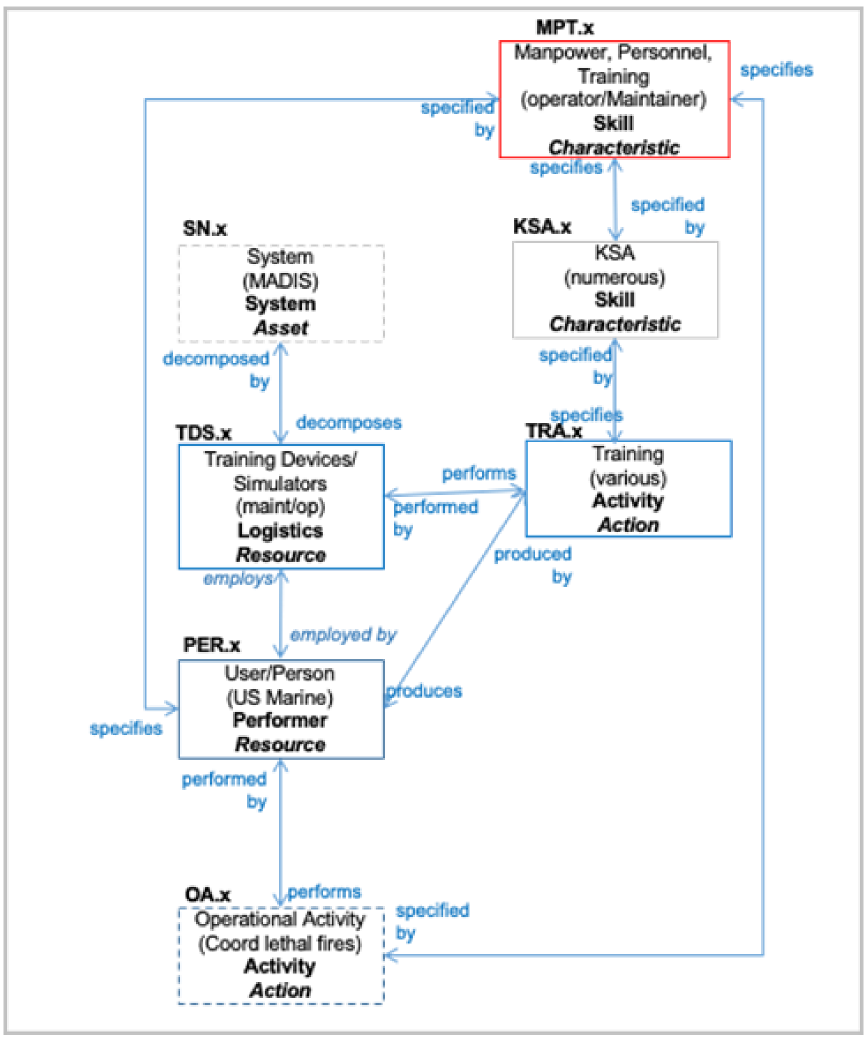


Figure 18. MCLD Manpower and Personnel Viewpoint. Source: Vaneman et al. (2022).

7. MCLD Location Viewpoint

Figure 19 depicts the Location viewpoint of the CDM, which focuses on the geolocation of the MADIS system, which may be at a specific facility like Marine Corps Air Station (MCAS) Kaneohe Bay, a deployed location, or a training location (Vaneman et al. 2022). These locations determine the environmental conditions necessary for the system to function properly. It is worth noting that this part of the CDM includes some aspects not addressed in this use case, such as orbital or virtual locations, which may be relevant for other systems. Therefore, they are still included in this view.

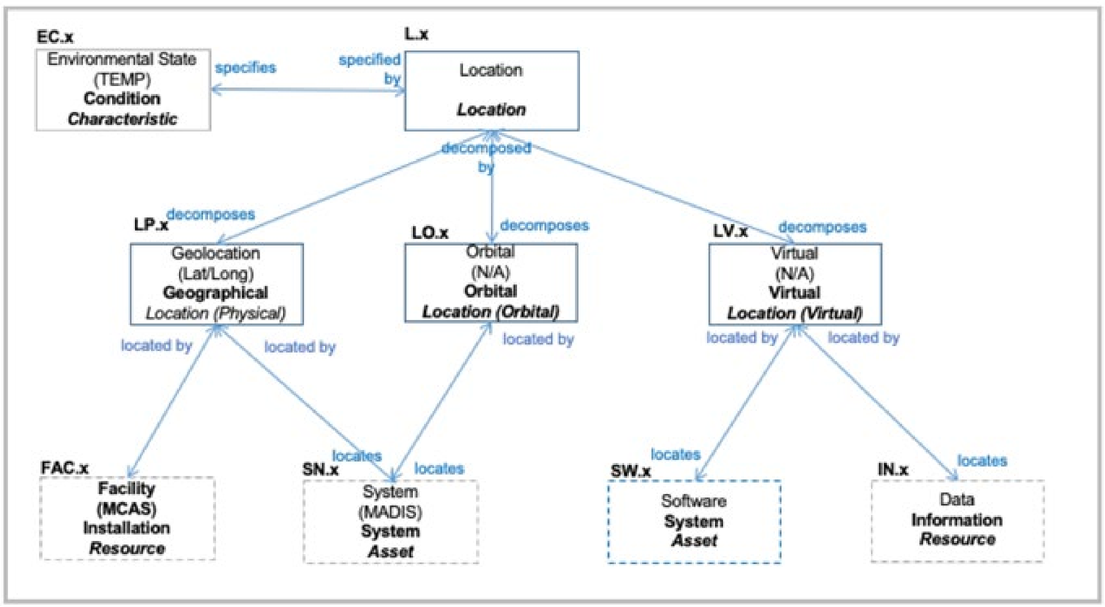


Figure 19. MCLD Location Viewpoint. Source: Vaneman et al. (2022).

