NATIONAL CENTER FOR MANUFACTURING SCIENCES

NAMKDS

Naval Additive Manufacturing Knowledge Delivery System

Blueprint Project and Descriptions

Final Report

Prepared under:

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for the
Commercial Technologies for Maintenance Activities (CTMA) Program

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Acronyms and Abbreviations

3D	Three Dimensional
AM	Additive Manufacturing
APEX	Application Express
ATO	Authority to Operate
BDAR	Battle Damage Assessment & Repair
BPA	Business Process Analysis
BPM	Business Process Modeling
BPMN	Business Process Model and Notation
COTS	Commercial Off-the-Shelf
CTMA	Commercial Technologies for Maintenance Activities
DLA	Defense Logistics Agency
DoD	Department of Defense
EPS	Electronic Procurement System
FIIRE	Facilitated & Interactive, Idea Remote Evaluation
GOTS	Government Off-the-Shelf
IGOE	Inputs, Guides, Outputs and Enablers
IT	Information Technology
LCC	Lifecycle Cost
NAMKDS	Naval Additive Manufacturing Knowledge Delivery System
NAVFAC	Naval Facilities Engineering Command
NCMS	National Center for Manufacturing Sciences
OV1	Overarching View Level 1/ Operational View Level 1
PEO	Program Executive Officer
PLM	Product Lifecycle Management
RC-AM	Required Capabilities for Additive Manufacturing
SPIDERS	Specialized Infrastructure Data Enterprise Reporting System
UAT	User Acceptance Testing
UGG	United Global Group

1. Executive Summary

Naval Facilities Engineering Command (NAVFAC) currently manages the Specialized Infrastructure Data Enterprise Reporting System (SPIDERS 3D) which is an easy-to-use, browser-based, N4 Logistics Information Technology (IT) Defense Business System application allowing users to employ three-dimensional (3D) visualizations to understand facility impacts resultant of the introduction of new platforms, systems, and subsystems. SPIDERS 3D permits advance planning of geospatial-based concepts, ship berthing and aircraft laydown scenarios, a repository of 3D models, real-time enterprise collaboration for multi-functional working groups and users, and much more.

The Naval Additive Manufacturing Knowledge Delivery System (NAMKDS) concept is an expeditionary ecosystem of Activities, Participants, and Information to share, learn and engage on everything 3D. The vision of this effort goes beyond delivering files for 3D printers to include 3D models for virtual operational and logistics planning, CNC machines, technical publications, dynamic information sharing, and more. Envisioned as a web-enabled portal to the 3D Virtual Environment where a community of operators, logisticians, system managers, academia, and commercial industry can:

- **share** 3D models and technical information
- **learn** about 3D models and related subjects such as additive manufacturing (AM) and virtual reality
- **engage** in forums to share lessons-learned, tips, and tricks.

Lifecycle management of Navy and Marine Corps assets is enhanced when the physical world is transformed digitally into a 3D Virtual Environment (Figure 1). The scanning or development of 3D models as a "Digital Asset," coupled with support tools, permits operational and logistics leaders to plan and analyze in a virtual world proactively. This results in a better-informed decision-making process that enables optimal use of assets and the resources required to support them.

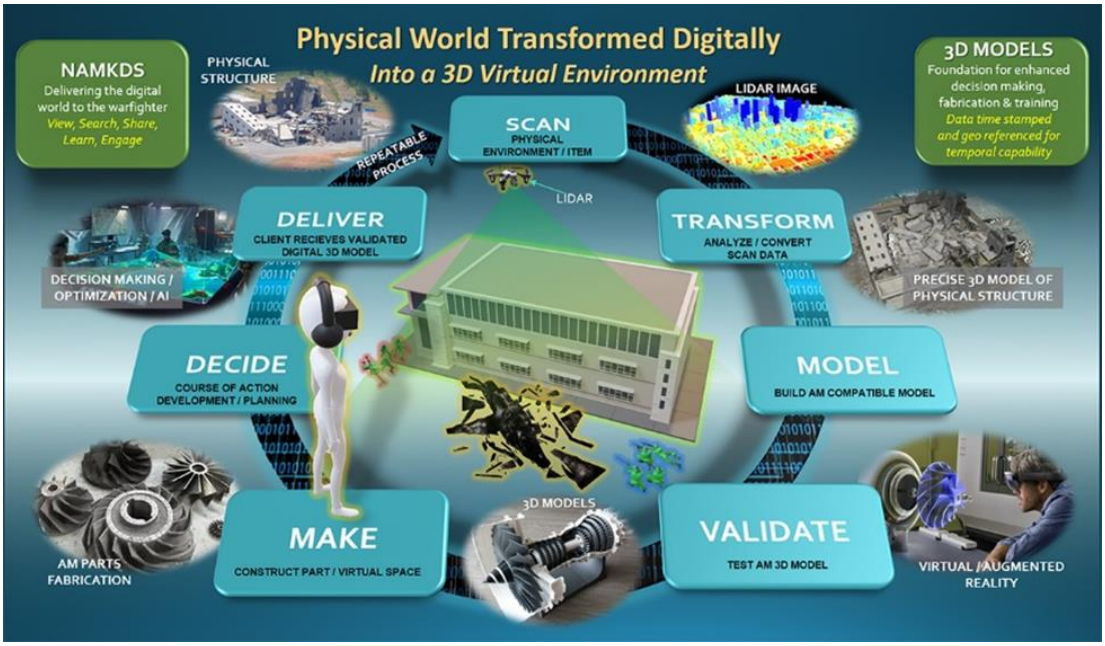


Figure 1. Envisioned 3D Virtual Environment

Funded through a Cooperative Agreement under the National Center for Manufacturing Sciences (NCMS) Commercial Technologies for Maintenance Activities (CTMA) Program, the project team members researched, collected and evaluated user needs and documented the initial risk for the NAMKDS environment. This information informed the research, requirements development, business processes, risk, and programmatic components surrounding the maturation of a Navy and Marine Corps 3D Virtual Environment.

1.1 Benefits to the General Public

The National Institute of Health has matured a web-enabled repository of 3D print files and knowledge. Likewise, there has been a rise in the desire to develop and sell 3D print files to consumers for licensing to enable consumer manufacturing as an alternative to tool a manufacturing production line. The capabilities of this benefit the public good interests by maturing an AM ecosystem that removes the growing concerns and expands 3D print capabilities.

As the Department of Defense (DoD) matures NAMKDS, the commercial sector will inherit a new entry point into the DoD digital marketplace where licenses are offered for government consumption. This shift in technology will supplement their manufacturing and sales of parts where they will realize a balance between their active and passive profits necessary to support innovation and a booming economy.

Maintenance and sustainment organizations will have a faster way to procure licenses from a library of 3D print files resulting in a reduced contract, production, and delivery lead-times. This time reduction increases exposure to new innovative solutions and reduces time-to-market by prototyping innovation solutions faster. Commercial industry will notice reduced investment costs by creating digital-parts made for 3D printing vice the traditional machining, molding, and production of parts to consumers.

The PLM and Blockchain components of NAMKDS will mitigate risk to the commercial industry by providing control of intellectual property. The commercial provider will be able to see printing trends to determine the lifecycle of their product licenses and understand consumer demands to innovate additional 3D print files for rapid consumer consumption. Blockchain technology will provide the necessary links between use-of-file and their related financial transactions to increase confidence and trust in managing the intellectual property. Consumer confidence will grow from having a delivery system that prevents knock-offs or intentional tampering of the desired product and manufacturer.

Additional benefits include:

- Risk mitigation from the verification of prototyped designs through 3D printed solutions.
- Increased learning by physically interacting with 3D printed items vice a visual representation on a computer screen.
- Improved control of intellectual property, traceability of provenance of digital data when developing new products in globally competitive markets and a secure means to share 3D print information.
- Increased quality by quickly prototyping and conducting market testing of the product before full production runs.

1.2 Benefit to DoD

DoD-wide maintainers and logisticians will benefit by having the ability to:

- Access 3D print files to help combat obsolescence, reduce long-lead times, offset unaffordable pricing, and support Battle Damage Assessment & Repair (BDAR) activities.

- Share locally-produced 3D print files and experiences with the AM enterprise.
- Locally access training and lessons learned to strengthen one's knowledge of AM.

The DoD-wide AM enterprise will benefit from the:

- Low-risk (TRL 6-7), affordable and sustainable open-standards-based Web3D technology foundation to support the logistics of maintenance and sustainment and logistics of 3D data positively.
- Feasible rapid scaling enterprise IT capability.
- Open-standards-based "mash-up" 3D environment that enables interoperability, contextualization and repurposing disparate 3D data.
- Real-time group collaboration across the DoD enterprise.
- Web-enabled delivery of 3D digital data and expeditionary facilities; fully accredited by engineering and safety assessments.
- Knowledge repository that delivers 3D technology information and training.

1.3 Project Partners

- U.S. Navy, Naval Facilities Engineering Command (NAVFAC) HQ, AM
- NAVFAC EXWC, EX53
- United Global Group (UGG)
- BMO Logistics
- CANA Advisors
- Synergy Software Design
- National Center for Manufacturing Sciences (NCMS)

2. Introduction

2.1 Background

NAVFAC is currently working to implement SPIDERS 3D to an open-source HTML/X3D rendering construct that will enable a level of digital thread standardization across 3D model-based visualization, 3D printing, 3D scanning, data compression, data security and metadata practices.

2.2 NAMKDS Project Team

Table 1 identifies the project team members in the CTMA NAMKDS initiative.

2.3 Problem Statement

Many of the existing population of 3D makers across AM enterprise have different file formats due to the printer's antiquity or by manufacturer's design. Dissimilar formats in engineering software, product lifecycle management (PLM) tools, and scanner-generated models requiring conversion for 3D printing further exacerbate the problem. The efforts of the 3MF Consortium (which is redefining 3D printing formats for evolving applications, platforms, services, and printers), only means changing formats and specifications in the future.[1]

Table 1. CTMA NAMKDS Team Members

Government Participants	
Mr. Alex Viana Program Manager NAVFAC, HQ, AM	**Mr. Todd Jonas** Functional Project Manager NAVFAC EXWC, EX53
Mr. Ray Wogec Technical Project Manager NAVFAC EXWC, EX53	
Industry Participants	
Dr. Larry Paige Industry Program Manager United Global Group	**Mr. Dana Ellis** Program Manager National Center for Manufacturing Sciences
Mr. Robert Persely Functional Lead BMO Logistics	**Mike Russalesi** Proof of Concept Program Manager Synergy Software Design
Mr. Bruce Tweedy Technical Analysis Team Member United Global Group	**Tom Cowan** Technical Analysis Team Member Synergy Software Design
Norman Reitter Senior VP Analytics Operations CANA Advisors	**Mr. Greg Miller** Wireframe Design Team Member Synergy Software Design
Terry Hagen Principal Logistics Analyst CANA Advisors	**Koa Beam** Lead Graphic Artist CANA Advisors

[1] *3MF Consortium*. (n.d.). Retrieved April 2017, from 3MF Consortium, a Joint Development Foundation project | Association management services by Virtual, Inc.: http://3mf.io/

The maintenance and sustainment community across public and commercial industries consistently face repair parts obsolescence. Data rights and availability of technical data packages are limited and in short supply across DoD and the general public domains. This limitation significantly affects the availability of 3D files leading to the need for a standardized, accredited, collaborative, and enduring source of knowledge, training, 3D file requisitioning, lessons learned, and safety and environmental specifications.

2.4 Solution

The NAMKDS concept (Figure 2) is an eco-system of Activities, Participants, and Information collaborating to share:

- Trusted and authoritative 3D models
- 3D knowledge
- 3D education to customers from DoD, NATO/ Coalition and 3D printer hardware.

At its foundation was an organizational structure resourced to govern and manage NAMKDS lifecycle. Technical, logistics, accounting and IT engineers supported the design, development, delivery, and maintenance and sustainment of NAMKDS functionality and content. Highly mature technologies were integrated to provide a backbone for an access-controlled, web-based system of "everything AM." NAMKDS allows consumers to: 1) search, request, and retrieve 3D print files, technical information, and shared knowledge, 2) share locally-developed 3D models for technical validation, and 3) share knowledge and experiences.

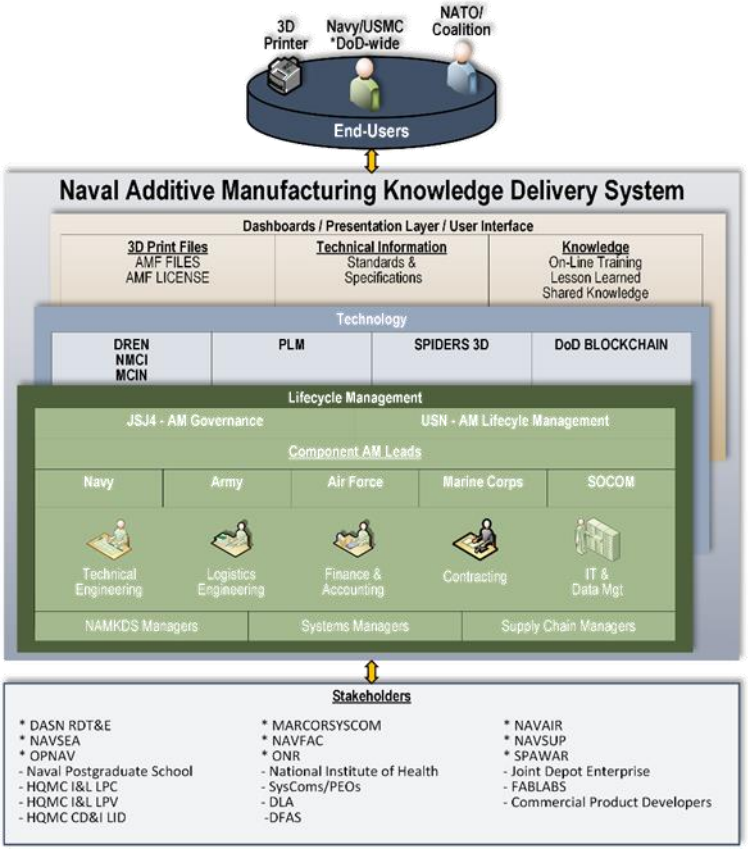


Figure 2. NAMKDS Concept

2.5 Objectives

The overall objective of NAMKDS was to provide a lifecycle management capability of "all things AM" where consumers have ready access to validated print files, technical information, training, and shared experiences. The commercial and public entities will realize lower costs for maintenance and sustainment of equipment and a reduction in the cost of supply, transportation, and distribution channels for repair parts. To meet these ends, the goals were:

- Launch a ready-exploitation of open-sourced, web-based 3D graphics standards to rapidly enable and scale an enterprise-shared 3D visualization for product model optimization, and secure/standardized/sustainable delivery of 3D digital data to facilitate AM capabilities for end-users.
- Build on demonstrated web-enabled IT techniques to establish the capability to standardize disparate 3D product models, create enterprise data repository/archiving, and deliver optimized digital AM files efficiently over the web across multiple government and industry IT domains.
- Provide a web-based, user-interactive dashboard for understanding coverage and gaps in standards and AM files usage across the enterprise.
- Integrate BlockChain technology for maintaining a digital ledger of transactions. Primarily financial and accounting, the concept extended to the main activities of PLM and the exchange and commercial licensing of AM files, knowledge, and training.
- Use DoD-wide and commercial logistics data to identify performance and cost baselines. Provide web-based dashboard and use open-source data analytics tools for understanding the impact of the application of AM standards and implementations on performance and cost trade-offs between inventory, obsolescence, distribution, and maintenance and sustainment current vs. future states.

2.6 Overarching Approach

A collaboration between government, academia, and commercial industry participants worked to integrate efforts concentrated on defining and maturing NAMKDS. The participants identified and combined best practices with open-source and highly mature technologies existing in both government and commercial sectors. The overall implementation approach of NAMKDS consists of a series of capability and functionality maturity blocks as follows:

- Block 1 – NAMKDS Definition Blueprint
- Block 2 – Technology Pilot
- Block 3 – Lifecycle Management Pilot
- Block 4 – External System Integration
- Block 5 – DoD BlockChain Integration
- Block 6 – Joint/NATO Integration
- Block 7 – Maintenance & Sustainment

This CTMA NAMKDS initiative executed *Block 1* which is the end-to-end description of NAMKDS documented into a Definition Blueprint. The assembly of this final report is as follows:

- **Section 3 – Blueprint**
  Overview of the Blueprint Diagrams and describes each component of the diagram. Presented out of sequence, however, given up front for the reader to get to the final results first.
- **Section 4 – Methodology**
  Overview of the procedures to mature information and content for the Blueprint.
- **Section 5 – Business Process Requirements**
  Overview the maturation of the Business Process Analysis (BPA) and Business Process Modeling (BPM) efforts.

- **Section 6 – 3D Virtual Environmental System Design**
  Overviews of the architecture, components, data, security, accreditation, and development approach of NAMKDS.

- **Section 7 – PLM Approach**
  Overview of test strategies, NAMKDS management, design options, and initial lifecycle implications.

3. Blueprint

3.1 Blueprint – 3D Virtual Environment Summaries

On the path to creating the NAMKDS Blueprint, mature, relevant, and evidence-based artifacts were devised, developed, and documented using tailorable BPA and system engineering processes. The philosophy of the CTMA NAMKDS team was to produce a Blueprint with a visually appealing artistry that was integrated with high-quality substance and thorough research. How the evidence for the Blueprint was collected is outlined in Section 4 of this report.

The CTMA NAMKDS outputs consisted of two Blueprints that overview the end-to-end descriptions of NAMKDS to inform Block 1 through Block 7 activities. The remainder of this section overviews the two Blueprints:

1. 3D Virtual Environment Summaries by Weapon System, Facility, and Medical Lifecycle Managers
2. 3D Virtual Environment Summaries by Education and Research; and Supply and Logistics Chain Manager

3.1.1 3D Virtual Environment Summaries by Weapon System, Facility, and Medical Lifecycle Managers

Figure 3 illustrates the business process interactions between NAMKDS, end-users, and stakeholders with a concentration on the Weapon System, Facility, and Medical Lifecycle Managers. Along the periphery are key components and capabilities inherent to the NAMKDS ecosystem.