By using the MCLD Ontology presented in section C, and the seven different views of the CDM, it becomes possible to understand how system entities relate to each other, from the highest-level missions defined by strategic guidance down to the lowest levels of components (Vaneman et al. 2022). This approach also allows for the decomposition and definition of these entities.

Using the defined MCLD Ontology and CDM enables separate organizations to contribute to the model, with each model layer linking to the next. This helps to create a cohesive and comprehensive understanding of the system, highlighting the interdependencies between different components and how changes at one level can impact the entire system.

E. SUMMARY

As stated in Chapter III, combining the MCLD Ontology and the CDM can act as a "Rosetta stone" for the exchange of data among model entities developed using different modeling languages, MBSE tools, or presentation frameworks (Vaneman et al. 2022). Section B provided an overview of FD2030 and the EABO, which were vital to this research. Section C discussed the data included in the MCLD Ontology. Section D provided a visual depiction of the relationships defined in the MCLD Ontology to show that a single mission thread could be decomposed to a single SoS mission, followed by a specific SoS, down to a platform, system, subsystems, and components.

Creating and owning models in the USMC involves many organizations, including CD&I, MCSC, program offices, contractors, subcontractors, and government components. They all work together to develop models that align with the mission objectives and requirements, and comply with regulations and guidelines. Collaboration, coordination, and communication are essential for the successful development and implementation of these models.

Utilizing the MCLD Ontology and CDM ensures that the model created at various levels, potentially using different language and MBSE tools, adheres to a consistent schema and fully represents the system (Vaneman et al. 2022). Although several more threads of the USMC land domain need modeling to obtain the complete set of missions, capabilities, and systems, the effectiveness of this approach is demonstrated in the MCLD use case presented in this chapter.

THIS PAGE INTENTIONALLY LEFT BLANK

V. CONCLUSION

A. OVERVIEW

The goal of this research was to validate the recently developed Marine Corps Land Domain (MCLD) Ontology and CDM. The research confirmed that the MCLD Ontology and CDM could be used to fully decompose the entire MCLD. The decomposition that was completed on one single capability would need to occur on every mission associated with the MCLD. The research revealed several benefits that MCSC program offices would see using the MCLD Ontology and CDM. Several overarching benefits are discussed here; specific details are provided as each research question is explored in the following sections. All the critical acquisition details would be contained in the system model rather than in multiple acquisition documents housed in various locations. The overarching guidance that led to the development of the system is easily identifiable and accessible to all stakeholders. Another advantage of using the MCLD Ontology and CDM is that it portrays clearly the "authoritative source of truth" for each data element. Consequently, the acquisition professional knows which organization is responsible for the data element. Finally, the system model would contain real-time status for every aspect of an acquisition program accessible to all stakeholders.

As stated in Chapter I, to fully embrace MBSE, the acquisition community needs to shift the focus from the artifacts and documentation to the system models which serve as virtual representations of a system. Chapter III provided a methodology to extract the pertinent data from the artifacts and documentation that were authoritative, current, relevant, and related to the system of interest. The pertinent data contained in the documentation was extracted using the definitions provided in the artifacts, and subsequently, mapping that data to the Data Type entities defined in the MCLD Ontology and CDM.

B. RESEARCH QUESTIONS

(1) Does the MCLD Ontology and CDM accurately and completely represent the MCSC program?

The data contained in the acquisition documentation, as demonstrated in section C in Chapter IV, was accurately mapped to the entities listed in the MCLD Ontology. Thus, indicating a consistent and coherent representation of the data in accordance with the MCLD Ontology. Likewise, the relationships depicted in the CDM were in alignment with the data, adding to the validity of the CDM. These observations led to the conclusion that the MCLD Ontology and CDM, combined, form a comprehensive representation of the system. They encompass all aspects of a program, including every stage of a program's life cycle.

(2) What program insights emerge that would not otherwise be gleaned when using the MCLD Ontology and CDM?

Several insights emerged by examining the relationships depicted in the viewpoints in the CDM.

One insight was revealed after examining the Capabilities, Operations, and Requirements viewpoint: a few key data elements heavily influenced the overall system. A simple change in one of those data elements would have ramifications that permeate throughout the entire system. For example, if the capability to "conduct short range ground-based air defense" would be altered to "conduct long range ground-based air defense," all decomposed elements would be affected.

Another insight was revealed after examining the Program Management and the System and Services viewpoints: the MCLD Ontology and CDM include areas where external entities may need to provide authoritative input. For example, if the OEM suggested adding a sub-assembly to the system to increase productivity and lower costs, this change would affect the entire system model. The Program Management viewpoint would depict the cost savings, the schedule adjustment, and the additional sub-assembly entity. The System and Services viewpoint would depict the sub-assembly entity as well as any additional measures associated with that sub-assembly.

Finally, the MCLD Ontology and CDM identified terminology contradictions throughout the multiple data sources. These contradictions provide objective evidence supporting one of the fundamental reasons a universal ontology is necessary: to ensure all stakeholders use common terminology to avoid confusion or ambiguity.