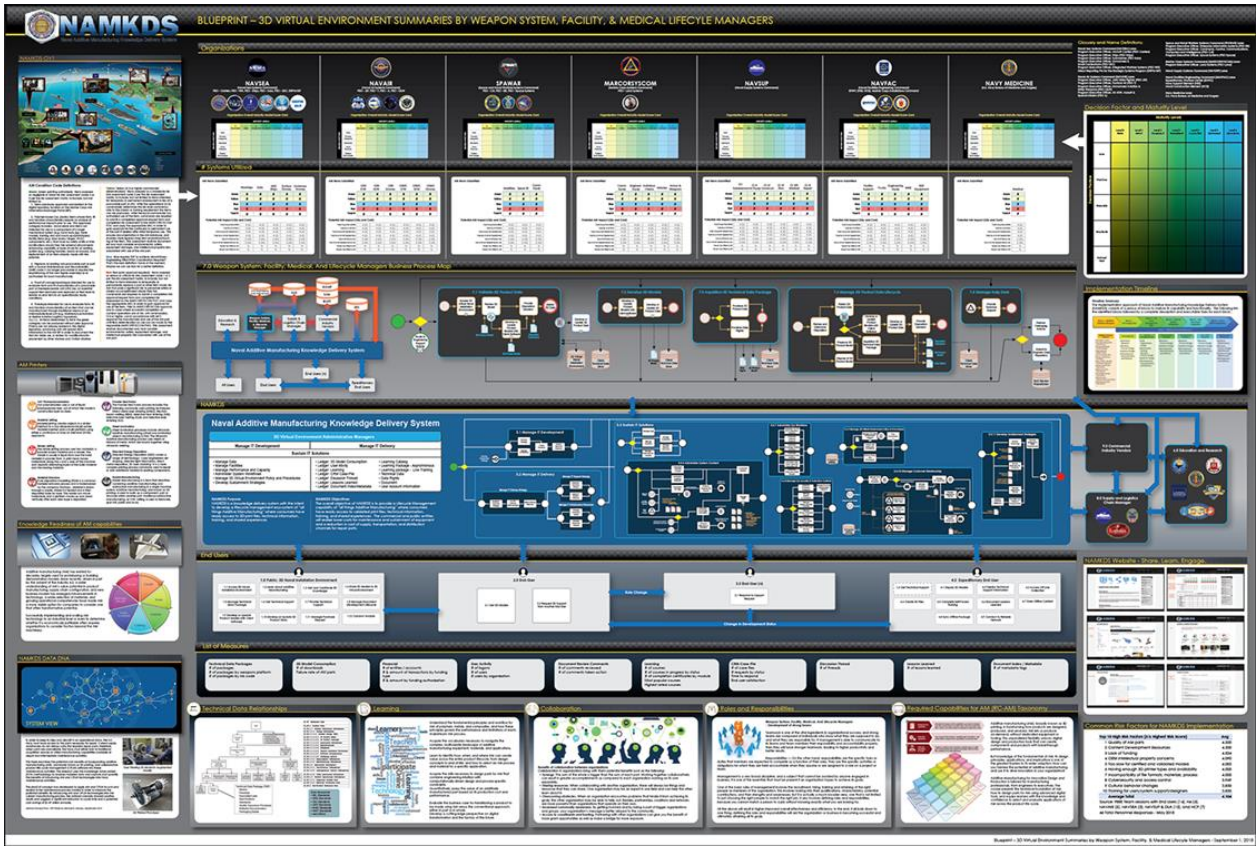


Figure 3. 3D Virtual Environment Summaries by Weapon System, Facility, and Medical Lifecycle Managers

3.1.2 3D Virtual Environment Summaries by Education and Research; and Supply and Logistics Chain Manager

Figure 4 illustrates the business process interactions between NAMKDS, end-users, and stakeholders with a concentration on the Education and Research; and Supply and Logistics Chain Manager. Along its periphery are key components and capabilities inherent to the NAMKDS ecosystem.

3.2 Blueprint – 3D Virtual Environment Summaries Components

The following section overviews the common components making up the two 3D Virtual Environment Summaries discussed previously.

3.2.1 Business Process Overarching View Level 1 (OV1)

Derived from the business processes efforts, the Business Process OV1 illustrates the stake-holder interactions with NAMKDS (Figure 5). The center of the diagram is NAMKDS. Below NAMKDS, is the customer perspective interactions of: 1) *All Users*, 2) *End-User*, 3) *End-User (n)*, and 4) *Expeditionary End-User*. Above NAMKDS is the interactions of the supporting participants and the conventional external data systems where NAMKDS must interact. It is not the intent of NAMKDS to assimilate existing make/buy processes of product data; instead, it is the intent to integrate with mature product data for NAMKDS customer's consumption.

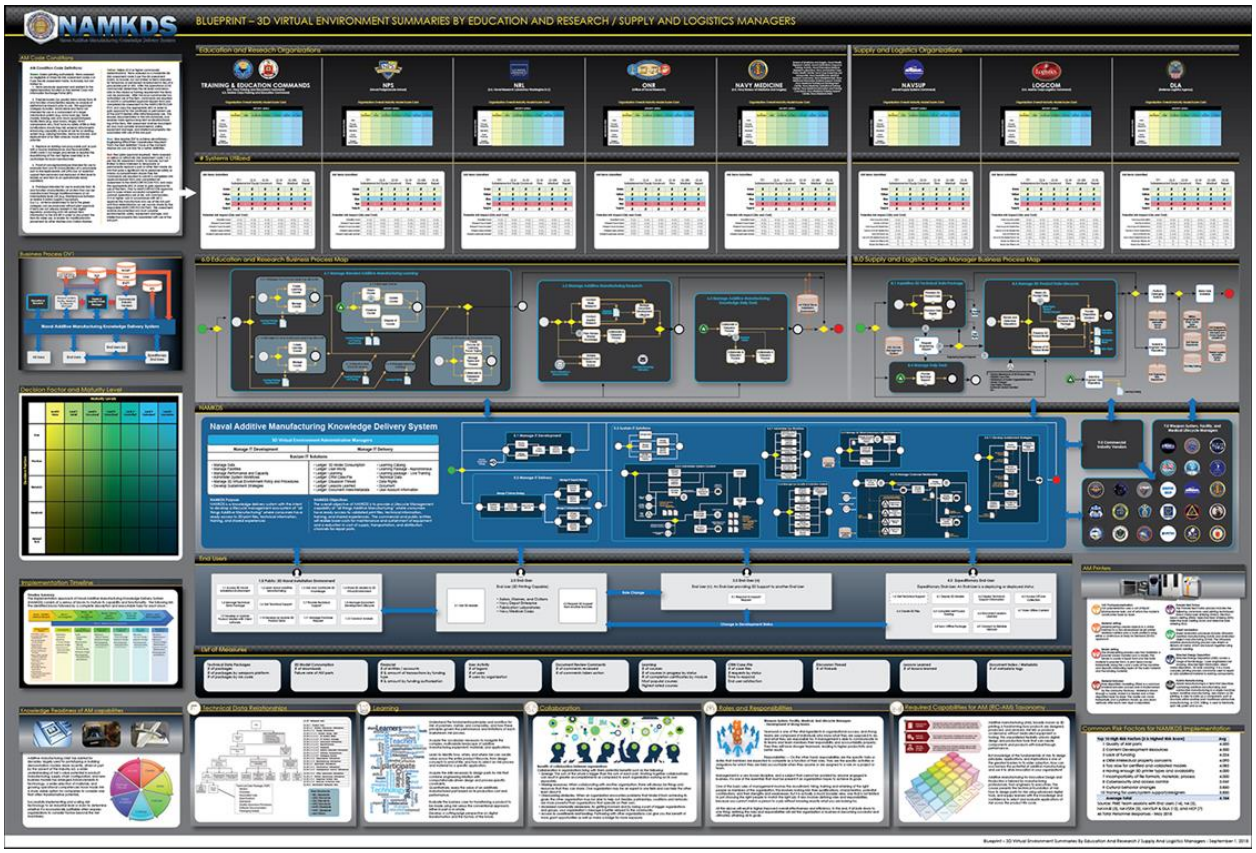


Figure 4. 3D Virtual Environment Summaries by Education and Research; and Supply and Logistics Chain Manager

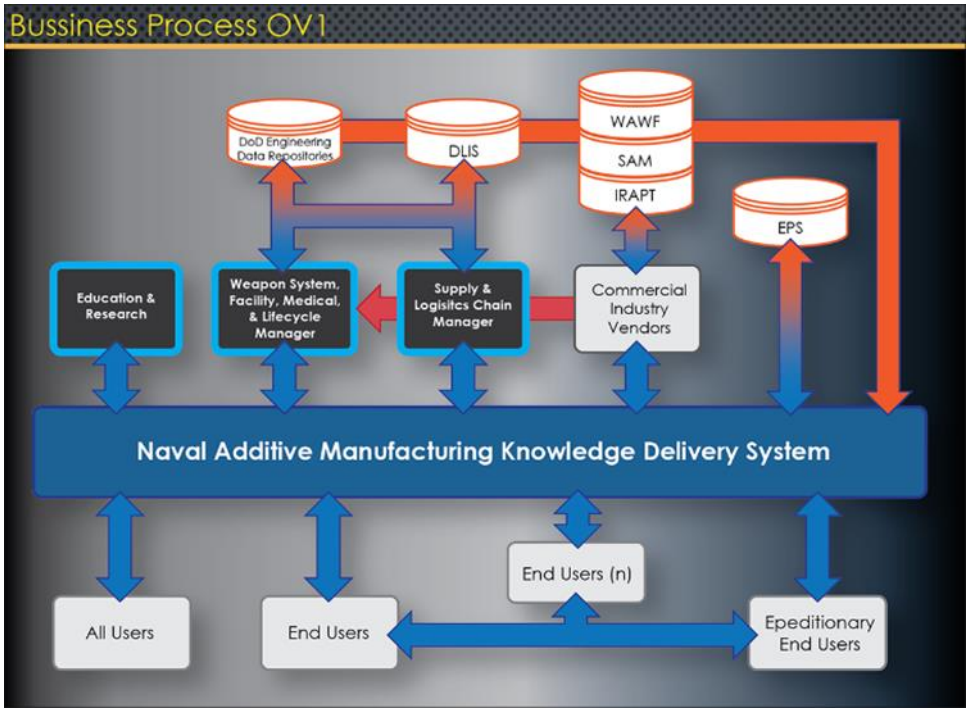


Figure 5. Business Process OV1

3.2.2 NAMKDS Operational View Level 1 (OV1)

The NAMKDS OV1 diagram depicts an operationalized enterprise where the application of NAMKDS is necessary (Figure 6). Due to the expeditionary nature of Navy and Marine Corps Forces, NAMKDS maturation considers the expeditionary environments on land, sea (surface and sub-surface), air, and space. Also, NAMKDS considers the delivery of 3D information for bases, posts, and stations. A key component of NAMKDS is the ability to make use of 3D models in both high-, low-, and no-bandwidth environments.

3.2.3 AM Condition Code Definitions

Navy and Marine Corps organizations categorize 3D models into several condition codes to determine print worthiness application to the respective platform (Figure 7). As NAMKDS matures its capabilities, additional 3D model categorizations for virtual planning and virtual analytics will emerge. NAMKDS will continually coordinate with respective organizations and maintain the accessibility, information, and warnings necessary to alert users of appropriate business rules.

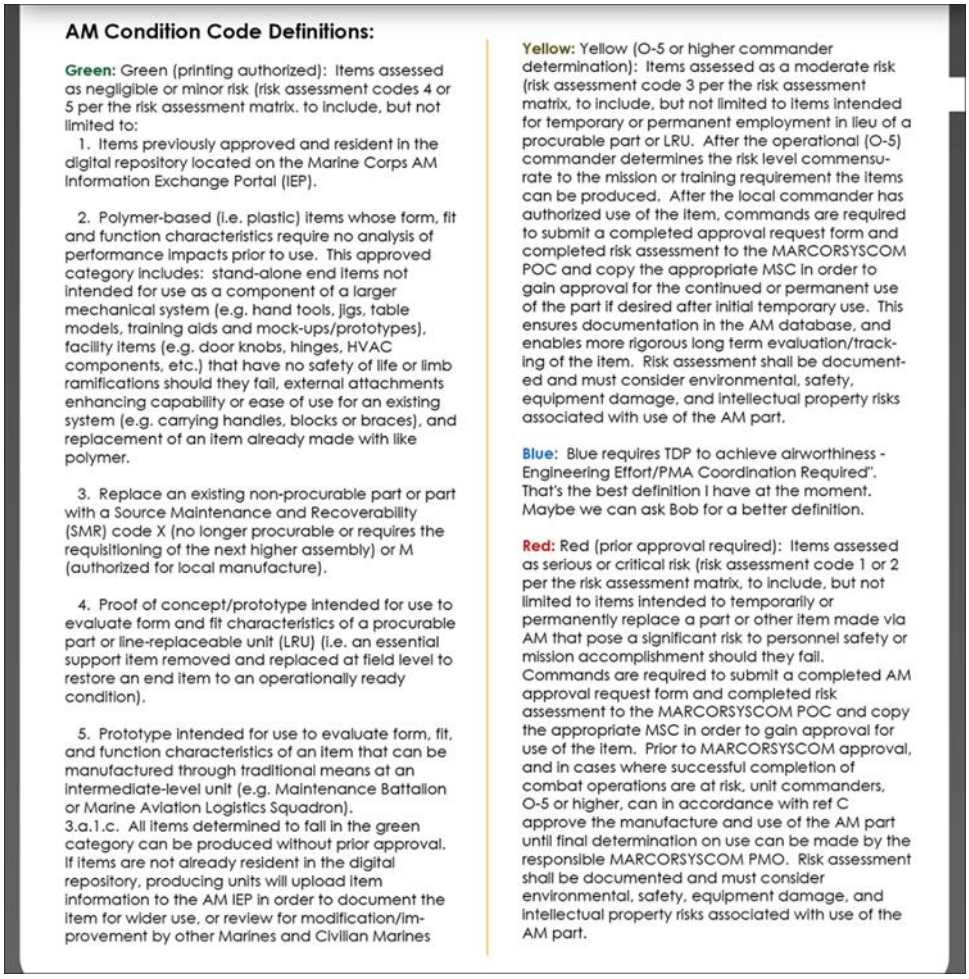
3.2.4 Condition Codes Matrix

As a dashboard item, NAMKDS must provide the stakeholders perspective into the categorization of the items (Figure 8). Using a dimensional view of the categories, stakeholders are enabled to track the type, quantity, and cost. Also, stakeholders can identify which parts could be part of the AM environment by organization and domain.

3.2.5 AM Printers

3D model formats are relevant to printer types, purpose and categories. The file format is influenced by the nature of printing, printer manufacturer, printer model, and more (Figure 9). NAMKDS must consider the kinds of demands by printer types to affect cataloging, browsing, conversion, and delivery of 3D models.

Figure 6. NAMKDS OV1



AM Condition Code Definitions:

Green: Green (printing authorized): Items assessed as negligible or minor risk (risk assessment codes 4 or 5 per the risk assessment matrix. to include, but not limited to:

1. Items previously approved and resident in the digital repository located on the Marine Corps AM Information Exchange Portal (IEP).

2. Polymer-based (i.e. plastic) items whose form, fit and function characteristics require no analysis of performance impacts prior to use. This approved category includes: stand-alone end items not intended for use as a component of a larger mechanical system (e.g. hand tools, jigs, table models, training aids and mock-ups/prototypes), facility items (e.g. door knobs, hinges, HVAC components, etc.) that have no safety of life or limb ramifications should they fail, external attachments enhancing capability or ease of use for an existing system (e.g. carrying handles, blocks or braces), and replacement of an item already made with like polymer.

3. Replace an existing non-procurable part or part with a Source Maintenance and Recoverability (SMR) code X (no longer procurable or requires the requisitioning of the next higher assembly) or M (authorized for local manufacture).

4. Proof of concept/prototype intended for use to evaluate form and fit characteristics of a procurable part or line-replaceable unit (LRU) (i.e. an essential support item removed and replaced at field level to restore an end item to an operationally ready condition).

5. Prototype intended for use to evaluate form, fit, and function characteristics of an item that can be manufactured through traditional means at an intermediate-level unit (e.g. Maintenance Battalion or Marine Aviation Logistics Squadron).

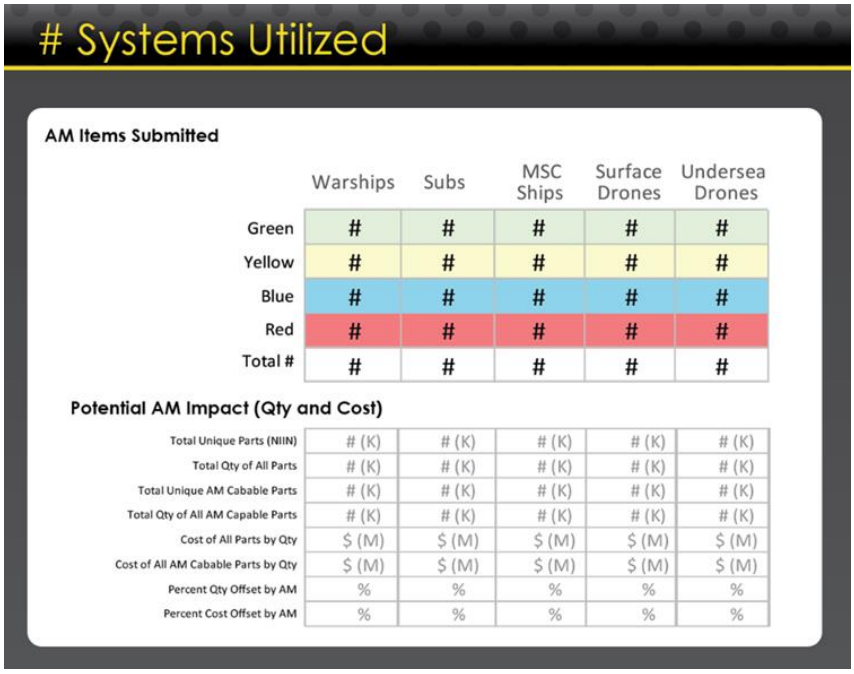
3.a.1.c. All items determined to fall in the green category can be produced without prior approval. If items are not already resident in the digital repository, producing units will upload item information to the AM IEP in order to document the item for wider use, or review for modification/improvement by other Marines and Civilian Marines

Yellow: Yellow (O-5 or higher commander determination): Items assessed as a moderate risk (risk assessment code 3 per the risk assessment matrix, to include, but not limited to items intended for temporary or permanent employment in lieu of a procurable part or LRU. After the operational (O-5) commander determines the risk level commensurate to the mission or training requirement the items can be produced. After the local commander has authorized use of the item, commands are required to submit a completed approval request form and completed risk assessment to the MARCORSYSCOM POC and copy the appropriate MSC in order to gain approval for the continued or permanent use of the part if desired after initial temporary use. This ensures documentation in the AM database, and enables more rigorous long term evaluation/tracking of the item. Risk assessment shall be documented and must consider environmental, safety, equipment damage, and intellectual property risks associated with use of the AM part.

Blue: Blue requires TDP to achieve airworthiness - Engineering Effort/PMA Coordination Required". That's the best definition I have at the moment. Maybe we can ask Bob for a better definition.

Red: Red (prior approval required): Items assessed as serious or critical risk (risk assessment code 1 or 2 per the risk assessment matrix, to include, but not limited to items intended to temporarily or permanently replace a part or other item made via AM that pose a significant risk to personnel safety or mission accomplishment should they fail. Commands are required to submit a completed AM approval request form and completed risk assessment to the MARCORSYSCOM POC and copy the appropriate MSC in order to gain approval for use of the item. Prior to MARCORSYSCOM approval, and in cases where successful completion of combat operations are at risk, unit commanders, O-5 or higher, can in accordance with ref C approve the manufacture and use of the AM part until final determination on use can be made by the responsible MARCORSYSCOM PMO. Risk assessment shall be documented and must consider environmental, safety, equipment damage, and intellectual property risks associated with use of the AM part.

Figure 7. AM Condition Code Definitions



Systems Utilized

AM Items Submitted

	Warships	Subs	MSC Ships	Surface Drones	Undersea Drones
Green	#	#	#	#	#
Yellow	#	#	#	#	#
Blue	#	#	#	#	#
Red	#	#	#	#	#
Total #	#	#	#	#	#

Potential AM Impact (Qty and Cost)

Total Unique Parts (NIIN)	# (K)	# (K)	# (K)	# (K)	# (K)
Total Qty of All Parts	# (K)	# (K)	# (K)	# (K)	# (K)
Total Unique AM Cabable Parts	# (K)	# (K)	# (K)	# (K)	# (K)
Total Qty of All AM Capable Parts	# (K)	# (K)	# (K)	# (K)	# (K)
Cost of All Parts by Qty	$ (M)	$ (M)	$ (M)	$ (M)	$ (M)
Cost of All AM Cabable Parts by Qty	$ (M)	$ (M)	$ (M)	$ (M)	$ (M)
Percent Qty Offset by AM	%	%	%	%	%
Percent Cost Offset by AM	%	%	%	%	%

Figure 8. Condition Code Matrix

Figure 9. AM Printers

3.2.6 Knowledge Readiness of AM Capabilities

Figure 10 depicts the lifecycle for management of 3D modes. How decisions are made and how the capability is created leads to the sharing, validation, cataloging, management, availability, and access of 3D models for NAMKDS.