(3) How do the MCLD Ontology and CDM help demonstrate how the MCSC program aligns with FD2030?

As discussed in Chapter IV, the USMC published FD2030 to address gaps in its capabilities identified by the *Commandant's Planning Guidance*. These gaps include long-range precision fires, air defense systems, unmanned systems with ISR, EW, and lethal strike capabilities. The redesign of FD2030 enables the USMC to adapt to new warfighting concepts and evolving threats. The MADIS system's ability to detect, track, and destroy enemy aircraft addresses some of these capability gaps.

As shown in Figure 14, the CDM depicts a clear and well-defined decomposition, from the high-level mission documented in FD2030, to the hardware components and software modules of the MADIS system.

A comprehensive examination of the MCLD Ontology and CDM found no missing connections between the MADIS System and FD2030. In other words, the MCLD Ontology and CDM fully and accurately captured the relationships between the MADIS System and FD2030. This provides clear evidence that the MCLD Ontology and CDM are comprehensive and can be considered a reliable representation of the relationship between the MADIS System and FD2030.

(4) How can the MCLD Ontology and CDM be used to correlate data between different models and modeling tools used by the MCSC program office?

The MCLD Ontology and CDM, and the associated Numbering Schema, shown in Figure 4, can facilitate data correlation across diverse models and modeling tools used by the MCSC program office. Some of the ways in which they can be utilized include serving as a common language for various modeling tools to communicate with each other, aiding in data integration across multiple modeling tools and models, helping to identify clear boundaries between data entities, and identifying the authoritative source of truth for each data entity in the MCLD Ontology and CDM. As a result, the MCLD Ontology and CDM, along with the associated Numbering Schema, can be used by the modeling and simulation standards experts as a starting point to correlate data between different models and modeling tools employed by the MCSC program office.

C. RECOMMENDATIONS FOR FUTURE RESEARCH

- Utilize the MCLD Ontology and CDM as a "Rosetta Stone" to develop the Application Program Interfaces necessary to transfer data from one modeling tool to another.
- Determine how to share the system model with outside stakeholders and OEMs.
- Safeguards are needed to protect intellectual property and data rights.
- Cybersecurity and Access control of the virtual environment housing the System Model
- Establish the method required for the system model to interact with the "Classified Material" tied to many Capabilities and Threats associated with DOD acquisition programs.
- Verify that the MCLD Ontology and CDM could be used across all services by applying the methodology proposed in Chapter III to multiple systems across all services.
- From large, complex SoS to small ACAT III programs, recommendations are provided in Table 10.

Table 10. Recommended Programs to Further Verify the MCLD Ontology and CDM.

Service	ACAT Designation	System Type	Life cycle Stage	Program
USMC	I	Advanced Reconnaissance Vehicle	New Start	ARV
USMC	I	Logistics Vehicle	Sustainment	MTVR
USMC	I	Amphibious Tracked Combat Vehicle	Sunsetting	AAV
Navy	I	*Arleigh Burke* Class Destroyer	Production & Sustainment	DDG 51
Navy	I	*Virginia* Class Submarine	Production & Sustainment	SSN 774
Navy	II	*Lewis B. Puller* ESB-3 – Class	Production & Sustainment	Expeditionary Sea Base
Navy	III	Unmanned Influence Sweep System	Production	UISS
Airforce	I	Joint Strike Fighter	Production & Sustainment	F-35
Airforce	I	Combat Rescue Helicopter	Production & Sustainment	CRH
Army	I	Armored Vehicle	New Start	AMPV
Army	I	Tactical Vehicle	Production & Sustainment	JLTV
Army	I	Armored Vehicle	Sustainment	Stryker
Army	II	Counter Radio Controlled Improvised Explosive Device	Production & Sustainment	CREW
Army	III	Common Sensor Payload for manned and unmanned aircraft	Production and Sustainment	CSP

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX A. ENTITY SUBCLASS DEFINITIONS

Table 11. Entity Subclass Definitions. Adapted from Vaneman et al. (2022)

Entity Class	Entity Subclass	Entity Subclass Definition	Definition Source
Artifact	**Guidance**	An authoritative document intended to lead or steer the execution of actions.	DOD (2010)
	Governance	The set of rules, policies, and decision-making criteria that will guide the SoS to achieving its goals and objectives.	Vaneman et. al. (2022)
	Agreement	A consent among parties regarding the terms and conditions of activities that said parties participate in.	DOD (2010)
	Standard	A formal agreement documenting generally accepted specifications or criteria for products, processes, procedures, policies, systems, and/ or personnel.	DOD (2010)
Action	**Activity**	Work, not specific to a single organization, weapon system or individual that transforms inputs (Resources) into outputs (Resources) or changes their state.	DOD (2010)
	Capabilities	The ability to achieve a desired effect under specified (performance) standards and conditions through combinations of ways and means (activities and resources) to perform a set of activities.	DOD (2010)
	Function	Constitutes a specific or discrete action required to achieve a desired objective.	Blanchard and Fabrycky (2011)