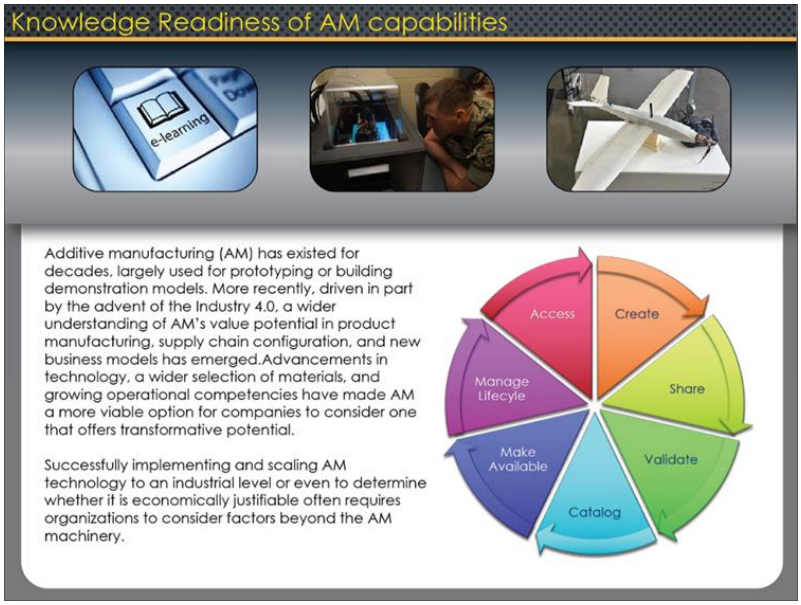


Figure 10. Knowledge Readiness of AM Capabilities

3.2.7 NAMKDS Data DNA

The Data DNA is representative of many enterprise data nodes that implicate NAMKDS capabilities development (Figure 11). Navy and Marine Corps enterprise business systems with interconnections with DoD agencies, Joint Services, and commercial industry, as examples, will enable machine learning. The maturation of their taxonomies and ontologies will result in a system where a 3D virtual world can be overlaid with cognitive information about operations, logistics, readiness, systems, facilities, human health, decision patterns, and more. These capabilities will be closer to reality as the NAMKDS components mature.

3.2.8 Technical Data Relationships

Many relevant technical data standards and specifications currently exist or are in development (Figure 12). The purpose of this component is to communicate the lack of need for additional specification and definitions relative to NAMKDS. The data management maturity will consider and apply the applicable data standards and specifications to enable dynamic search capabilities, robust analytics, the various levels of management attributes for the digital asset lifecycle.

Figure 11. NAMKDS Data DNA

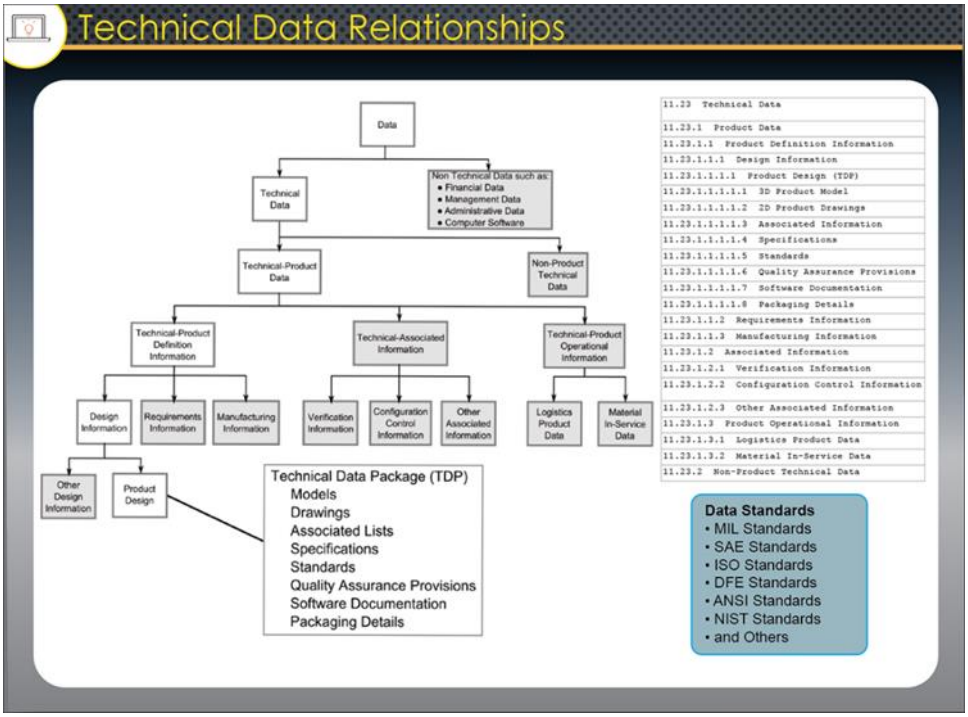


Figure 12. Technical Data Relationships

3.2.9 Learning

Stakeholder elicitation during this effort revealed the need to enable users to learn about 3D models, 3D printers, conversion, and more (Figure 13). The capability to share and access, formal and informal, video; technical manuals, instructions, research papers, and training will mature quickly in the early maturation blocks of NAMKDS. The end-state is to have the ability to provide instructor-led, web-enabled training and access to training modules from similar to or linked to organization's offerings such as the Defense Acquisition University.

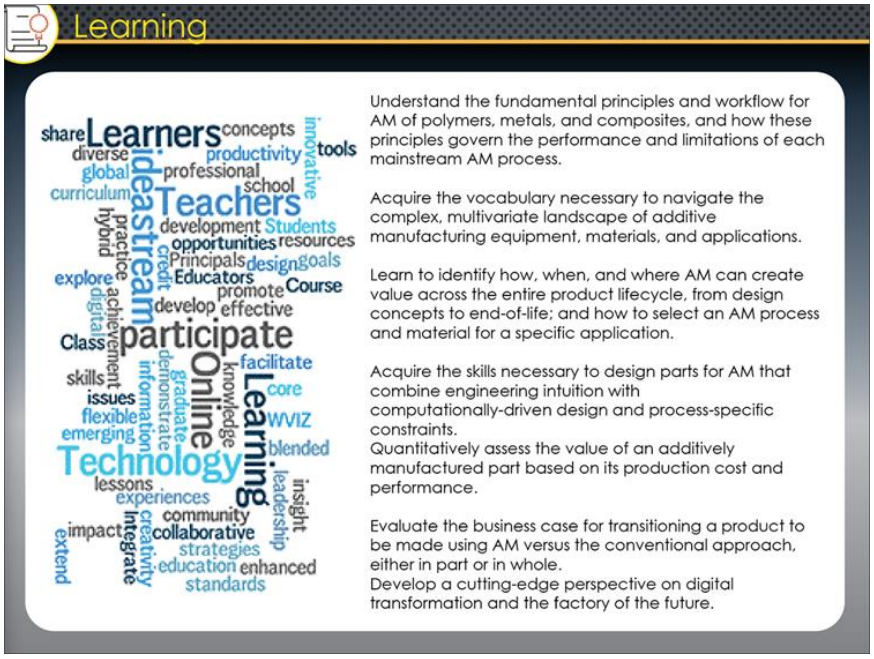


Figure 13. Learning

3.2.10 Collaboration

An essential capability of NAMKDS is the ability of individuals to engage in community forums (Figure 14). Forum topics for lessons learned, system specific, printer specific, and operational environments are a few examples.

3.2.11 Roles and Responsibilities

The need for defined roles and responsibilities is necessary to ensure safe, secure and productive use of 3D models to meet mission requirements (Figure 15). Security, access, data rights, model maturity, and user qualifications are a few examples NAMKDS will endeavor to manage and control in the 3D Virtual Environment.

Figure 14. Collaboration

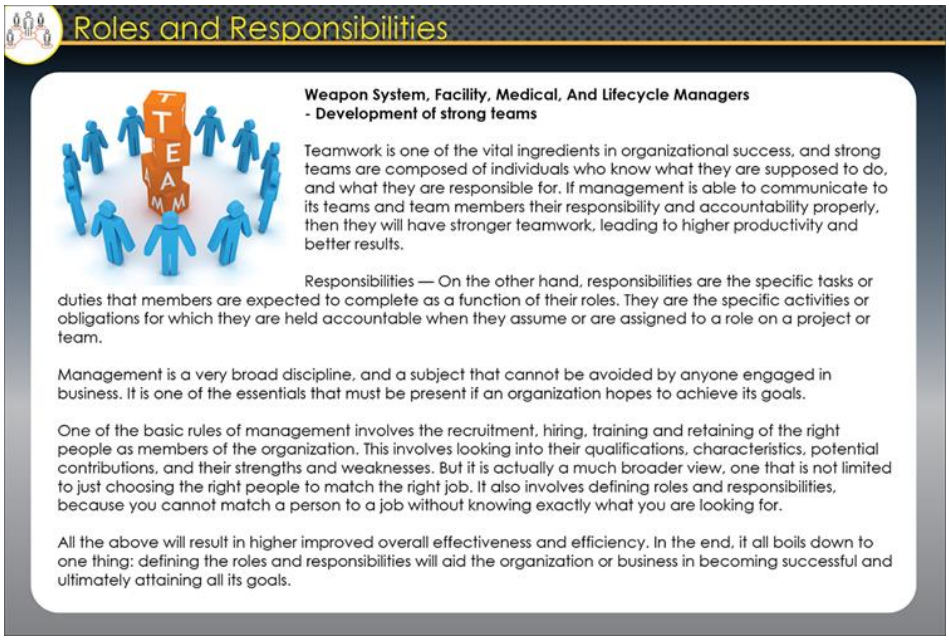


Figure 15. Roles and Responsibilities

3.2.12 Required Capabilities for AM (RC-AM) Taxonomy

Quality, inspections, security, and other dimensional aspects of the data environment demands the definition of taxonomies for the 3D Virtual Environment (Figure 16). This aspect overviews the initial thoughts that NAMKDS will enable the blueprinting, building, and scaling of efforts and projects to take full advantage of AM and 3D virtualization. Relative to the NAMKDS Data DNA that is a global view, this portion is internal to the Navy and Marine Corps 3D Virtual Environment to enable machine learning for knowledge and cognitive processes dimensions.

3.2.13 Common Risk Factors for NAMKDS Implementation

Risk management is the identification, management, and resolution of project and program threats. During Navy and Marine Corps stakeholder engagements, participants contributed in an initial risk assessment. This portion of the model identified the need for risk management and recognized the stakeholder efforts to guide the project's risk management efforts (Figure 17).

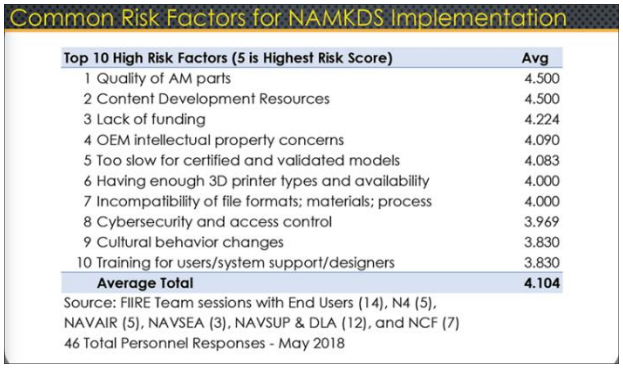


Figure 17. Common Risk Factors for NAMKDS Implementation

3.2.14 Implementation Timeline

Figure 18 illustrates the portion of the Blueprint which recognizes the incremental maturity of NAMKDS.

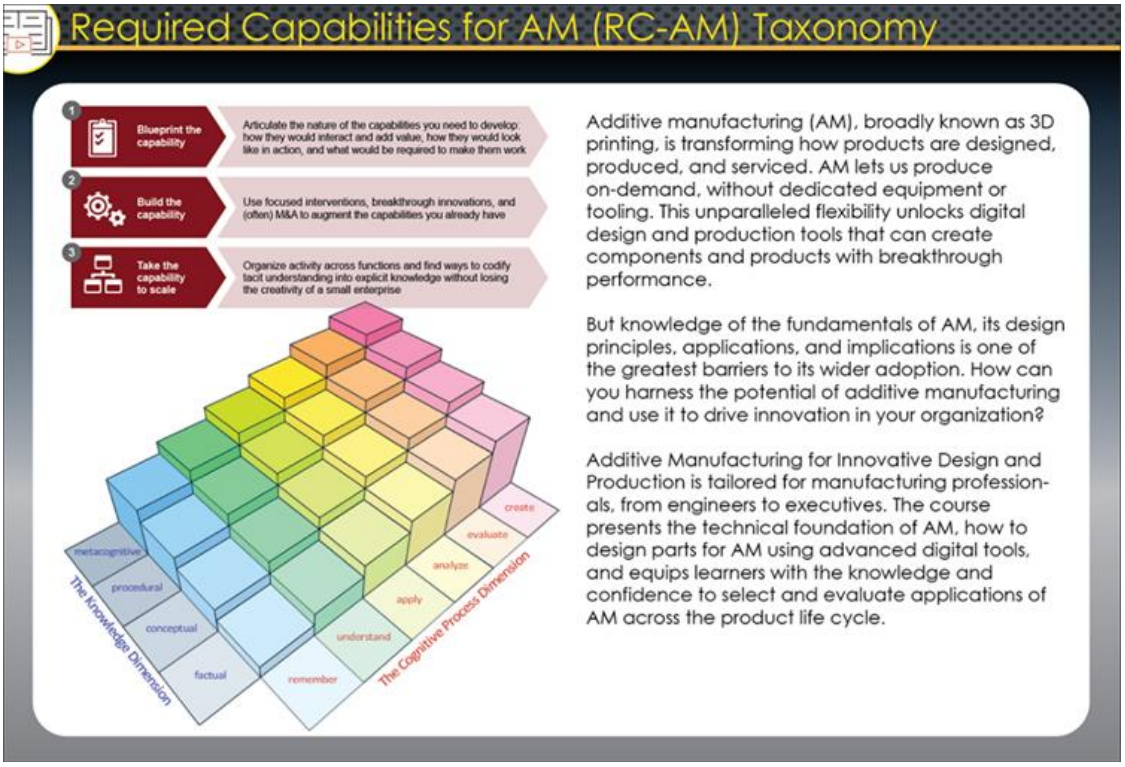


Figure 16. Required Capabilities for AM (RC-AM) Taxonomy

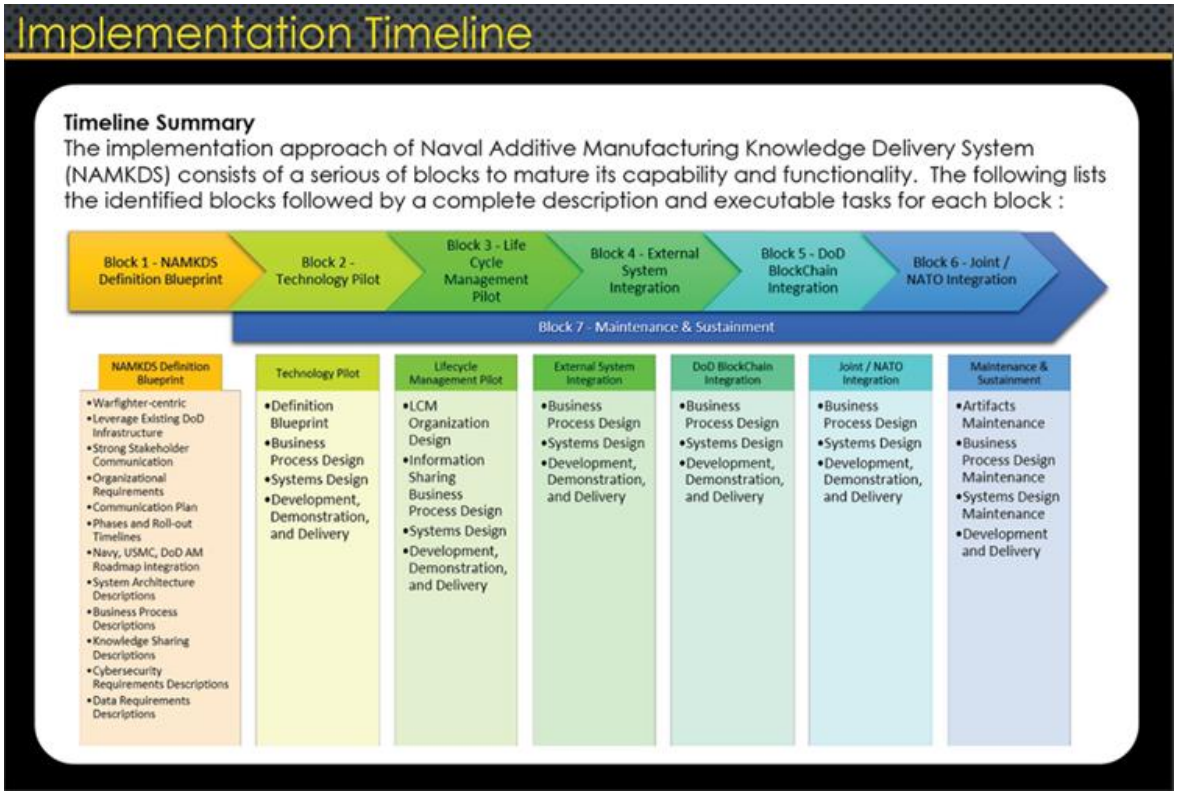


Figure 18. Implementation Timeline

3.2.15 Organization Overall AM Maturity Model Score Card

Traditional to any maturity model, varying levels and subject areas define the attributes for improvement based on organizational business processes, capabilities, technology, corporate culture, as examples. Future NAMKDS efforts will consider the incorporation of emerging and standardized maturity models surrounding the 3D Virtual Environment. Navy and Marine Corps organizations will have a dashboard to reference and measure improvements (Figures 19 and 20).

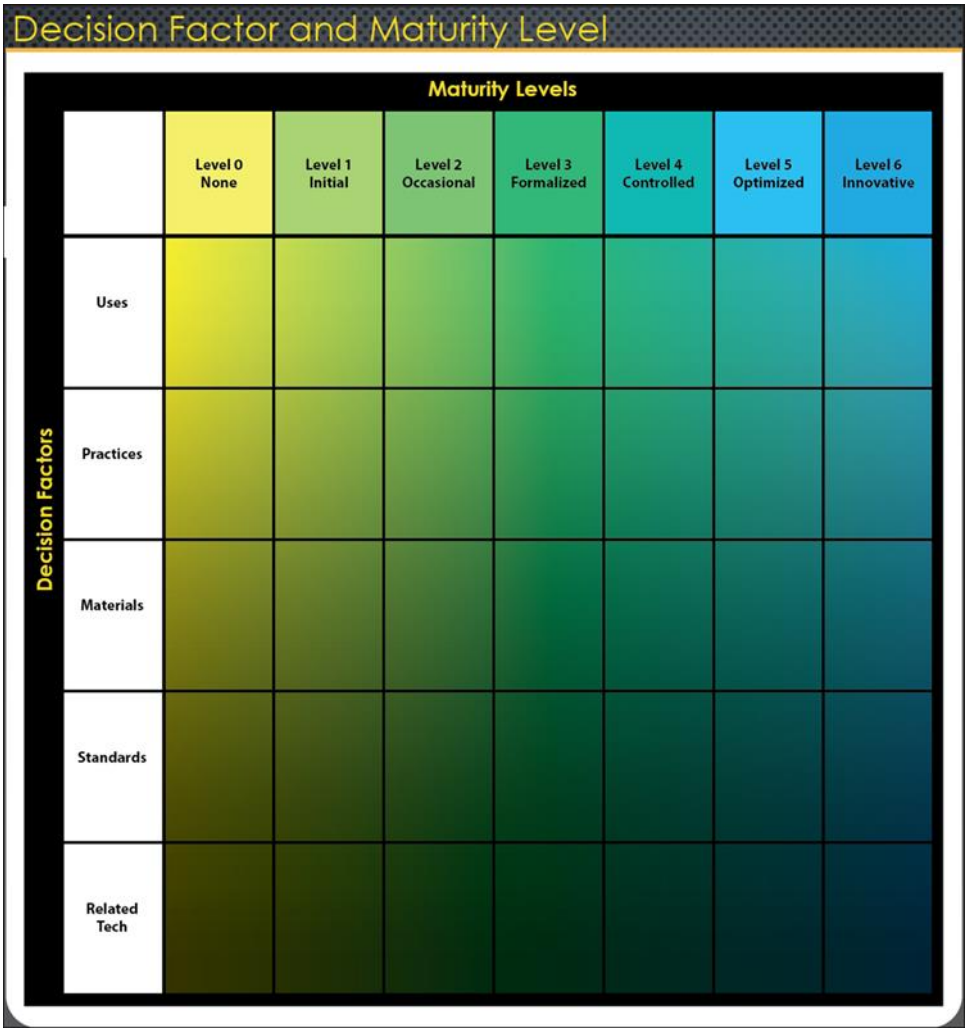


Figure 19. Decision Factor and Maturity Level

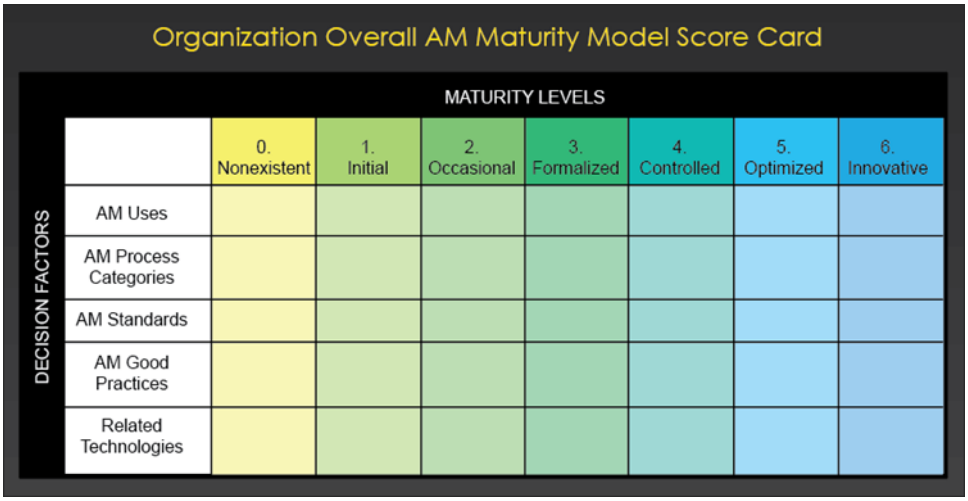


Figure 20. Organization Overall AM Maturity Model Score Card

4. Methodology

The developmental approach is a "*business process perspective first; IT solution next; balance both, last.*" With the existence of many 3D print exchanges, the CTMA NAMKDS team focused on "*what we should do*" vice "*what we can do*" to better Blueprint the NAMKDS ecosystem. As depicted in Figure 21, the methodology process included two key activities of: 1) Collect and Document Requirements and 2) Interpret Requirements and Document System Design. The outputs included:

- NAMKDS Blueprint Project and Definitions Document
- NAMKDS Blueprint
- NCMS Final Report.

The remainder of this section overviews the activities for the methodology.

4.1 Collect and Document Requirements

This process included the actions of:

- Define Scope
- Capture Stakeholder Needs
- Interpret and Document Requirements
- Document Business Process Requirements.

4.2 Interpret Requirements and Document System Design

For this process, the activities were executed in parallel and included: System Definitions Development, Design Notional Web Pages, and Conduct Research and Document NAMKDS Blueprint.

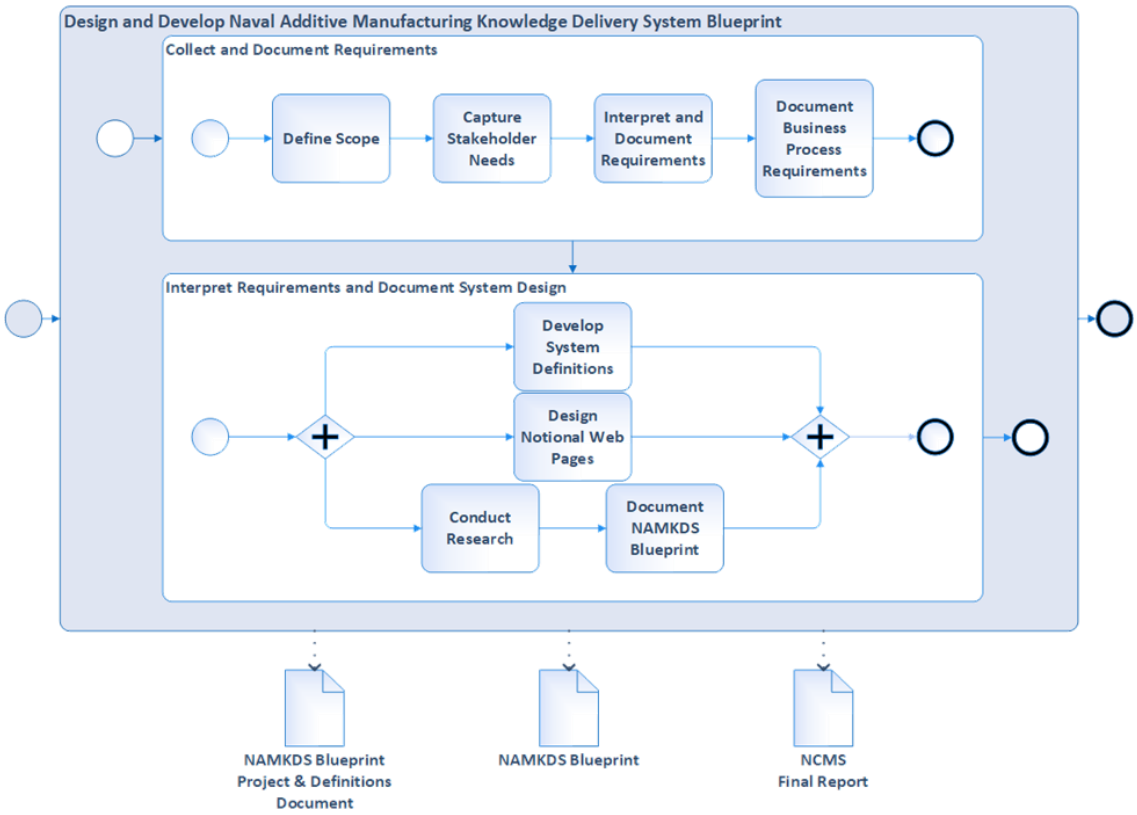


Figure 21. Define NAMKDS Blueprint – Methodology Business Process Diagrams

4.3 Define Scope

In this first step, the team scoped the effort through the use of the Inputs, Guides, Outputs and Enablers (IGOE) model and a Facilitated & Interactive, Idea Remote Evaluation (FIIRE) Team® session.

4.3.1 IGOE Model

The IGOE model is a business analysis tool used for establishing project scope. The team imagined the vision, core processes, and core service offerings of NAMKDS. Further, the group listed: the inputs and outputs, the guides that influence or inform activities, and the supporting enablers of NAMKDS.[2] The results of this effort are illustrated in Figure 22.

4.3.2 FIIRE Team® Session

Through a core service offering of BMO Logistics and UGG, a FIIRE Team® of tailored experts was assembled to conduct analysis and assessment of the business needs. Consisting of two or more analysts, the FIIRE Team® worked closely with NAVFAC to identify improvement areas and evaluate solutions most meaningful and beneficial to an organization. Rooted in the knowledge that an organization consists of multi-dimensional activities, the team explored the lifecycles of:

- Business Interests
- Business Perspectives
- Product Lifecycles
- Environment
- All Strategy Levels.

This approach is a cross-cutting technique supporting a decision-making process that yielded a more balanced and relevant selection of strategic initiatives, innovation investments, cost-cutting strategies, and continuous process improvements.

The tool used in the FIIRE Team® sessions was Powernoodle®, which is a cloud-based platform with parallel workflows to facilitate guided and structured decision-making activities. Groups or individuals, which were cross-functional stake-holders at all organizational levels, submitted [*Noodle*] ideas on promoted topics. The stakeholders evaluated the ideas during *Tag*, *Combine*, *Vote*, *Rate* and *Prioritize* activities and finally, recommended implementation steps during the *Actions* activity.

A trained Decision Facilitator guided the team through FIIRE Team® sessions to:

- Mature the IGOE
- Identify the desired outcomes of the NAMKDS Blueprint project
- Conduct a Risk Assessment.

The results of the FIIRE Team® sessions were: 1) published into a Program Action Logic Model document, 2) used to identify NAMKDS stakeholders, 3) used to inform for the scope of the effort, and 4) used to guide the BPA and modeling efforts.

4.4 Capture Stakeholder Needs

FIIRE Team® sessions using Powernoodle® collected and evaluated end-user and stakeholder ideas on the topics of: *Desired Outcomes* (Needs) and *External Factors – Barriers* (Initial Risk Assessment). The sessions were facilitated in seven separate sessions, each targeted to a specific group of stakeholders. The following identifies the stakeholder sessions:

1. End-user
2. N4

[2] A Guide to the Business Analysis Body of Knowledge (Ver 3.0 ed.). (2015). Toronto: International Institute of Business Analysis.

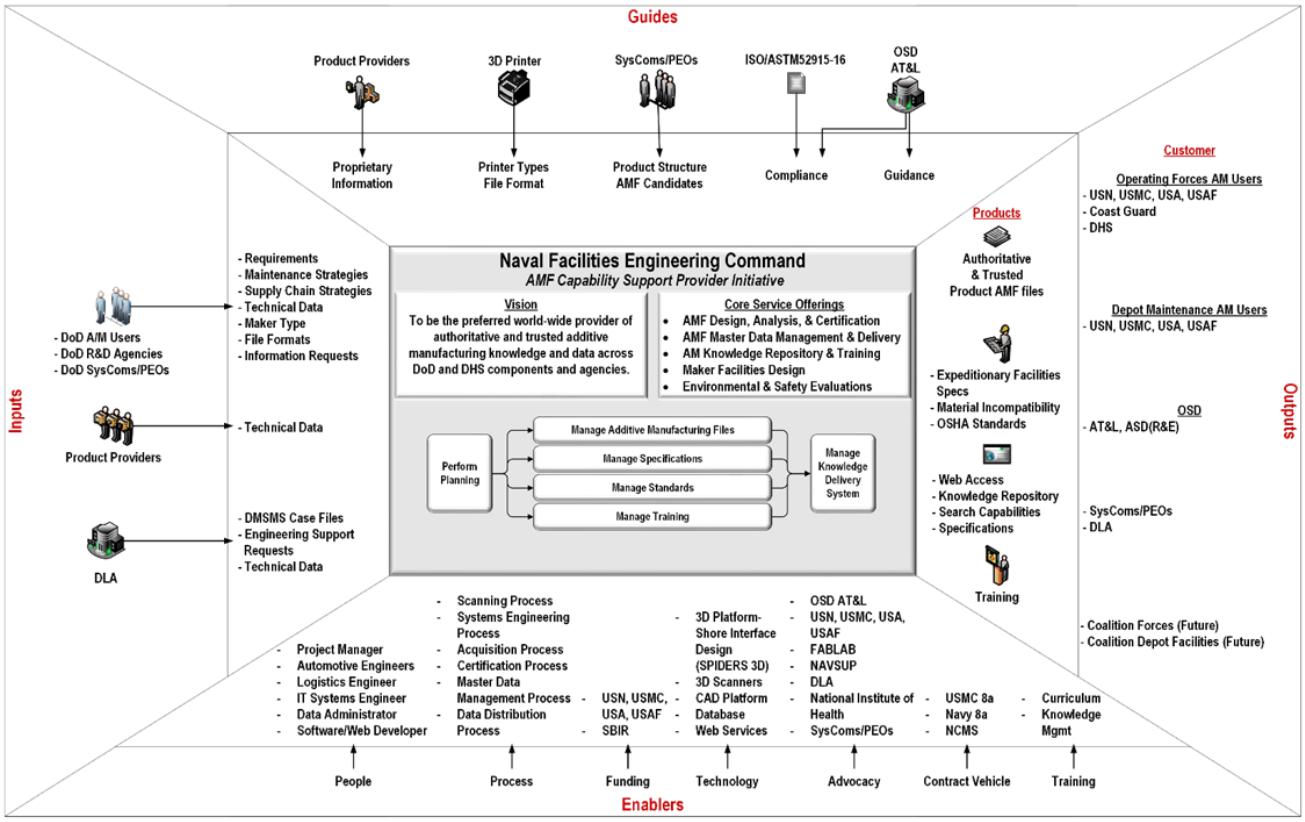


Figure 22. NAMKDS IGOE Model

3. NAVAIR
4. Naval Construction Force
5. NAVSEA
6. NAVSUP and DLA
7. SPAWAR

4.4.1 Desired Outcomes

Desired outcomes were the descriptions of the needs. Each session elicited from end-users and stakeholders, their ideas and interpretation of what they want NAMKDS to achieve, to possess, to do, to be or what conditions to meet. Immediately following, the participants evaluated the ideas as follows:

- Vote: Vote if the idea was relevant or realistic. Following the vote, the participants reviewed the voting outcomes to determine which ideas advanced to *Rate* activity.
- Rate: Participants rated the remaining ideas for *Benefit* and *Ease of Implementation*. Following the *Rate* activity, participants reviewed the rating results and determined which ideas advance to *Prioritization* activity.
- Prioritization: Participants used this activity to reprioritize the ideas advanced from the *Rate* activity. The results of this activity were a focused and prioritized list of functional needs. The benefit of the session was that group consensus was achieved through evaluation and discussion.

4.4.2 External Factors – Barriers

This facilitated topic was the initial risk assessment. Risks were potential-future or currently-occurring events or conditions that might have an adverse effect on achieving the

desired outcomes. The process to elicit and evaluate stakeholders risk ideas was similar to the *Desired Outcomes* topic. However, this used different evaluation criteria. Participants identified risk to achieve the *Desired Outcomes* and assessed those ideas as follows:

- Vote: Vote if the risk idea was relevant or realistic. Following the vote, the participants reviewed the voting outcomes to determine which risk ideas advanced to *Rate* activity.
- Rate: Participants rated the remaining ideas for *Likelihood* and *Consequences*. Following the *Rate* activity, participants reviewed the rating results and determined which risk ideas would advance to *Prioritization* activity.
- Prioritization: Participants used this activity to reprioritize the risk ideas advanced from the *Rate* activity. The results of this activity were a focused and prioritized list of risk. As in *Desired Outcomes*, the group consensus was achieved through evaluation and discussion.

4.5 Interpret and Document Requirements

The *Desired Outcomes* were reduced, clarified, and translated into internal project requirement statements. The functional team devised, developed and documented internal project requirements statements to communicate design considerations that informed and guided:

- Functional team efforts for business processes analysis and BPM.
- Technical team efforts in developing system requirements.
- Analytic team efforts to research and document the Blueprint deliverable.

Describing the end-state of NAMKDS, the requirements will continue to evolve as the team members progress through the increments described in Section 2.8.

4.6 Document Business Process Requirements

In this activity, the functional team used the requirements and BPA techniques to document the Business Process Requirements for NAMKDS. The processes were documented into the FIIRE Team Business Process Manager®, and the *descriptive* Business Process Diagrams were developed in Microsoft Visio® guided by Business Process Model and Notation (BPMN) 2.0 techniques. The purpose of the business process requirements was to inform and guide further:

- Technical team efforts in developing system requirements.
- Analytic team efforts to research and document the Blueprint deliverable.

See Section 5 for the overview of the Business Process Requirements.

4.7 Systems Definition Development

The technical team used this activity to translate the concepts and requirements artifacts into a system definition that proposed a path for the incremental development of NAMKDS. The team identified variances, options, and system design considerations that responded to cybersecurity, cost, low- and no-bandwidth considerations, and more.

4.8 Web Page Screenshots

The results of market research of 3D model exchanges by the analytic team led to the maturation of notional web page screenshots for NAMKDS. By developing screenshots with a familiar look and feel, the team ensured the design of NAMKDS would result in a “best-of-breed” future web page.

See Section 6 for the notional screenshots as they were integrated into the Systems Definition Development.

4.9 Blueprint

Derived from all the contents of this Blueprint, is the culminating, dimensional summaries presented in Section 3 of this final report. The analytic team devised, documented, and peer-reviewed the Blueprint diagrams to summarize the complexity and volume of information obtained in this effort. The analytic group, inclusive of their graphic artist, summarized and better illustrated the process, system, analytical, and system engineering that support the seven incremental development blocks.

See Section 3 for an overview of the Blueprint.

5. Business Process Requirements

As described in the previous section, the Business Process Requirements were derived from interpretation of the functional requirements and documented based on BPMN 2.0 normative documentation. Section 5 presents the overarching business process documented for the NAMKDS effort.

5.1 Participants

In BPMN 2.0, a *Participant* was an individual, organization, role, or an item that controlled, interacted, or was responsible for the business process. Table 2 describes the *Participants* identified in the NAMKDS business processes. The ID Column was a unique Work Breakdown Structure numbering system used throughout the process diagram to identify a Participant's activities quickly. The Participant Column identified and categorized distinct entities identified in the Stakeholders Column. A description of the Participant is provided in the Description Column.[3]

5.2 Business Process Diagrams Overview

Figure 23 is the Business Process Diagrams illustrating the overarching, 1st level, *Participant* activities and flows.

The center of the diagram illustrates:

- NAMKDS
- *3D Virtual Environment Administrative Managers Participant* key activities
- Key data objects administered by the ecosystem.

Above NAMKDS is the customer perspective consisting of:

- *All Users*
- *End-User*
- *End-User (n)*
- *Expeditionary End-User* activity and interactions.

Below NAMKDS are the supporting Participants, and their key activities.

Illustrated are the key activities traditional to the acquisition and cataloging of product data. It was not the intent of NAMKDS to assimilate existing make/buy processes of product data; instead it was the intent to integrate with mature product data for NAMKDS customer's consumption.

The color coding of the diagram is represented as follows:

- Blue: Processes that directly interacted with or within NAMKDS.
- Gold: Existing DoD, Navy, and Marine Corps processes and *data stores* in which NAMKDS could interact with technical information.
- Red: Process interactions between commercial industry and organizations traditionally responsible for the acquisition of technical data and information.

[3] Business Process Model and Notation (BPMN). (2011). Version 2.0. Object Management Group.

Table 2. NAMKDS Participants Table

ID	Participant	Description	Stakeholders
1.0	public: 3D Virtual Naval Installation Environment (All Users)	The *public* participants consisting of any user requesting access or approved for access to the 3D Virtual Naval Installation Environment	All Below Listed
2.0	End-User	Navy and Marine Corps deploying forces and the Navy Depot Enterprise. These users actively possess a 3D Printing capable and consist of any individual or organization fitting to the right-listed stakeholder categories	•Sailors & Marines •Navy and Marine Corps Government Civilians •Navy Depot Enterprise •Fabrication Laboratories •Navy Medical Corps
3.0	End-User (n)	Performs the same activities as an *End-User*. This participant provides 3D model and print support requested from another *End-User*. An *End-User (n)* could be local or regional; higher, lower or adjacent in command or support structure; and typically possesses a greater capability or capacity over the requestor. The *End-User (n)'s* role automatically changes between *End-User* and *End-User (n)* as they switch between supporting roles.[4]	See *End-User*
4.0	Expeditionary End-User	Performs the same activities as an *End-User*. An *Expeditionary End-User* is an *End-User* in a deploying or deployed status.	See *End-User*
5.0	3D Virtual Environment Administrative Managers	Participants responsible for the daily operations, lifecycle management, and sustainment of NAMKDS environment.	NAMKDS: •Lifecycle Managers •IT Administrators
6.0	Education and Research	Participants responsible for the development and delivery of 3D blended learning and research	•Navy and Marine Corps Training & Education Commands •Naval Post Graduate Schools •Applied Research Laboratories •Office of Naval Research •Navy Medicine
7.0	Weapon System, Facility, & Medical Lifecycle Managers	Participants responsible for the lifecycle management of weapon systems, facilities, and biomedical 3D models.	•SYSCOM Commanders •Program Executive Officers (PEOs) •Navy Medicine
8.0	Supply and Logistics Chain Manager	DoD, Navy, and Marine Corps organizations and agencies responsible for logistics information inclusive of cataloging, digital asset management, and technical information surrounding 3D Models	•Naval Supply Systems Command •Marine Corps Logistics Command •Defense Logistics Agency
9.0	Commercial Industry Vendors	Traditional and nontraditional commercial industry entities providing product and technical data that meets DoD, Navy, and Marine Corps 3D Modeling and AM needs	Any commercial industry entity

[4] *End-User (n)* and *Expeditionary End-User (n)* - Depending on deployment status, an *End-User (n)* can provide support to an *End-User* or an *Expeditionary End-User*. In such case, an *Expeditionary End-User* providing support to another *End-User* or *Expeditionary End-User* will be considered an *Expeditionary End-User (n)* and perform the same activities inclusive of *End-User (n)*.