Entity Class	Entity Subclass	Entity Subclass Definition	Definition Source
	Program	The process for controlling the cost, schedule, and performance of a project or group of projects to achieve a stated goal.	AcqNotes (2023)
Asset	**Platform**	A system that is able to host other systems. The platform retains all of the relationships, attributes, and characteristics of a system.	Vaneman et al. (2022)
	System	A functionally, physically, and/or behaviorally related group of regularly interacting or interdependent elements.	DOD (2010)
	Service	A mechanism to enable access to a set of one or more capabilities, where the access is provided using a prescribed interface and is exercised consistent with constraints and policies as specified by the service description. The mechanism is a Performer. The capabilities accessed are Resources -- Information, Data, Materiel Performers, and Geo-political Extents.	DOD (2010)
Resource	**Organization**	A specific real-world assemblage of people and other resources organized for an ongoing purpose.	DOD (2010)
	Performer	Any entity – human, automated, or any aggregation of human and/or automated – that performs an activity and provides a capability.	DOD (2010)
	Installation	A military or industrial establishment.	Vaneman et al. (2022)

Entity Class	Entity Subclass	Entity Subclass Definition	Definition Source
	Logistics	The detailed coordination of a complex operation involving many people, facilities, or supplies.	Vaneman et al. (2022)
	Information	The state of a something of interest that is materialized -- in any medium or form -- and communicated or received.	DOD (2010)
Characteristic	**Condition**	The state of an environment or situation in which a Performer performs.	DOD (2010)
	Skill	The ability, coming from one's knowledge, practice, aptitude, etc., to do something well.	DOD (2010)
Measure	**MOE**	The "operational" measures of success that are closely related to the achievement of the mission or operation being evaluated, in the intended operational environment, under a specified set of conditions.	Roedler and Jones (2005)
	KPP	Key Performance Parameters are a special case of Measures of Effectiveness, that are so critical, that failure to achieve the KPP may result in program cancellation or significant program restructuring.	Roedler and Jones (2005)
	MOP	The measures that characterize physical or functional attributes relating to the system operation, measured or estimated, under specific testing and/or operational environment conditions.	Roedler and Jones (2005)

Entity Class	Entity Subclass	Entity Subclass Definition	Definition Source
	TPM	Metrics which measure the attributes of a system element to determine how well a system, or system element, is satisfying, or expected to satisfy, a technical requirement or goal.	Roedler and Jones (2005)
Cost	**Cost**	An amount that has to be paid or spent to buy or obtain something.	Vaneman et al. (2022)
Location	**Orbital**	An Orbital entity specifies a location along an orbit around a celestial body (e.g., Orbit).	LML v1.4 (2022)
	Physical	A Physical entity specifies a location on, above, or below the surface (e.g., geographic coordinates).	LML v1.4 (2022)
	Virtual	A Virtual entity specifies a location within a digital network (e.g., URL).	LML v1.4 (2022)
Statement	**Guidance**	An authoritative statement intended to lead or steer the execution of actions.	DOD (2010)
	Standard	The set of rules governing the arrangement, interaction, and interdependence of parts or elements of the system or model, of the system.	Vaneman et al. (2022)
Requirement	**Originating**	Requirements that are the cornerstone upon which the systems engineering process is based. These requirements do not just appear but involve a great deal of work using several important systems	Buede (2009)

Entity Class	Entity Subclass	Entity Subclass Definition	Definition Source
		engineering tools: the operational concept, the external systems diagram, and the objectives hierarchy.	
	Derived	Requirements that result from the analysis and allocation of technical requirements to logical functional architectures that are developed as part of the requirements analysis process. Derived technical requirements become the basis for the solution-specified requirements for the system model and are a 'design-to' requirement for the system.	AcqNotes (2023)
Risk	**Risks**	The potential that something will go wrong as a result of one or a series of events. It is measured as the combined effect of the probability of occurrence and the assessed consequence given the occurrence.	Vaneman et al. (2022)

THIS PAGE INTENTIONALLY LEFT BLANK

APPENDIX B. DATA TYPE DEFINITIONS

Table 12. Data Type Definitions. Adapted from Vaneman et al. (2022).

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
Artifact	**Guidance**	Strategic Objectives & Policies	A long-term plan to achieve pre-set goals.	DOD (2010)
		Directives	An authoritative statement intended to impel actions and the achievement of goals.	DOD (2010)
		Defense Planning Guidance (DPG)	The product of the planning, programming, budgeting and execution process' planning phase. The DPG reflects the president's national security strategy, the secretary of defense's national defense strategy, and the chairman's national military strategy. It also reflects results of the national defense strategy, and the annual chairman's program recommendations. The DPG drives the development of the program objective memoranda and budget estimate submissions.	DAU (2023)
		Plans	A set of activities that result in a goal, desired effect, outcome, or objective.	DOD (2010)
		Tactics, Techniques, and Procedures (TTP)	The actions and methods that implement doctrine and describe how forces will be employed in operations.	DOD (2010)
		Doctrine	The body of principles by which an enterprise seeks to guide its activities.	DOD (2010)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
		Program of Record	A directed funded effort that provides a new, improved, or continuing materiel, weapon, or information system or service capability in response to an approved need.	DOD (2010)
	Governance	Regulations	An agency statement of general applicability and future effect, that the agency intends to have the force and effect of law, that is designed to implement, interpret, or prescribe law or policy or to describe the procedure or practice requirements of an agency	Joint Chiefs of Staff (2019b)
		Policy	A course of action, guiding principle, or procedure considered expedient, prudent, or advantageous.	DOD (2010)
	Agreement	Memorandum of Understanding (MOU)	De facto agreement generally recognized by all partners as binding even if no legal claim could be based on the rights and obligations delineated therein.	DAU (2023)
		Memorandum of Agreement (MOA)	1.) In contract administration, an agreement between a program manager (PM) and a contract administration office (CAO) establishing the scope of responsibility of the CAO with respect to the earned value management system (EVMS) criteria surveillance functions and objectives, and/or other contract administration functions on a specific contract or program.	DAU (2023)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
			2.) Any written agreement in principle as to how a program will be administered.	
	Standard	Joint Capabilities Areas Document (JCA)	High-level capabilities specified at the joint level.	DOD (2010)
		Mission Essential Task List (METL)	A list of mission-essential tasks selected by a commander to accomplish a mission, defined using the common language of the Service task list in terms of tasks, conditions, and standards, and includes the identification of supporting and supported tasks, as applicable.	DOD (2011)
		Required Operational Capabilities (ROC)/Projected Operational Environment (POE)	ROC: Statements prepared by mission and warfare sponsors which detail the capabilities required of ships and squadrons in various operational situations. The level of detail sets forth which weapons will be ready at varying degrees of readiness. Example: Perform Anti-Air Warfare with full capability condition of readiness I; partial capability in condition of readiness III. POE: The environment in which the ship or squadron is expected to operate, including the military climate. Example: "at sea, at war, capable of continuous operations at readiness Condition III."	DON (2022)
		Technical Standard	Technical standards document specific technical methodologies and practices to design and implement.	DOD (2010)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
Action	**Activity**	Operational Activity	An activity is an action performed in conducting the business of an enterprise. It is a general term that does not imply a placement in a hierarchy (e.g., it could be a process or a task as defined in other documents and it could be at any level of the hierarchy of the Operational Activity Model). It is used to portray operational actions not hardware/software system functions.	DOD (2010)
		Training	To make proficient by instruction and practice in particular knowledge or skills.	DOD (2010)
		Maintenance	1. All actions, including inspection, testing, servicing, classification as to serviceability, repair, rebuilding, and reclamation, taken to retain materiel in a serviceable condition or to restore it to serviceability. 2. All supply and repair action taken to keep a force in condition to carry out its mission. 3. The routine recurring work required to keep a facility in such condition that it may be continuously used at its original or designed capacity and efficiency for its intended purpose.	Joint Chiefs of Staff (2019b)
	Capabilities	Capabilities	The ability to achieve a desired effect under specified (performance) standards and conditions through combinations of ways and means (activities and	DOD (2010)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
			resources) to perform a set of activities.	
	Function	Function	Constitutes a specific or discrete action required to achieve a desired objective.	Blanchard and Fabrycky (2011)
		System Function	A function that is performed by a system. Although commonly used to refer to the automation of activities, data transformation or information exchanges within IT systems, it also refers to the delivery of military capabilities.	DOD (2010)
		Service Function	White box implementation of the activities of the service.	DOD (2010)
		SOA Function	A distinct part of the functionality that is provided by a technical system on one side of an interface to a general system on the other side of the interface (Derived from IEEE 1003.0). Characterized by transparency, autonomy, loose coupling, and discovery.	DOD (2010)
		Test Process	The process of evaluating and verifying the data on functional features and equipment operation under fully controlled and traceable conditions.	DAU (2023)
		Test and Diagnostic	Calibrated test measurement diagnostic equipment (TMDE) used in DOD maintenance replicates the precision, performance, and safety that are built into equipment during the manufacturing process. The capability of DOD weapon	DOD (2022)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
			platform mechanical systems, radios and communication devices, radar systems, targeting devices and fire control systems, missiles, and aviation platforms to operate accurately and effectively depend on the synchronization of these precise measurements against known standards. The calibration measurement requirements need to be linked to the measurement performance requirements of the TMDE. The measurement traceability from the prime system measurement requirement through the TMDE to the calibration reference standards is documented in a Calibration, Measurement and Requirements Summary (CMRS) format. When not linked to system measurement requirements, the resulting tendency is to calibrate to incorrect specifications.	
	Program	Program Activity	A directed, funded effort that provides a new, improved, or continuing materiel, weapon, or information system or service capability in response to an approved need.	DOD (2010)
Asset	**System**	Enterprise	An umbrella term for the management systems, information systems and computer systems within an organization.	DOD (2010)
		System of Systems (SoS)	A set or arrangement of interdependent systems that are related or connected to provide a	DOD (2010)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
			given capability. The loss of any part of the system could significantly degrade the performance or capabilities of the whole. The development of an SoS solution will involve trade space between the systems as well as within an individual system performance.	
		Family of Systems (FoS)	A set of systems that provide similar capabilities through different approaches to achieve similar or complementary effects. For instance, the warfighter may need the capability to track moving targets. The FoS that provides this capability could include unmanned or manned aerial vehicles with appropriate sensors, a space-based sensor platform, or a special operations capability. Each can provide the ability to track moving targets but with differing characteristics of persistence, accuracy, timeliness, etc.	DOD (2010)
		Platform	A set of subsystems/technologies that provide a coherent set of functionality through interfaces and specified usage patterns that any subsystem that depends on the platform can use without concern for the details of how the functionality provided by the platform is implemented.	DOD (2010)
		System	A functionally, physically, and/or behaviorally related group of	DOD (2010)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
			regularly interacting or interdependent elements.	
		Sub-System	A functional grouping of components that combine to perform a major function within an element such as electrical power, attitude control, and propulsion.	DAU (2023)
		Assembly	A portion of a system or subsystem that can be provisioned and replaced as an entity and which incorporates multiple, replaceable parts	Joint Chiefs of Staff (2019a)