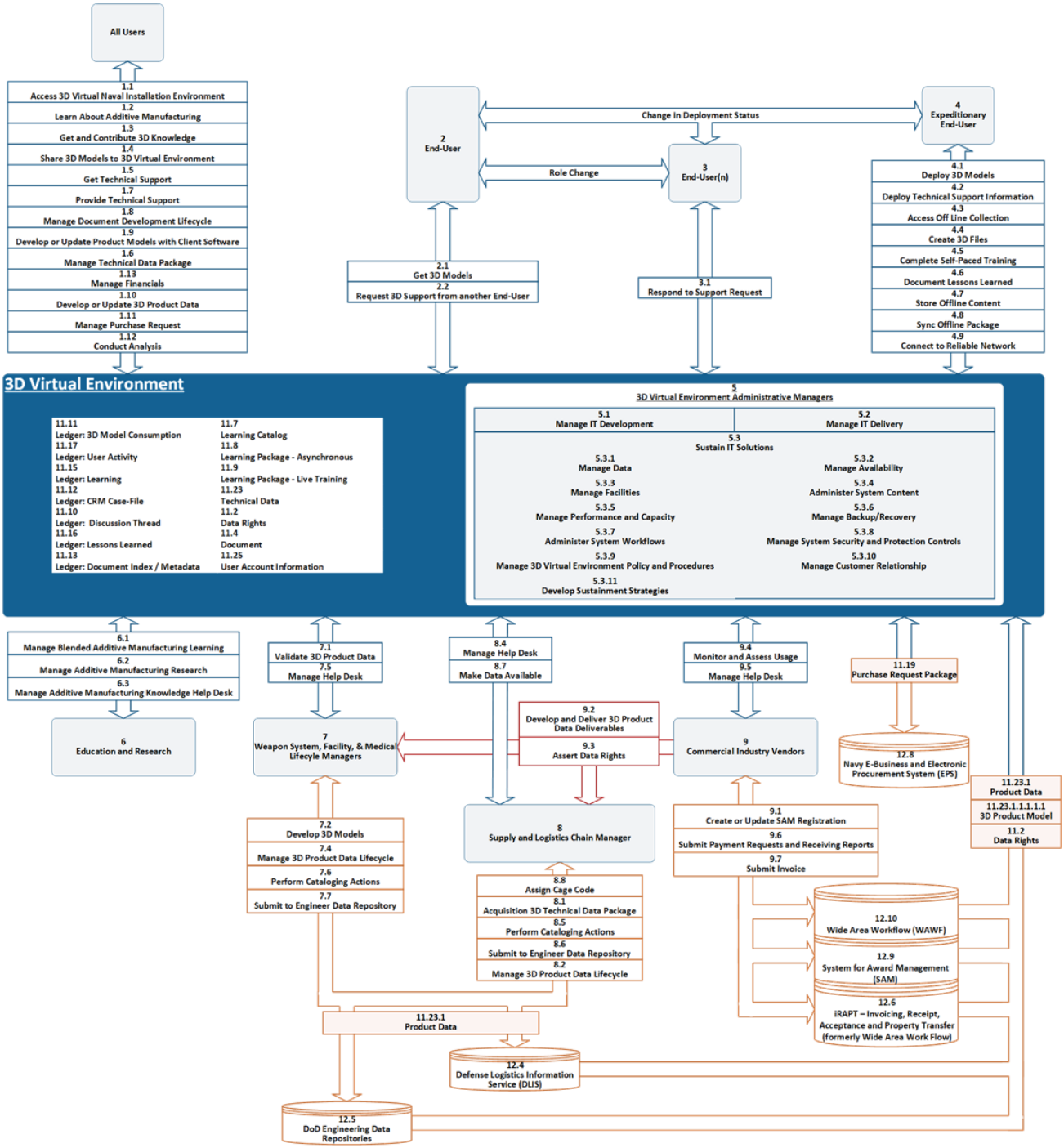


Figure 23. NAMKDS Process Overview

6. 3D Virtual Environmental System Design

6.1 Overview

Lifecycle management of Navy and Marine Corps assets is enhanced when the physical world is transformed digitally into a 3D Virtual Environment. The scanning or development of 3D Models as a "Digital Asset," coupled with support tools, permits operational and logistics leaders to plan and analyze in a virtual world proactively. This results in a better-informed decision-making process that enables optimal use of assets and the resources required to support them.

The system design intends to respond to the internal requirements developed by the functional team. The technical team postulates that DoD must establish a common infrastructure and methodology relative to 3D printing, 3D modeling, and technical information architecture. The team believes the following design considerations for the incremental development of NAMKDS will serve as the base for implementing DoD's common infrastructure and further thinks this responds to the following assumptions:

- Extent of the 3D model sharing is unknown within DoD.
- Quality of the 3D models is unknown within DoD.
- Printed part reliability (or lasting success) is unknown within DoD.
- What DoD equipment contains 3D printed parts is unknown within DoD.
- Level of engineering of the printed parts or selection of the best materials to use in the printer is unknown within DoD.

The NAMKDS Blueprint addresses these issues, incorporates DoD users' feedback and needs, and presents an approach using DON CIO processes to establish an IT system to accommodate the needs of DoD, the 3D printing users, and the assurances needed by the users of equipment that may contain 3D printed parts. Furthermore, NAMKDS also considers the 24x7 use case that exists within DoD. The basis of this estimate is that one of the primary needs that NAMKDS will fulfill will be to provide ready, rapid, and on-the-spot part replacement for forward deployed units in any Service branch anywhere in the world at any time. As such, NAMKDS availability will have to follow the sun. Technology today allows for such high availability yet supports the routine operation and maintenance of an IT system concerning backups, patches, other routine maintenance activities.

A phased approach to development will allow NAMKDS to deploy iteratively. The Blueprint will serve as a guideline for each iteration; this will enable functionality to be prioritized and implemented in a production environment while maintaining the long-term vision of the system. The full NAMKDS Blueprint presents a broad vision that includes interactions with various external systems and services. These interactions are documented descriptively, and Block 3 through Block 6 identified in Section 2.6 schedules the exact methodologies of these negotiation of connections.

6.2 Concept Architecture

The NAMKDS application will have three primary layers as illustrated in Figure 24 consisting of:

- Data
- Business Logics
- Presentation

The remainder of this section describes the concept architecture further.

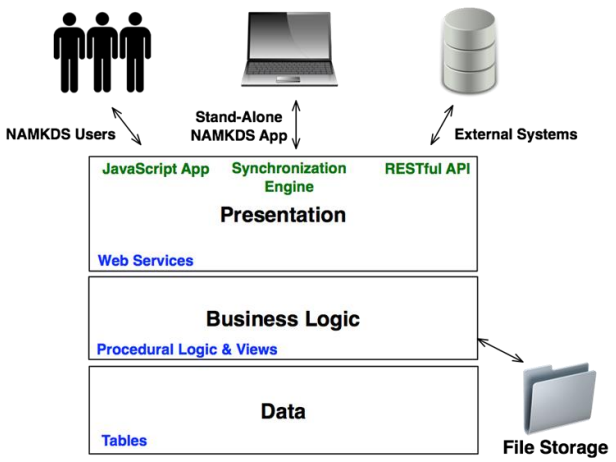


Figure 24. NAMKDS Application Layers

6.2.1 Data

A relational database, such as Oracle, will house the tabular data. NAMKDS is a repository for the exchange of both knowledge and 3D models. Therefore, the alignment of digital files with supporting data is an essential aspect of the overall architecture. Binary object types allow files to be indexed and referenced in database tables while the actual file is stored in standard file space. This arrangement provides easy access to the data by administrators and allows the users to search, request, and download files efficiently from the repository. Maintaining files on a SAN, or in regular file space, is also crucial to the synchronization engine.

The NAMKDS system will be interfacing with several external systems. One example of this is the Navy E-Business and Electronic Procurement System (EPS). Users will be creating purchase requests that are handled by EPS. Interfacing with external systems requires more than a "hand-off," the goal is for a user actually to create and monitor the purchase request via NAMKDS. This type of exchange could be implemented using web services, however, if both systems are built on Oracle, and the network topology permits it, database links will provide a far superior interface for this type of transparent interaction.

6.2.2 Business Logic

All of the business rules that drive the NAMKDS application will be maintained in the Business Logic layer of the system. Users will connect and authenticate through the application, and their requests will ultimately filter down to a logical unit such as a procedure. These encoded rules also include canned queries that interact with the data layer. This layer also has access to the file system. If the synchronization engine makes a file package request, a procedure will query the database to build the list of appropriate files, compress them, and package them up for delivery via web services.

6.2.3 Presentation

The web server and server application reside in the presentation layer (Figures 25 and 26). The server application manages user authentication and session. If NAMKDS is built on an Oracle RDBMS, Application Express (APEX) can be used to perform this function. APEX also offers flexibility regarding authentication. NAVFAC Portal utilizes a common single sign-on infrastructure that enables two-factor authentication. This managed security layer can be inherited by APEX, satisfying the requirement to establish a secure exchange of data between each NAMKDS client and the server.

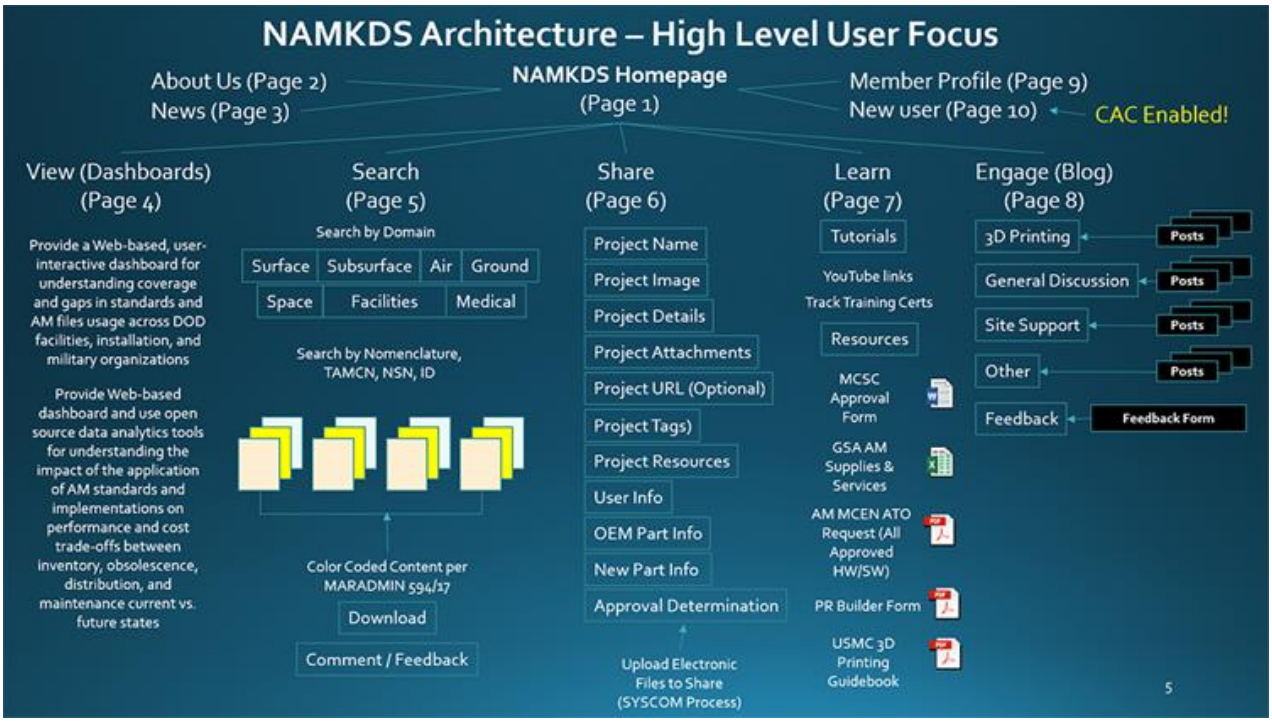


Figure 25. High-Level User-Focus Architecture

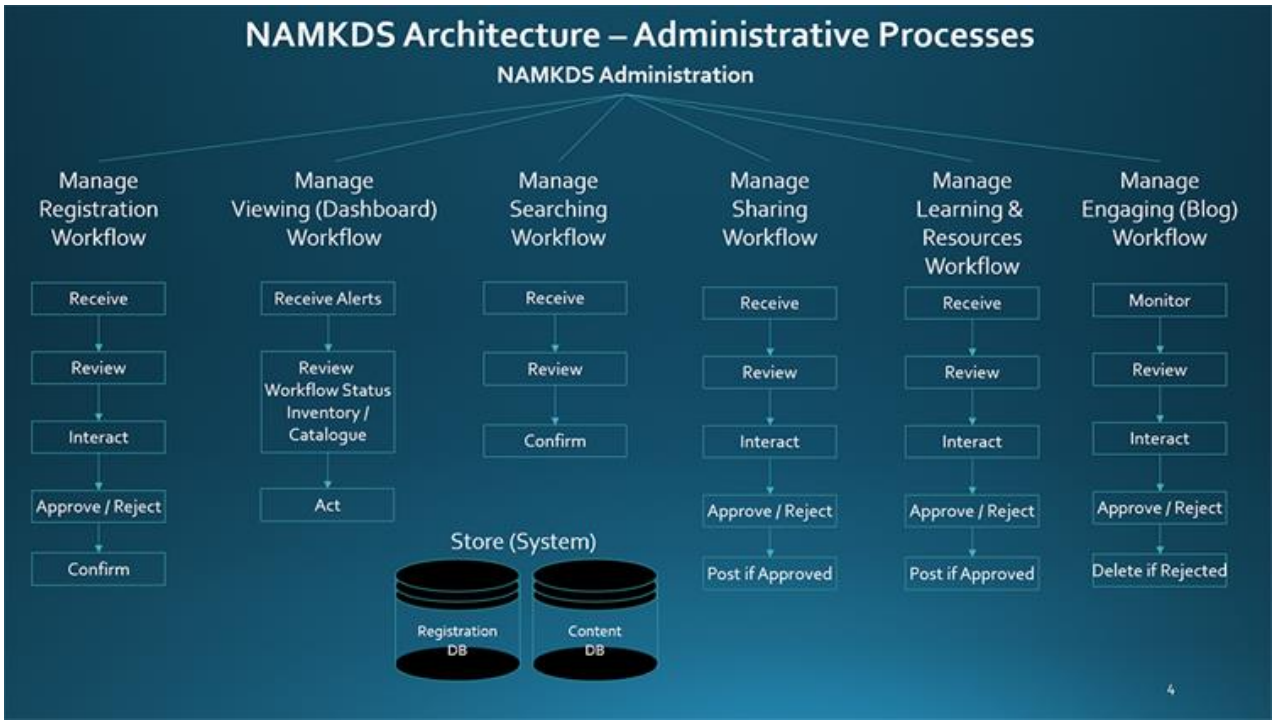


Figure 26. NAMKDS Architecture – Administrative Processes

6.2.3.1 Web Page Design Concept

Supporting the *Presentation Layer*, the analytic team produced a series of notional web page designs that illustrate the screenshots for users to Share, Learn and Engage in the 3D Virtual Environment (Figure 27). The notional web pages are as follows:

- Figure 28 – 3D Model Exchange Home Page
- Figure 29 – Create New Account
- Figure 30 – Login
- Figure 31 – Change Password
- Figure 32 – Member Profile and Contact Information
- Figure 33 – Contact Member
- Figure 34 – About Us
- Figure 35 – News
- Figure 36 – Dashboard Drill Down Metrics
- Figure 37 – Dashboard Drill Down Metrics Request by Priority
- Figure 38 – Dashboard Drill Down Metrics Request Multi-Dimensional
- Figure 39 – Dashboard Drill Down Parts Tracking and Classification Metrics
- Figure 40 – Search for 3D Digital Parts
- Figure 41 – Search/View 3D Model Details
- Figure 42 – Share 3D Models
- Figure 43 – Learning Resources 1
- Figure 44 – Learning Resources 2
- Figure 45 – Engage

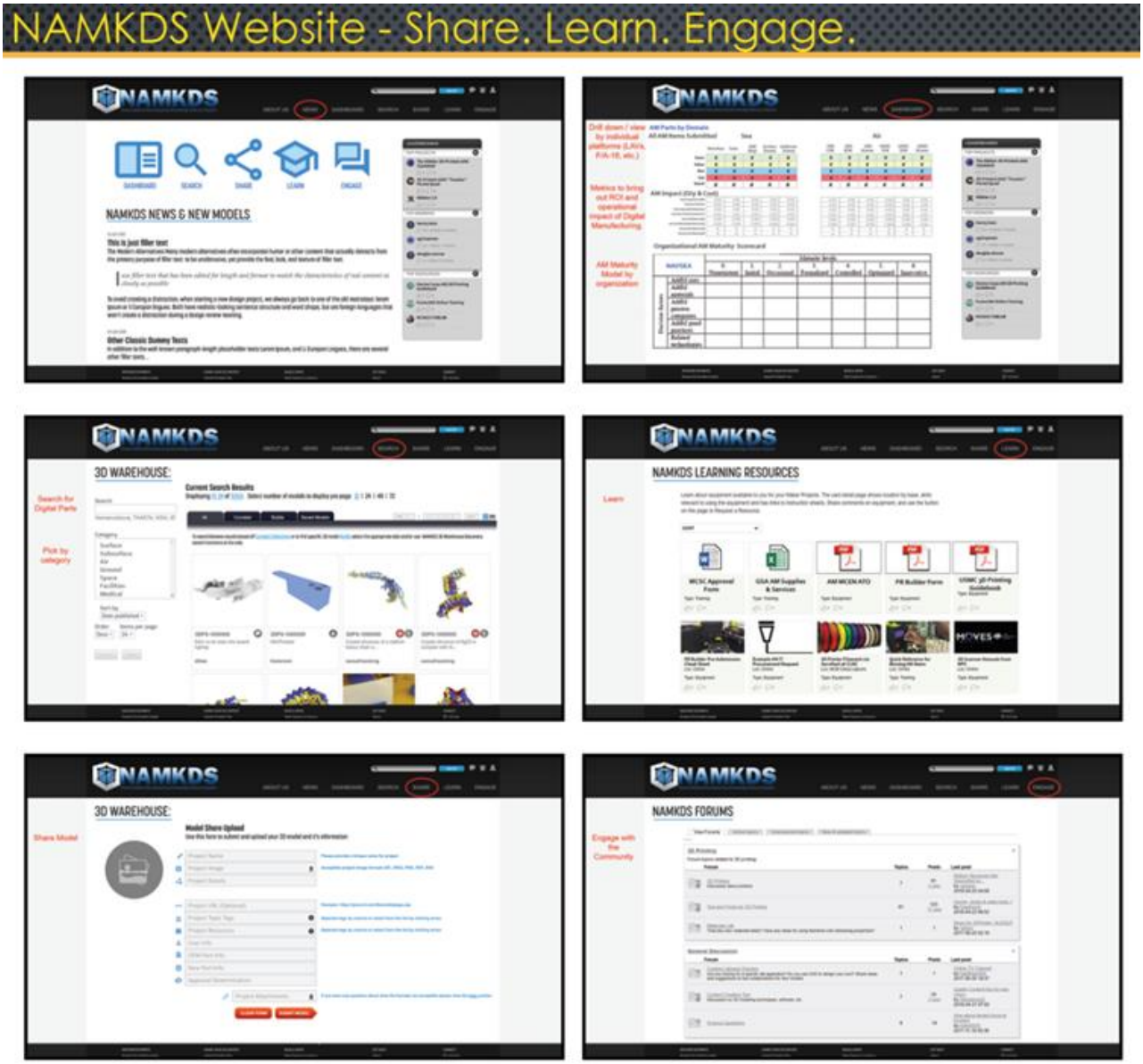


Figure 27. Web Design – Share, Learn, Engage

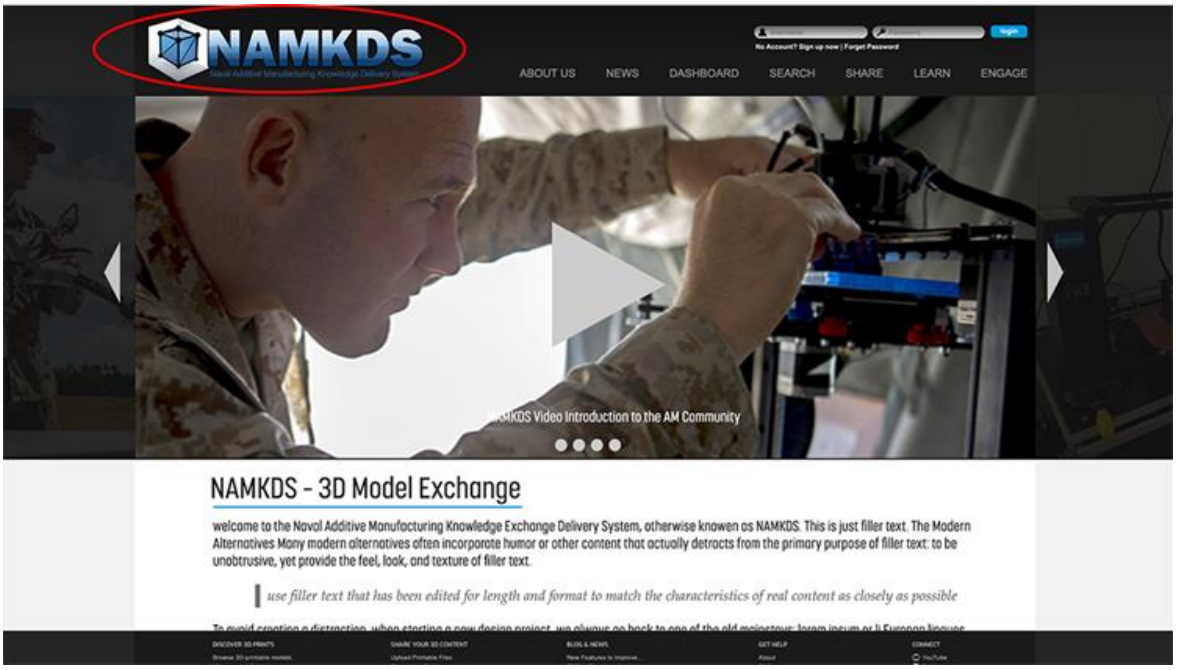


Figure 28. Web Design – 3D Model Exchange Home Page

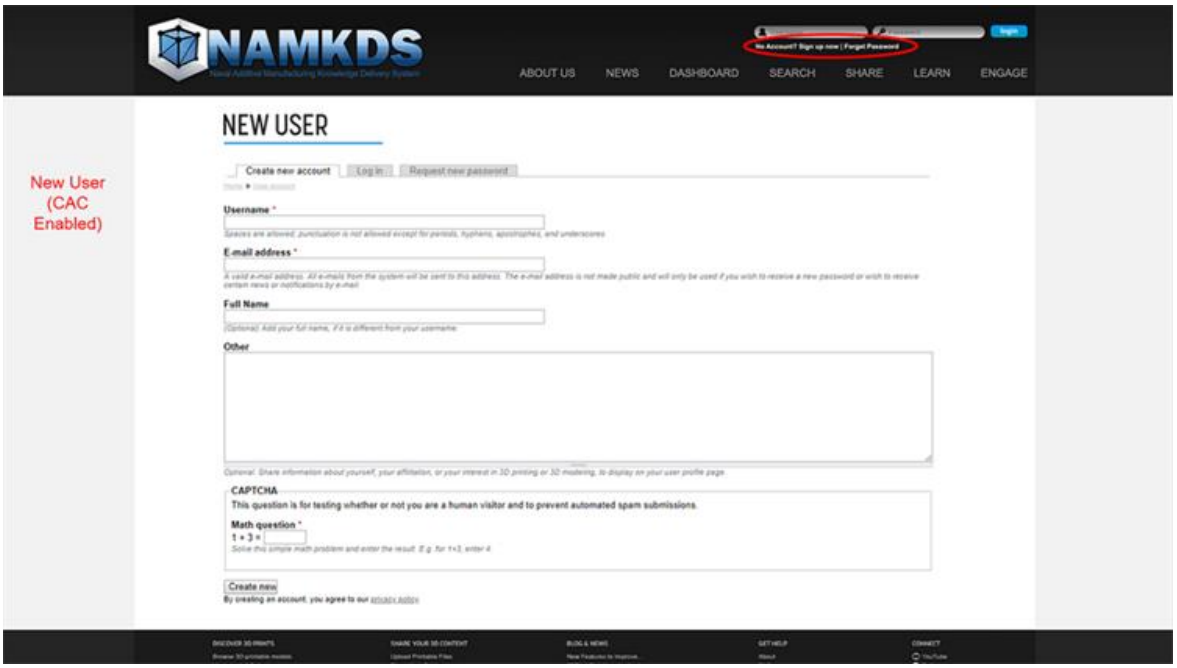


Figure 29. Web Design – Create New Account

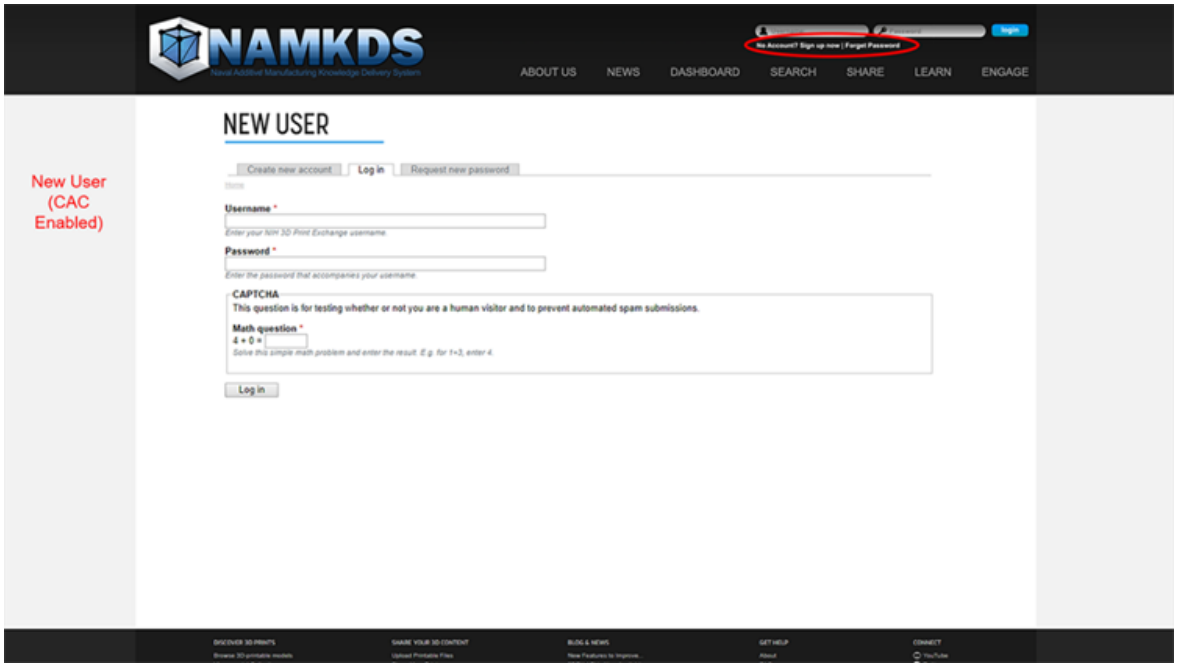


Figure 30. Web Design – Login

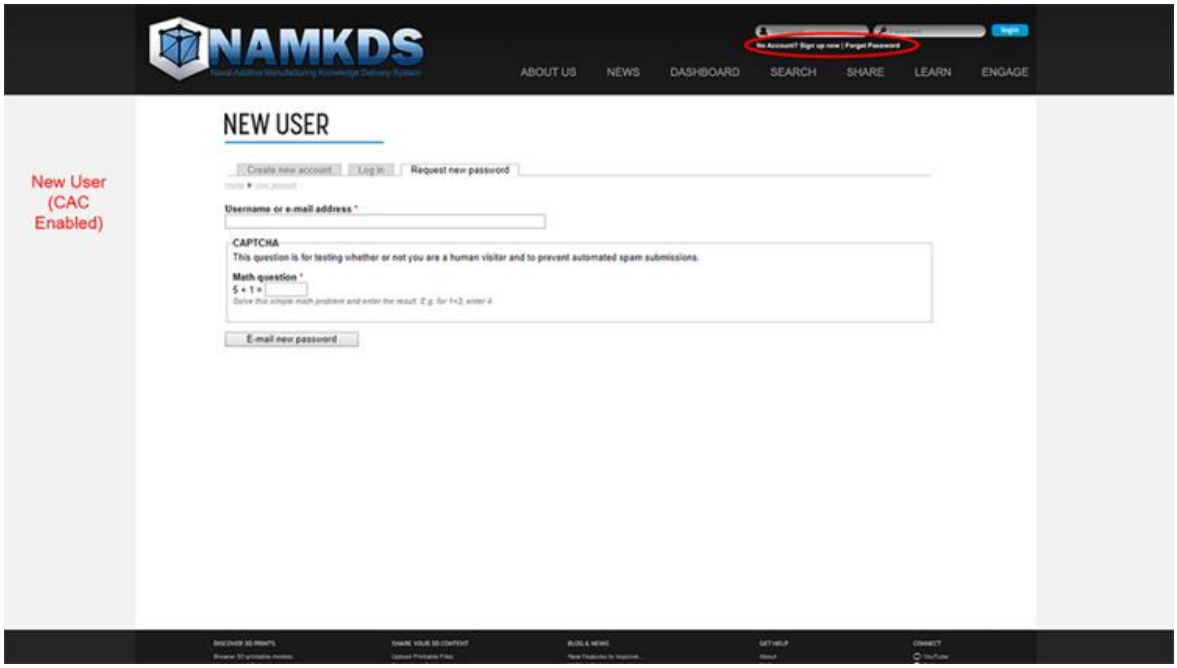


Figure 31. Web Design – Change Password

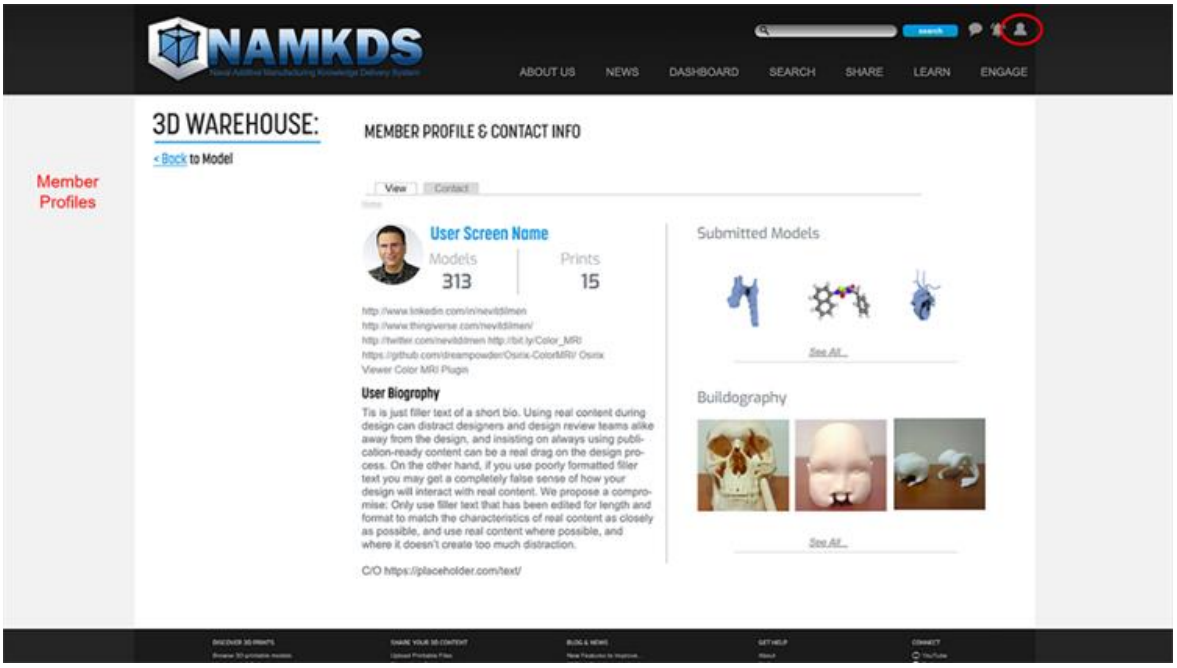


Figure 32. Web Design – Member Profile and Contact Information

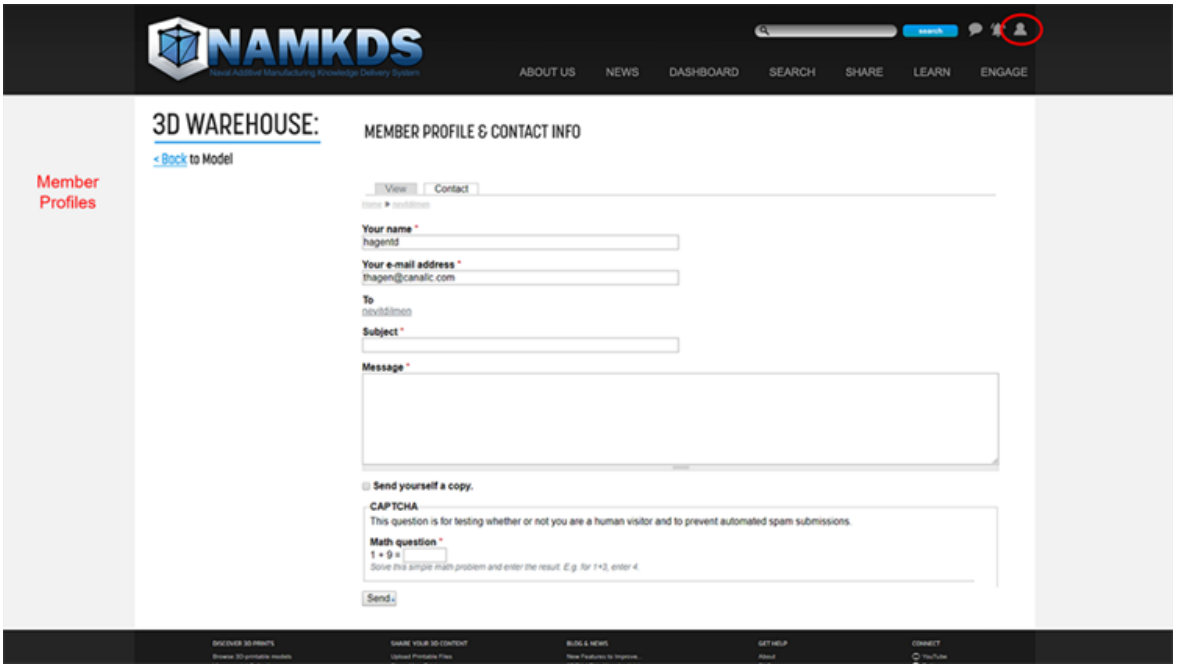


Figure 33. Web Design – Contact Member

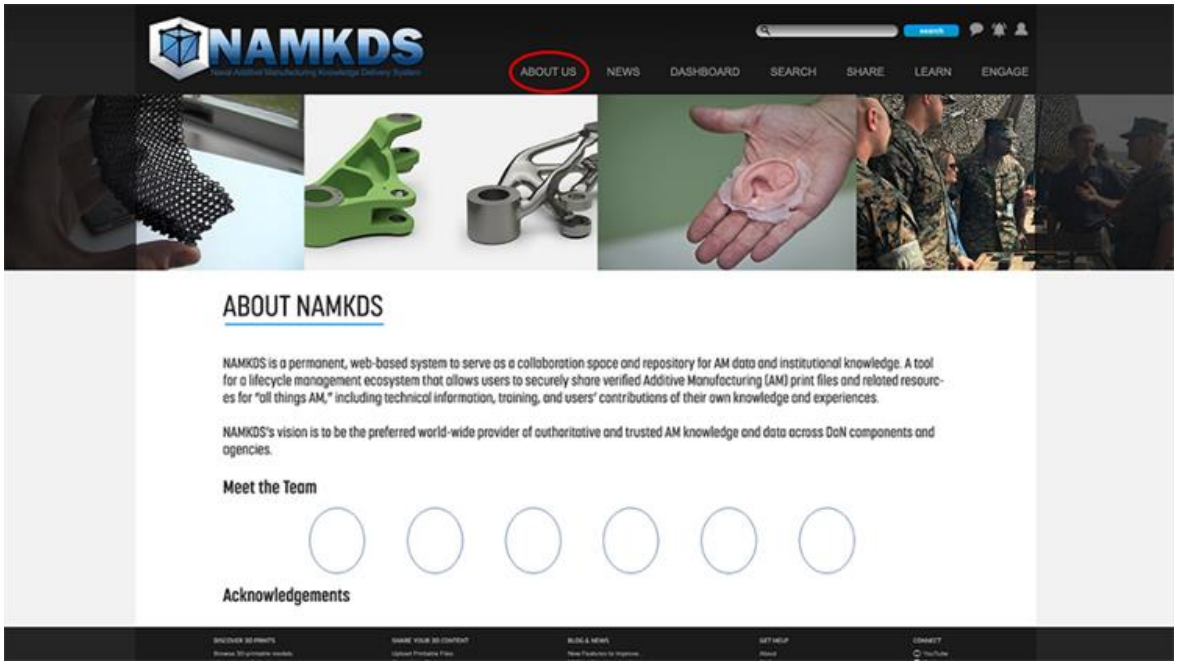


Figure 34. Web Design – About Us

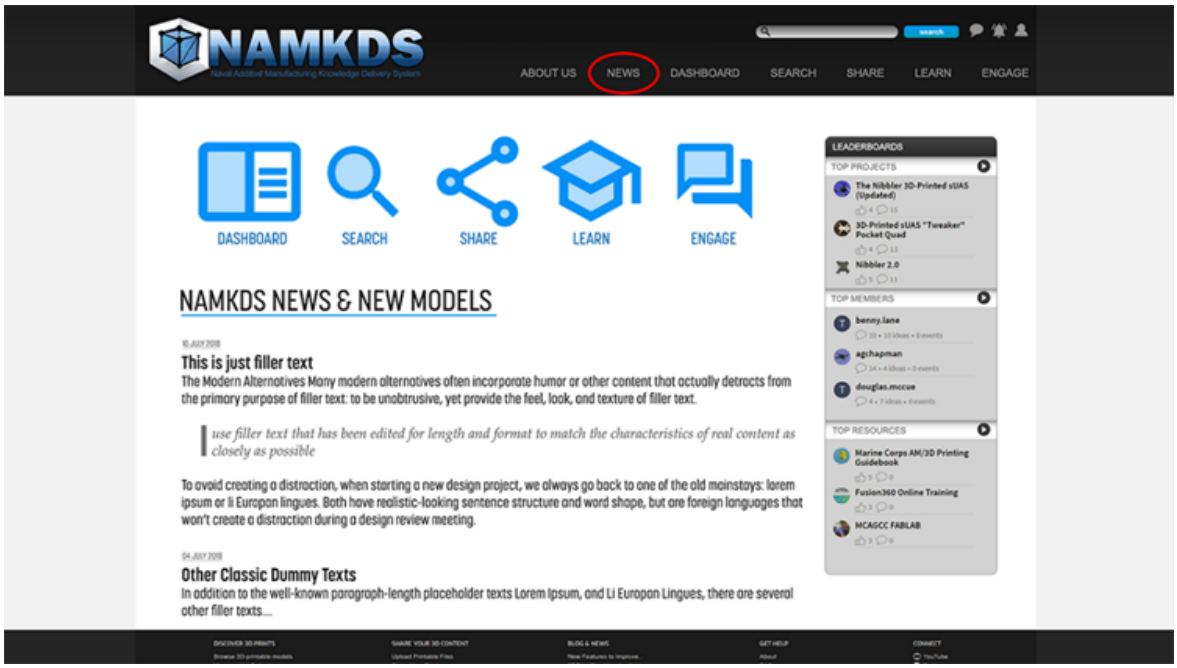


Figure 35. Web Design – News

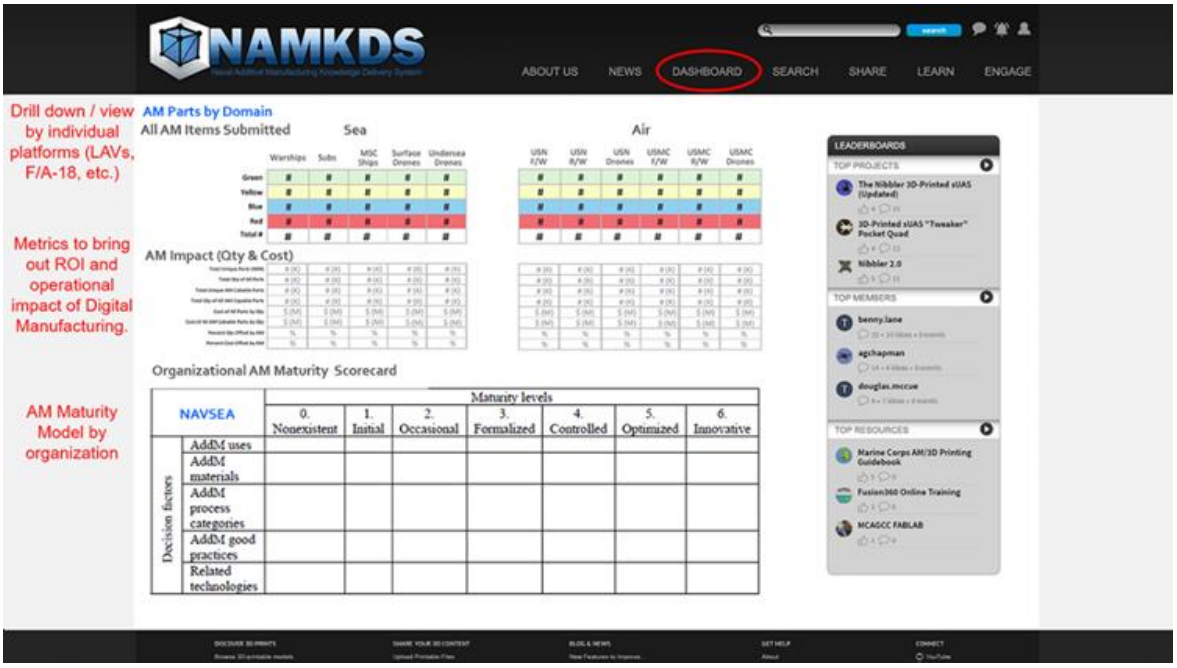


Figure 36. Web Design – Dashboard Drill Down Metrics

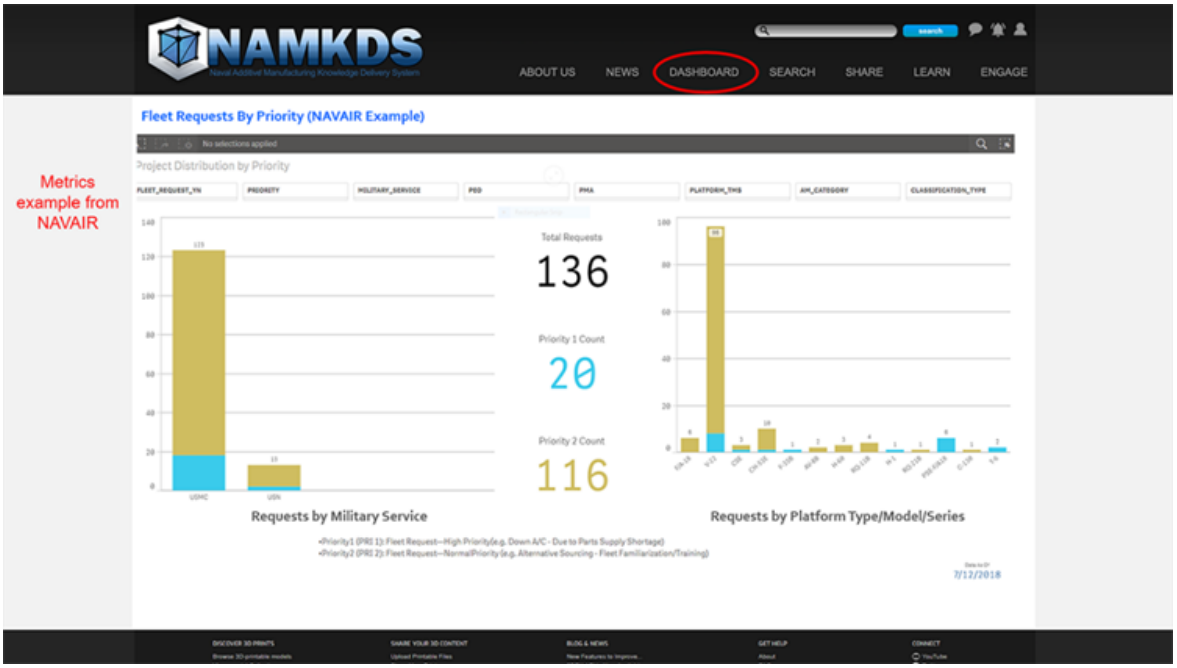


Figure 37. Web Design – Dashboard Drill Down Metrics Request by Priority

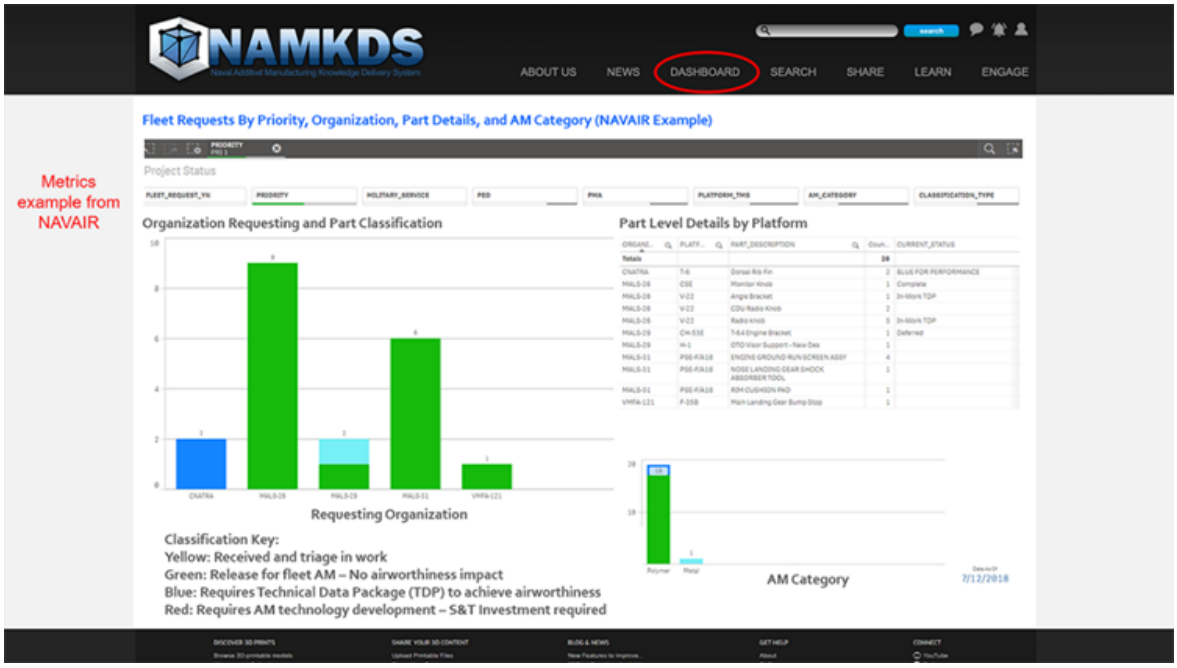


Figure 38. Web Design – Dashboard Drill Down Metrics Request Multi-Dimensional