		Sub-Assembly	Two or more parts joined to form a unit that is capable of being disassembled and that is only a part of a complete machine, structure, or other article.	DAU (2023)
		Component	A part or combination of parts having a specific function, which can be installed or replaced only as an entity.	Joint Chiefs of Staff (2019a)
		Hardware	The physical parts of a system.	Joint Chiefs of Staff (2019b)
		Software	Programs and applications that run on information systems.	Joint Chiefs of Staff (2019b)
	Service	Service	A mechanism to enable access to a set of one or more capabilities, where the access is provided using a prescribed interface and is exercised consistent with constraints and policies as specified by the service description. The mechanism is a	DOD (2010)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
			Performer. The "capabilities" accessed are Resources -- Information, Data, Materiel, Performers, and Geo-political Extents.	
Resource	**Organization**	Organization	A specific real-world assemblage of people and other resources organized for an ongoing purpose.	DOD (2010)
	Performer	User/Person	Any entity -- human, automated, or any aggregation of human and/ or automated -- that performs an activity and provides a capability.	DOD (2010)
	Installation	Facility	A real property entity consisting of underlying land and one or more of the following: a building, a structure (including linear structures), a utility system, or pavement.	DOD (2010)
		Property	An individual type whose members all exhibit a common trait or feature. Often the individuals are states having a property (the state of being 18 degrees centigrade), where this property can be a categorical property, or a dispositional property.	DOD (2010)
		Site	Physical (geographic) location that is or was owned by, leased to, or otherwise possessed. Each site is assigned to a single installation. A site may exist in one of three forms: (1) Land only, where there are no facilities present, and where the land consists of either a single	DOD (2010)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
			land parcel or two or more contiguous land parcels. (2) Facility or facilities only, where the underlying land is neither owned nor controlled by the government. A stand-alone facility can be a site. If a facility is not a stand-alone facility, it must be assigned to a site. (3). Land and all the facilities thereon, where the land consists of either a single land parcel or two or more contiguous land parcels.	
	Logistics	Consumables	Administrative or housekeeping items, general purpose hardware, common tolls, or any item not specifically identified as controlled equipage or spare parts.	DAU (2023)
		Support Equipment	One of the 12 Integrated Product Support (IPS) Elements. All equipment (mobile or fixed) required to support the operation and maintenance of a system. It includes, but is not limited to, ground handling and maintenance equipment, trucks, air conditioners, generators, tools, metrology and calibration equipment, and manual and automatic test equipment. During the acquisition of systems, program managers are expected to decrease the proliferation of support equipment into the inventory by minimizing the development of new support equipment and giving more attention to the use of existing	DAU (2023)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
			government or commercial equipment.	
		Test & Diagnostic Equipment	Calibrated test measurement diagnostic equipment (TMDE) used in DOD maintenance replicates the precision, performance, and safety that are built into equipment during the manufacturing process. The capability of DOD weapon platform mechanical systems, radios and communication devices, radar systems, targeting devices and fire control systems, missiles, and aviation platforms to operate accurately and effectively depend on the synchronization of these precise measurements against known standards. The calibration measurement requirements need to be linked to the measurement performance requirements of the TMDE. The measurement traceability from the prime system measurement requirement through the TMDE to the calibration reference standards is documented in a Calibration, Measurement and Requirements Summary (CMRS) format. When not linked to system measurement requirements, the resulting tendency is to calibrate to incorrect specifications.	DAU (2022)
		Training Devices & Simulators	A general term that defines training equipment that supports training in the live, virtual, constructive, and gaming environments. Justified,	Department of the Army (2018)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
			developed, and acquired to support designated tasks. Examples include, but are not limited to, battle simulations, targetry, training-unique ammunition, flight, and/or driving simulators, gunnery trainers, and maintenance trainers.	
	Information	Data	Representation of information in a formalized manner suitable for communication, interpretation, or processing by humans or by automatic means. Examples could be whole models, packages, entities, attributes, classes, domain values, enumeration values, records, tables, rows, columns, and fields.	DOD (2010)
Characteristic		Environmental State	The state of an environment or situation in which a Performer performs or is disposed to perform.	DOD (2010)
	Condition	Operational Condition	A statement of the values or states needed for the execution of actions within the processes and transactions of an enterprise.	DOD (2010)
		Quality of Service	The ability to provide different priority to different applications, users, or data flows, or to guarantee a certain level of performance to a data flow.	DOD (2010)
	Skill	Skill	The ability, coming from one's knowledge, practice, aptitude, etc., to do something well.	DOD (2010)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
Measure	**MOE**	MOE	The “operational” measures of success that are closely related to the achievement of the mission or operation being evaluated, in the intended operational environment, under a specified set of conditions.	Roedler and Jones (2005)
	KPP	KPP	Key Performance Parameters are a special case of Measures of Effectiveness, that are so critical that failure to achieve the KPP may result in program cancellation or significant program restructuring.	Roedler and Jones (2005)
	MOP	MOP	The measures that characterize physical or functional attributes relating to the system operation, measured or estimated, under specific testing and/or operational environment conditions.	Roedler and Jones (2005)
	TPM	TPM	Metrics which measure the attributes of a system element to determine how well a system, or system element, is satisfying or expected to satisfy, a technical requirement or goal.	Roedler and Jones (2005)
Cost	**Cost**	Cost	An amount that has to be paid or spent to buy or obtain something.	Vaneman et al. (2022)
Location	**Orbital**	Orbital	An Orbital entity specifies a location along an orbit around a celestial body. (e.g., Orbit).	LML v1.4 (2022)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
	Physical	Address, Geolocation	A Physical entity specifies a location on, above, or below the surface. (e.g., geographic coordinates).	LML v1.4 (2022)
	Virtual	IP Address	A Virtual entity specifies a location within a digital network. (e.g., URL).	LML v1.4 (2022)
Statement	**Guidance**	Mission	The task, together with the purpose, that clearly indicates the action to be taken and the reason; a duty assigned to an individual or unit.	DOD (2010)
	Standard	Joint Capabilities	The ability to execute a specified course of action at the Joint Level.	Joint Chiefs of Staff (2007)
		Task	An action, activity or undertaking enabling missions, activities or functions to be performed or accomplished.	Vaneman et al. (2022)
Requirement	**Originating**	Performance Requirement	Define quantitatively the extent, or how well and under what conditions, a function or task is to be performed (e.g., rates, velocities). These are quantitative requirements of system performance and are verifiable individually. Note that there may be more than one performance requirement associated with a single function, functional requirement, or task.	SEBoK (2023)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
		Operational Requirements	Define the operational conditions or properties that are required for the system to operate or exist. This type of requirement includes human factors, ergonomics, availability, maintainability, reliability, and security.	SEBoK (2023)
	Derived	Functional Requirements	Describe qualitatively the system functions or tasks to be performed in operation.	SEBoK (2023)
		System (Physical) Requirements	Define constraints on weight, volume, and dimension applicable to the system elements that compose the system.	SEBoK (2023)
		Interface Requirements	Define how the system is required to interact or to exchange material, energy, or information with external systems (external interface), or how system elements within the system, including human elements, interact with each other (internal interface). Interface requirements include physical connections (physical interfaces) with external systems or internal system elements supporting interactions or exchanges.	SEBoK (2023)
Risk	**Risks**	Risks	The potential that something will go wrong as a result of one or a series of events. It is measured as the combined effect of the probability of occurrence and the assessed consequence given the occurrence.	Vaneman et al. (2022)