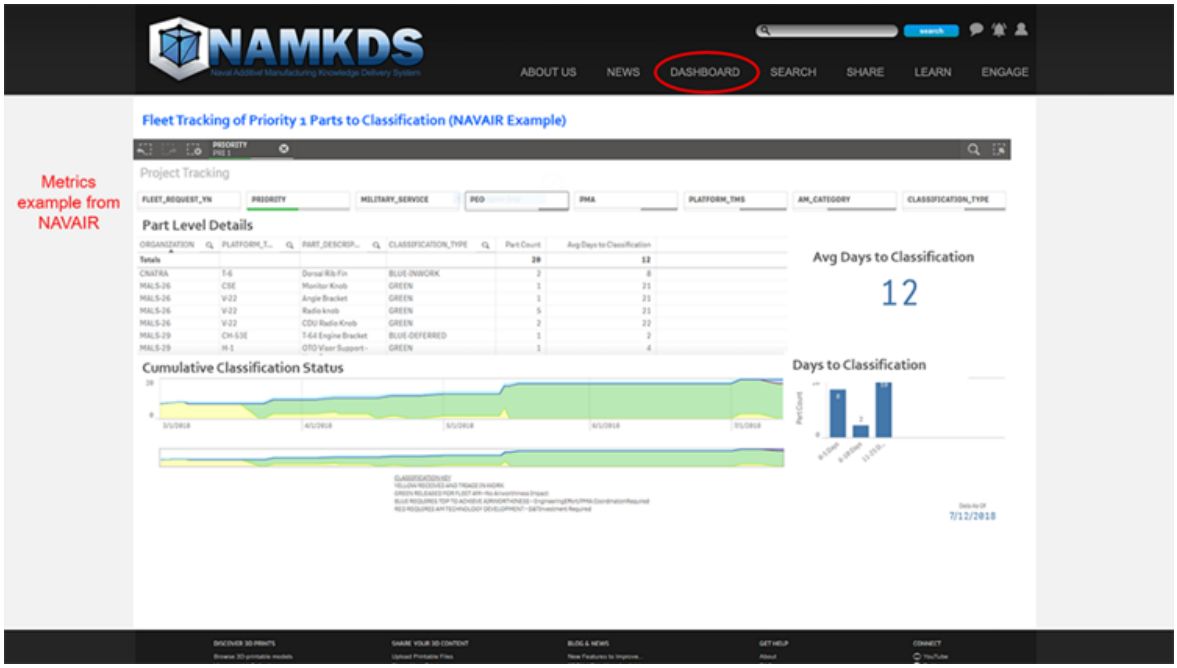


Figure 39. Web Design – Dashboard Drill Down Parts Tracking and Classification Metrics

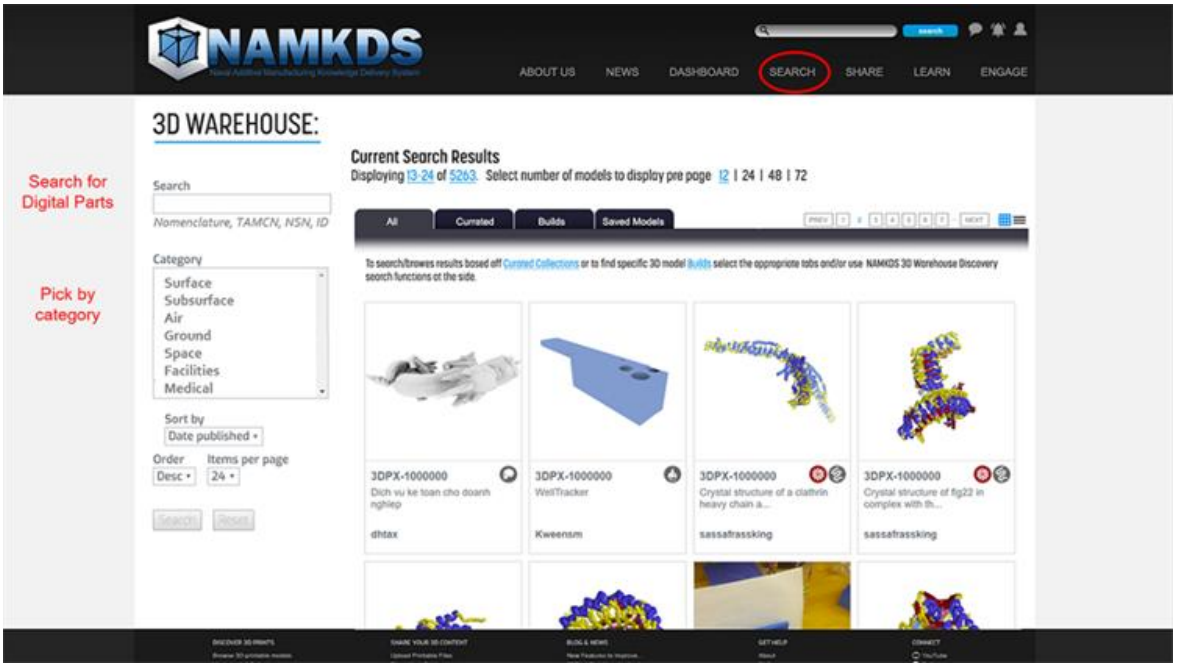


Figure 40. Web Design – Search for 3D Digital Parts

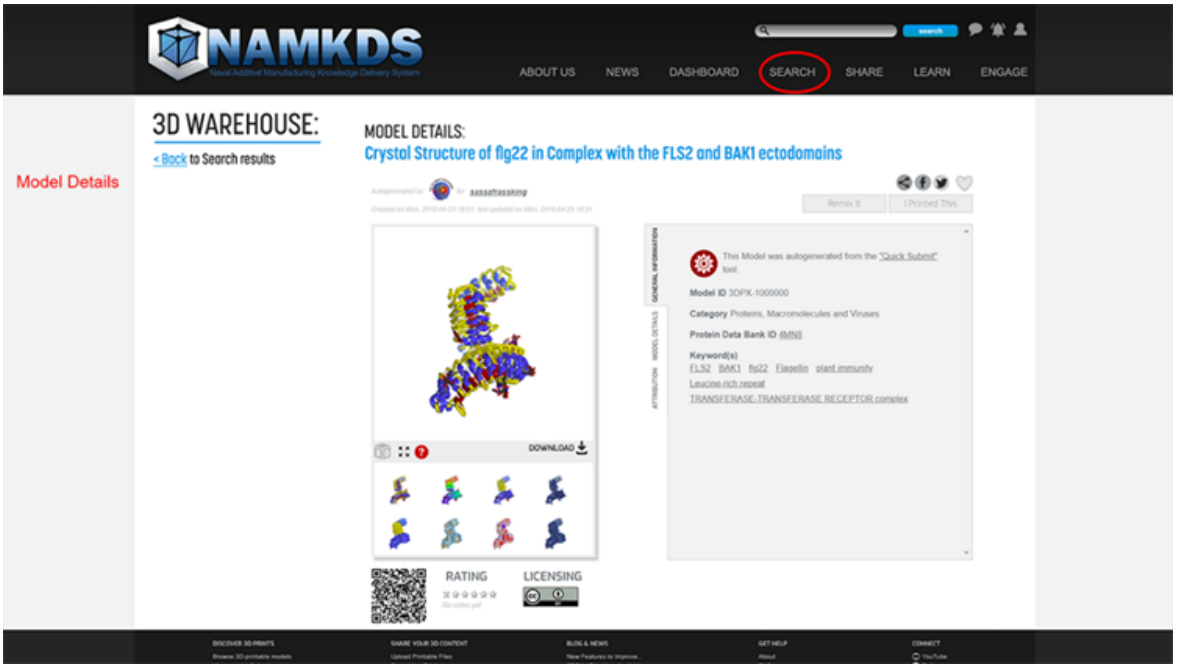


Figure 41. Web Design – Search/View 3D Model Details

6.2.3.2 Share

There will be a web page devoted to uploading of files and videos from users regarding topics related to 3D printing, 3D file creation, and 3D file rendering.

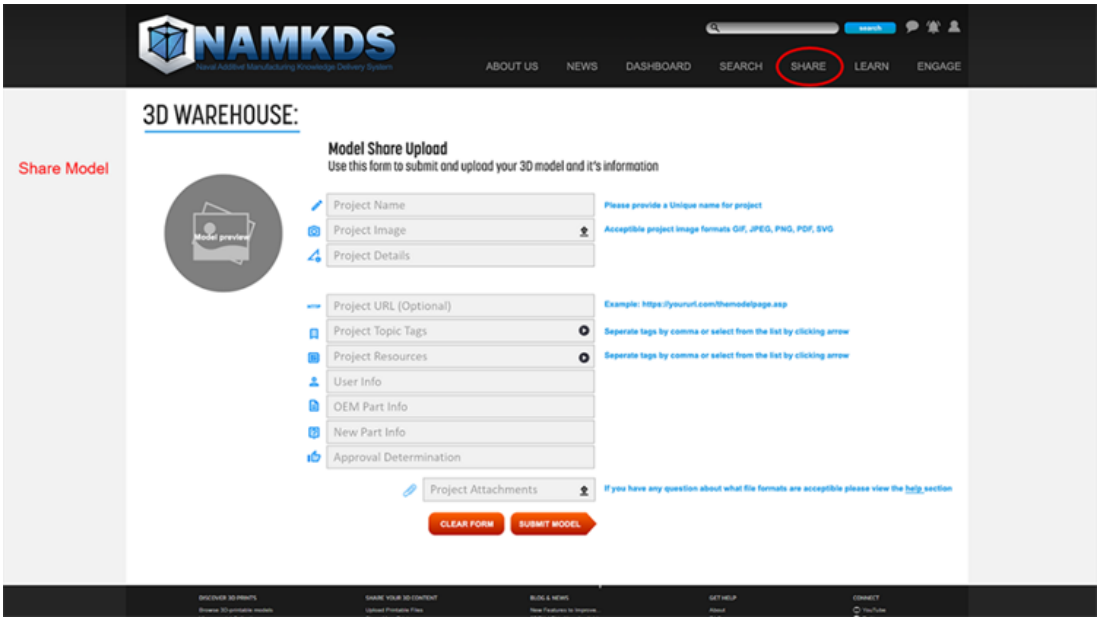


Figure 42. Web Design – Share 3D Models

6.2.3.3 Learn

Training will be accomplished primarily online. Part of the NAMKDS web application will include a web page that is dedicated to the delivery of training. This training can be accessed at any time by a user and will primarily consist of video training on the use of the NAMKDS module. This will allow new users to be trained as they are granted access to NAMKDS. As significant changes to NAMKDS occur, these video(s) will be updated and deployed on the web application.