Entity Class	Entity Subclass	Data Type	Data Type Definition	Definition Source
Time	**Time**	Event	Something that happens at an instant in the world, i.e., a near-zero-duration process (Activity).	DOD (2010)
		Milestone	Something that happens at an instant in the world, i.e., a zero-duration process (Activity).	DOD (2010)
		Phasing/ Evolution/ Forecast	Phase: A stage in a process of change or development. Evolution: Any process of formation or growth; development. Forecast: To predict a future condition or occurrence.	DOD (2010)

LIST OF REFERENCES

AcqNotes. 2023. "Program Management Tool for Aerospace." https://acqnotes.com/.

Berger, David H. 2019. *Commandant's Planning Guidance*. Washington, DC. United States Marine Corps. https://www.hqmc.marines.mil/Portals/142/Docs/%2038th%20Commandant%27s%20Planning%20Guidance_2019.pdf?ver=2019-07-16-200152-700

———. 2020. *Force Design 2030*. Washington, DC. United States Marine Corps. https://www.hqmc.marines.mil/Portals/142/Docs/CMC38%20Force%20Design%202030%20Report%20Phase%20I%20and%20II.pdf?ver=2020-03-26-121328-460.

Blanchard, Benjamin S. and Wolter J. Fabrycky. 2011. *Systems Engineering and Analysis.* 5th ed. Upper Saddle River, NJ: Pearson Hall.

Buede, D. 2009. *The Engineering Design of Systems.* Hoboken, NJ: John Wiley and Sons, Inc.

Defense Acquisition University. 2022. *Product Support Manager Guidebook*. Fort Belvoir, VA. https://www.dau.edu/tools/Lists/DAUTools/Attachments/129/Product-Support-Manager-(PSM)-Guidebook.pdf

———. 2023. "Glossary of Defense Acquisition Acronyms and Terms." https://dau.edu/glossary.

Department of the Army. 2018. *Policies and Management for Training Aids, Devices, Simulators, and Simulations.* AR 350-38. Washington, DC: Department of the Army. https://armypubs.army.mil/productmaps/pubform/Details.aspx?PUB_ID=1001898

Department of Defense. 2010. "The Department of Defense Architecture Framework Version 2.02." https://dodcio.defense.gov/library/dod-architecture-framework.

———. 2011. *Guidance for the Defense Readiness Reporting System (DRRS).* DOD Instruction 7730.66. Washington, DC: Department of Defense. https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/773066p.pdf

———. 2018a. *Department of Defense Digital Engineering Strategy.* Washington, DC: Office of the Deputy Assistant Secretary of Defense for Systems Engineering. https://ac.cto.mil/wp-content/uploads/2019/06/2018- Digital-Engineering-Strategy_Approved_PrintVersion.pdf.

———. 2018b. *National Defense Strategy*. Washington, DC: Department of Defense. https://dod.defense.gov/Portals/1/Documents/pubs/2018-National-Defense-Strategy-Summary.pdf

Department of the Navy. 2020. *United States Navy and Marine Corps Digital Engineering Transformation Strategy*. Washington, DC: Department of the Navy. https://go.usa.gov/xfQpx.

———. 2021. *Tentative Manual for Expeditionary Advances Base Operations*. PCN 501 007704 00. Washington, DC: Headquarters United States Marine Corps.

———. 2022. *Activity Manpower Management Guide*. Washington, DC: Department of the Navy. https://www.mynavyhr.navy.mil/Portals/55/NAVMAC/Documents/AMMG%20MAY%202022.pdf?ver=6UoTwk5ZEZcMYlVar9oCaQ%3d%3d

Giachetti, Ronald E., and Warren Vaneman. 2021. "Requirements for a System Model in the Context of Digital Engineering." In *2021 IEEE International Systems Conference (SysCon)*, 1–7. https://doi.org/10.1109/SysCon48628.2021.9447088.

Holt, Jon, and Simon Perry. 2019. *SysML for Systems Engineering – A Model-Based Approach.* 3rd ed. (The IET). Institution of Engineering and Technology. https://app.knovel.com/hotlink/toc/id:kpSMLSEA0L/sysml-systems-engineering/sysml-systems-engineering.

Joint Chiefs of Staff. 2007. *Doctrine for Irregular Warfare (IW) and Joint Operating Concept (JOC)*. IW. Washington, DC: Joint Chiefs of Staff. https://www.jcs.mil/Portals/36/Documents/Doctrine/concepts/joc_iw_v1.pdf?ver=2017-12-28-162020-260.

———. 2019a. *Doctrine for Joint Logistics.* JP 4. Washington, DC: Joint Chiefs of Staff. https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp4_0ch1.pdf?ver=2020-07-20-083800-823.

———. 2019b. *United States Government Compendium of Interagency and Associated Terms*. Washington, DC: Joint Chiefs of Staff. https://www.jcs.mil/Portals/36/Documents/Doctrine/dictionary/repository/usg_compendium.pdf?ver=2019-11-04-174229-423

Lifecycle Modeling Language Steering Committee. 2022. *Lifecycle Modeling Language (LML) Specification (v. 1.3).* Manassas, VA: LML Steering Committee. https://22132398.fs1.hubspotusercontent-na1.net/hubfs/22132398/LML%20specification%201.3%20(1).pdf.

Long, David. 2020. "Schema and Metamodels and Ontologies, Oh My!" YouTube video, December 3, 2020, 50.46. https://www.youtube.com/watch?v=47qCVelLiUE&t=1718s.

Long, David, and Zane Scott. 2011. *A Primer for Model-Based Systems Engineering.* 2nd ed. Blacksburg, VA: Vitech.

Lu, Jinzhi, Junda Ma, Xiaochen Zheng, Guoxin Wang, Han Li, and Dimitris Kiritsis. 2022. "Design Ontology Supporting Model-Based Systems Engineering Formalisms." *IEEE Systems Journal* 16, no. 4 (December): 5465–5476. https://doi.org/10.1109/JSYST.2021.3106195.

Marine Corps Task List Branch. 2023. *Marine Corps Task List*. MCTL–2.0. Quantico, VA. Capabilities Development Directorate. https://www.cdi.marines.mil/Portals/172/MCTL%202_0%20Word%20Doc%201%20FEB%202023.docx.

Roedler, Garry J., and Cheryl Jones. 2005. *Technical Measurement. A Collaborative Project of PSM, INCOSE, and Industry.* Technical Report, INCOSE-TP-2003-020-01. https://www.acqnotes.com/Attachments/INCOSE%20Technical%20Performance%20Measurements%20by%20Roedler%20and%20Jones,%20Dec%2005.pdf

SEBoK contributors. 2023. "Guide to the Systems Engineering Body of Knowledge." SEBoK.https://sebokwiki.org/w/index.php?title=Guide_to_the_Systems_Engineering_Body_of_Knowledge_(SEBoK)&oldid=66886.

Smith, Barry. 2018. "Ontology for Systems Engineering." Presentation at Navy SYSCOM and DOD Ontology Workshop. September 19, 2018. https://buffalo.box.com/s/2hoet9ko03ylaz2o7nrhbl6fj15a4qm8.

Vaneman, Warren K. 2019. "Model Based Systems Engineering De Mystified." INCOSE Webinar 121, February 20, 2019, 57:24. https://connect.incose.org/Library/Webinars/Documents/INCOSE%20Webinar%20121%20Model%20Based%20Systems%20Engineering%20Demystified.mp4.

Vaneman, Warren. 2022. "MBSE Structures." Class notes for SE4930: Model-Based Systems Engineering, Naval Postgraduate School, Monterey, CA. https://cle.nps.edu/access/content/group/db46b2d2-2c3a-462a-9fc3-53b863247315/Module%204%20-%20Notes/M04-2%20Model%20Structure.pdf.

Vaneman, Warren K, and Ronald Carlson. 2019. "Model-Based Systems Engineering Implementation Considerations." In *2019 IEEE International Systems Conference* 1–6. https://doi.org/10.1109/SysCon2019.8836888.

Vaneman, Warren K., Ron. R. Carlson, Corina White, and Raymond J. Stone. 2022. *Developing an MBSE Land Domain Construct for Marine Corps Systems Command*. Report No. NPS-SE-22-004. Monterey, CA: Naval Postgraduate School, https://apps.dtic.mil/sti/pdfs/AD1184547.pdf

THIS PAGE INTENTIONALLY LEFT BLANK

INITIAL DISTRIBUTION LIST

1. Defense Technical Information Center
   Ft. Belvoir, Virginia

2. Dudley Knox Library
   Naval Postgraduate School
   Monterey, California