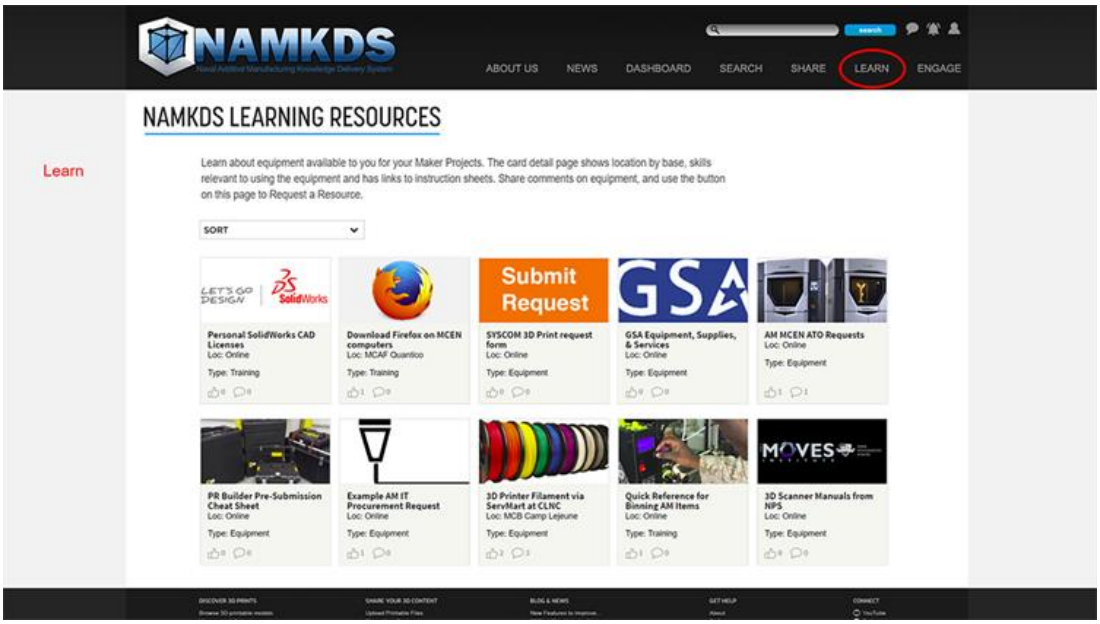


Figure 43. Web Design – Learning Resources 1

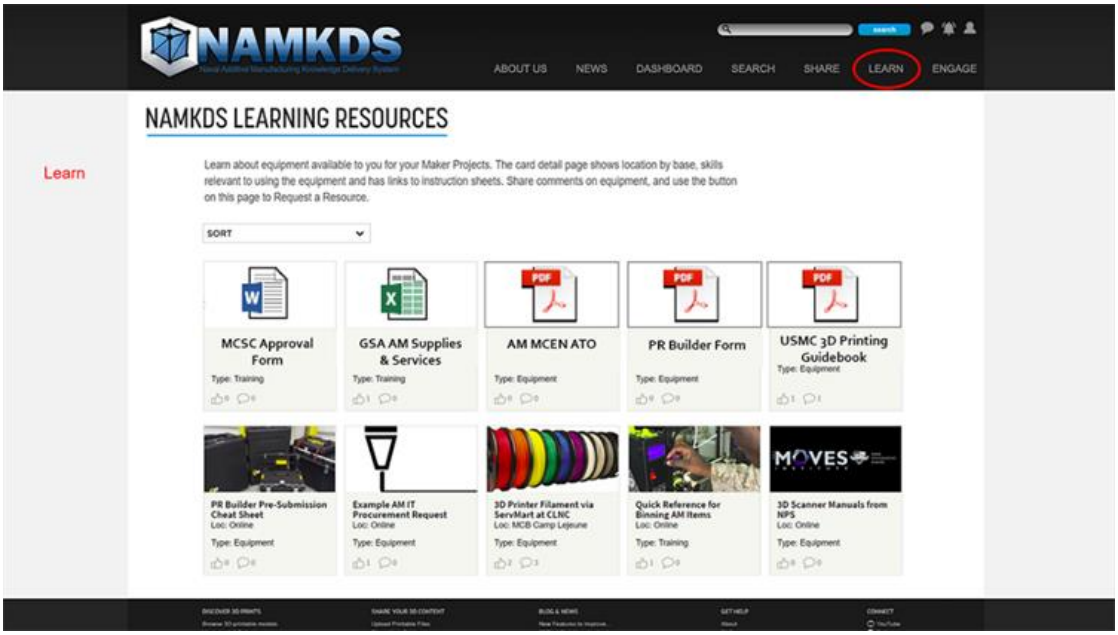


Figure 44. Web Design – Learning Resources 2

6.2.3.4 Engage

Knowledge sharing will be accomplished in a couple of ways. First, a voting feature (thumbs up/down) will be included in the application on each 3D file. This vote allows users to signify their approval of the quality of the file in a fashion similar to that used on various social media applications.

Another engagement activity is the use of forums for users to share lessons learned, tips, and tricks. General discussion topics and targeted discussion topics to enable crowd-sourcing opportunities across the 3D enterprise.

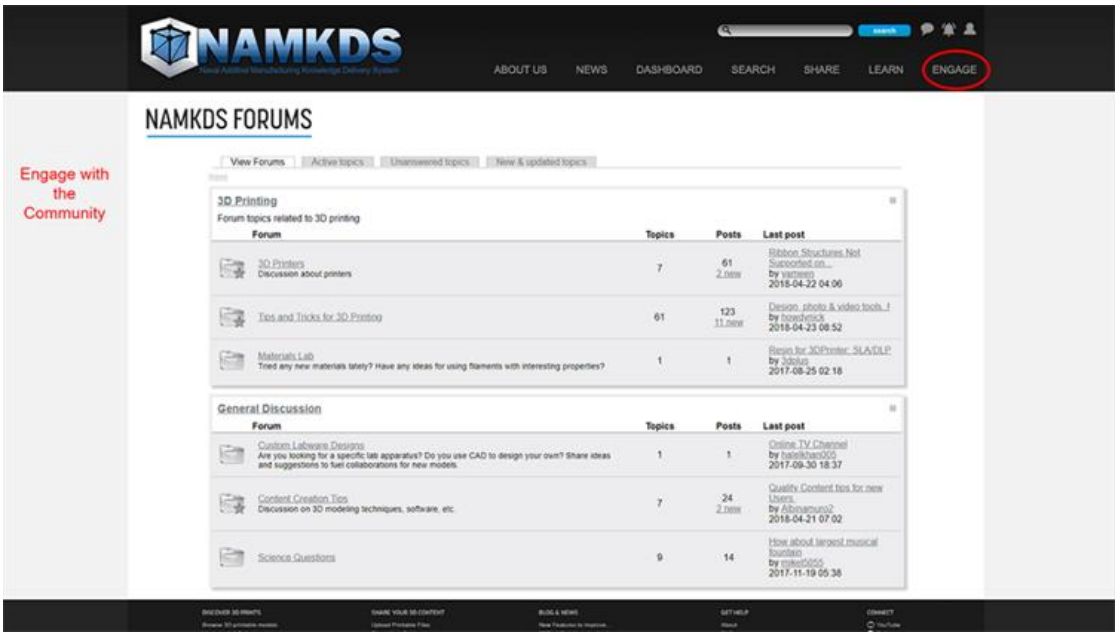


Figure 45. Web Design – Engage

6.3 Integration with Existing Systems

There are various ways in which NAMKDS will be interacting with external systems. These information exchanges include reading, querying, and monitoring data as well as generating and modifying information that is maintained in external data stores. Strategies and capabilities can be employed.

Database links – Regarding performance, the best way to exchange data with an external database is via database links. The downside to this strategy is that it requires developers to build an interface in both NAMKDS and the external system. This approach is not uncommon within the DoD and can be implemented on various levels.

Data monitoring – Probably the most common way database links are utilized. NAMKDS is meant to enable the exchange of knowledge and 3D models. Much of this data originates in external systems. To provide a seamless experience for NAMKDS users, the ability to search and view information from other systems is essential. NAMKDS will need this ability for things like tracking purchase requests that reside in the EPS. When EPS gives read access via database links to NAMKDS, that data can be indexed and related directly to internal NAMKDS tables. This means that queries into EPS perform and behave the same as any internal query. Product data is another rich set of information that is primarily maintained in DoD engineering data repositories and other information systems. There are also educational repositories that will support the NAMKDS Knowledge Help Desk.

NAMKDS users will also benefit by sharing data with external systems. The broader community that maintains product data, engineering data repositories and AM curriculum will be encouraged to contribute if they have visibility into NAMKDS directly from their day-to-day applications.

The level of integration made available by database links extends beyond sharing read access to select datasets. External data can potentially be created, updated, and deleted by NAMKDS users. If this permission is granted both ways, another system can become fully integrated with NAMKDS making for a seamless experience for all users. This level of integration is ideal for adding modules to NAMKDS such as a mature customer support application. The same holds true for an educational system that enables online webinars and classes. Immediate candidates for this type of integration include systems maintained by the Naval Postgraduate School and the Defense Acquisition University.

Web services are probably the most widely-used mechanism for cross-platform communication between systems. NAMKDS will provide a REST API for external systems to request and present data. This type of information exchange is generally asynchronous and transactional. Commercial vendors will almost certainly offer services that NAMKDS can request allowing NAMKDS users to find information residing in outside systems. *Thingaverse* is one example of a commercial system that provides a REST API. NAMKDS users will have access to models and information maintained in *Thingaverse* without the need to leave the NAMKDS application.

6.4 Offline Access to NAMKDS Content

Forward units require the capability to operate in disconnected (detached) mode; a “detached” function was included so the system can still be used in those situations. In the detached mode, users can download the equivalent of a “Go Disk” before deployment to take with them. This Go Disk contains 3D models they may need. During detached mode, data generally gathered during use or creation of 3D files will be stored locally and uploaded back to NAMKDS once the user is connected to the network again.

The NAMKDS application includes a synchronization engine to support detached mode. Expeditionary and other users that require this feature will first need to download the detached version of the NAMKDS application. The detached-application is capable of pushing and pulling updates via the synchronization engine when there is network availability. It is through the detached-application that users can identify the subset of data they require when working offline. This allows them to pull everything related from the server during an initial synchronization.

Given the requirement for users to search, create, update, and delete data in a detached-application, the preferred technical approach is to develop a new desktop application. Visual Studio.NET will be the Interface Development Environment and C# will be the language for development. This will offer the flexibility needed to enable all of the capabilities, including full file system access, to the end-user. A local SQLite database is included in the detached-application and enables efficient offline data management. The downside of creating a stand-alone application in C# is that it needs to be accredited as a new application. This may be avoided by implementing a detached browser-based application that is built using JavaScript. A browser tool should be considered part of the NAMKDS application and does not need its own application status. The advantage of using a JavaScript application is that file system access will be limited. It could offer a way for users to interact with models and help direct them to the tools and files they need when the inherent limits of a browser application are met.

6.5 Development Approach

6.5.1 Methodology

Development of NAMKDS was in accordance with DON CIO's Systems Development Lifecycle and related Systems Engineering processes. As such, development efforts underwent traditional development, test, and production phases. An Agile management approach to development was followed.

Numerous requirements were gathered during the Powernoodle® sessions and other meetings with users, makers, and leadership. Process flows were developed. An initial listing of data to be tracked was gathered. A crosscheck between processes that create data, requirements, and the data determined to be monitored was performed to ensure there were no gaps. Any identified deficiencies were resolved and incorporated into the system design. The business processes were mapped to use cases and formed the basis of system testing.

After process flows were mapped out, and their required core data elements identified, a logical database design commenced, and a function hierarchy was crosschecked against the logical design. Once the design phase was complete, a physical database was developed from the logical design and web page development commenced.

Each development iteration was driven by both short-term and long-term functional requirements. A scope of work defined all of the requirements for a development phase along with deliverables. Each phase produced a set of new tools and functionality to end-users that brought business value in a production environment. The approach and implementation strategy for each phase was carefully analyzed against and shaped by the full list of requirements identified in the NAMKDS Blueprint. This enabled incremental releases that will align with the NAMKDS long-term vision. A primary goal of the NAMKDS Blueprint was to direct these incremental releases providing immediate value and set the stage for future enhancements.

6.6 Maturation Phases or Sprints

The Implementation Strategy for NAMKDS was based on a series of maturation phases or sprints. The implementation strategy was based

on the establishment of a sound system foundation along with delivery of basic functionality first. Once that scope was considered stable, Agile software development methodology was recommended. The Agile approach supported an incremental rollout of scope (Table 3).

6.7 Components

6.7.1 Hardware

An initial design option was based on NITC hardware. NITC provides clients virtual machines based on VMWare architecture and software.

All implementation options for NAMKDS included two scenarios:

- Scenario 1: Host NAMKDS on an existing Navy system. This scenario placed NAMKDS dependent upon the host's hardware capability. The core capabilities of NAMKDS did not require substantial computer capability. A host system might have to add nominal hardware if the host was currently at maximum utilization.
- Scenario 2: This scenario was not host-based and thus NAMKDS required an entire set of hardware. The hardware needs were as follows:
  - Firewall
  - Web Serve
  - Application Server
  - Database Server
  - Login Access Server
  - Management Server.

Today's data centers generally provision computers to customers as virtual machines. As such, the hardware requirements for NAMKDS in such an environment requires the same six servers as virtual machines. However, the actual hardware that provides these virtual machines may be actually via one or two actual physical servers. Regardless, the virtual machines usually are based on the same number of computer cores, ram, hard disk storage, and network devices.

6.7.2 Estimated Hardware Requirements by Machine

- Web Server – 1x 6 core CPU (2x preferred), 16 GB RAM, 150 GB storage
- Application Server – 2x 8 core CPU, 64 GB RAM, 250 GB storage
- Database Server – 2x 8 core CPU, 128 GB RAM, 10 TB storage
- Login Access Server(s) – 2x 4 core CPU, 16 GB RAM, 100 GB storage
- Management Server – 1x 4 core CPU, 16 GB RAM, 100 GB storage

Table 3. NAMKDS Maturation Sprints

SPRINT	SCOPE
1	Foundational infrastructure (application server, database server) in DEV + Basic file storage/sharing capability/3D rendering for "part preview"
2	Server-side file management – identify and implement a strategy for managing files of various formats in the DEV environment. Enable BFILE object references in the database (allows easy access to source files via file systems)
3	Foundational infrastructure (application server, database server) in TEST + file sharing/tracking, file format management. Commence ATO mod paperwork for any required 3rd party file manipulation utilities.
4	User upload capability, to include the transfer of all pertinent metadata.
5	Create search/query capability for stored files and related metadata.
7	View Create browser-based 3D image previews on web page utilizing the X3D model format.
8	TBD

6.7.3 Software – Commercial Off-the-Shelf (COTS)

Software recommendations are provided in Table 4.

Table 4. Software Recommendations

Software	Version
Oracle Database	12c
Oracle Application Express (APEX)	5.0.4
Oracle Unbreakable Linux	4.1.12
Blender (or similar for file conversion)	2.79

6.7.4 Software – Government Off-the-Shelf (GOTS)

NAMKDS will be a GOTS application that leverages the above COTS products listed in Table 4 to provide 3D File Exchange functionality in a 3-tier web-based architecture. NAMKDS will initially provide the capabilities listed in Table 5.

Table 5. NAMKDS Initial Capabilities

ID	Capability
1	3D File Upload/Storage/Sharing (Download)
2	Search library of 3D files
3	Automatic gathering of uploaded 3D file metadata
4	Mandatory data gathering regarding the uploaded file (besides the metadata)
5	Tracking of files and usage
6	3D visual of part (in the 3D model(s))
7	Training and Help
8	Knowledge Sharing
9	Social collaboration, such as quality based voting (thumbs up/down)
TBD	TBD

6.8 Data

The data in NAMKDS is intended to be unclassified. The data primarily identifies files, documents, and users regarding the 3D printed objects and the equipment the printed objects are installed in, on, or related to.

To minimize typographical errors interfaces to Service branch work control systems (SAP for Navy and GCSS-MC for Marine Corps) are intended to allow users to select from pull-down menus or domains of equipment make, model, description, serial number, any other characteristics information where possible.

6.8.1 Data Normalization

As new and existing data is organized into a relational structure for storage, maintenance, and retrieval, it will be normalized to ensure data integrity and avoid any unnecessary, redundant storage. To this end, when related model data is maintained in external systems, NAMKDS will attempt to make that information available via live exchanges rather than duplicate and maintain the same information.

6.9 Security

6.9.1 Authentication

The system will be CAC-enabled and require users to login via two-factor authentication. The initial authentication will allow users to access the portal that contains NAMKDS. By leveraging existing portal authentication, NAMKDS will be more easily integrated regarding workflows and data exchange. DoD users are generally authenticated into a Portal or existing network of systems. It will be necessary for NAMKDS to inherit these authorization schemes to integrate and extend existing business processes successfully.

6.9.2 Authorization

Another substantial benefit of authenticating NAMKDS users via an existing Portal is that NAMKDS can then reliably retrieve active user information, removing the burden of identity confirmation. It also makes it possible for NAMKDS to enforce custom controls regarding data access. NAMKDS will have various types of users that can provide and retrieve data. Some users will be responsible for approving

data access as part of the NAMKDS business process. The business logic layer will enforce all rules regarding data authorization. Many examples of this type of approval exist in NAVFAC Portal and all Oracle applications within the Portal share the same Single Sign-On authentication. This enables API access for each Oracle application to information about actively connected users. It is common and usually required that these systems leverage this information for custom rules regarding data availability.

6.10 Accreditation

NAMKDS can potentially be integrated into an existing application that is already accredited. With this approach, the first iteration of NAMKDS may not demand an accreditation if it does not expose a new interface to external systems. The SPIDERS application within NAVFAC Portal could serve as an initial home for NAMKDS. SPIDERS is an Oracle system with 3D capabilities that would complement NAMKDS. SPIDERS already has the database links to iNFADS and MAXIMO which would immediately benefit NAMKDS. Regardless of the approach, a reaccreditation will be an eventual necessity. As described in this Blueprint, NAMKDS will be interfacing with several external systems and data stores. Each of those exchanges will likely require NAMKDS to be reaccredited at the point the new interface is implemented in a production environment. The same requirement will be placed on those external systems; they will each need to be reaccredited. The only exception to this would be commercial platforms, such as *Thingaverse*.

7. PLM Approach

7.1 Test Strategy

This Blueprint proposes the traditional software tests in accordance with DON CIO software development lifecycle requirements. However, besides the required testing that will be performed these additional tests will focus on the user to ensure NAMKDS performs as needed in the field.

7.1.1 Unit Test

Front-end application development will incorporate unit tests where appropriate. For Option 1, tests will be written during development via the qUnit framework. This will encourage pure functions and testable units that are less prone to failure as future functionality is layered on top of existing code.

7.1.2 System Integration Test

Front-end application development will incorporate system integration tests where appropriate. For Option 1, tests will be written via the qUnit framework and will ensure that the Model-View-Controller architecture employed by the web application is performing without error. These tests will continually check that users will not invoke bugs while navigating from page to page.

7.1.3 User Acceptance Test

User Acceptance Testing (UAT) is intended to be analogous to "sea trials." This testing will focus on scenarios where actual printing is performed, and actual files are created and shared. These tests are designed to direct a user through a series of actions. The tests also describe the expected results of specific user actions; each step is marked as pass or fail by the tester. Each UAT that is completed will result in a "score" that measures the success of newly developed functionality. When all UAT's are scored at 100%, the test can be considered a success from a user standpoint, and the users should have confidence the system will perform as required.

7.2 NAMKDS Management

Management of NAMKDS depends on the establishment (or assignment to) of a group that is focused on the likely users who will be 3D printing parts. These users will likely be distant from supply chains. This does not mean that some users will not be local to supply chains. However, the focus is to augment the normal supply chain. This augmentation is in the form of ready, local, and ad hoc printing capability to quickly obtain parts. Given that 3D printing of parts takes much time (hours), and the preparation of 3D models takes much time (hours to days), the decision to print a part for oneself rather than waiting for the part to arrive in a box is often made close to the "tip of the spear". The management of this system is encouraged to fall upon a group that is already closely aligned with this type of user.

Conversely, not all 3D printing of parts will occur "at the tip of the spear." Innovations, new designs, and augmentations of equipment systems will occur in almost any unit.

7.3 Design Options

7.3.1 Option 1

The first option for implementation of NAMKDS has been described in Section 6.5 and is based on including NAMKDS as a module(s) within the Navy's SPIDERS system. Additional modules can be added to the SPIDERS architecture in a few ways. The configuration in Section 6.5 depicts the NAMKDS module as another single-page web application contained within the SPIDERS APEX instance. In this configuration, NAMKDS data will be stored in the same

schema that holds all SPIDERS data. The advantages of this include a reduced integration impact and fewer interface adjustments that may require reaccreditation. However, due to the nature of the NAMKDS data, it may be advantageous to make it more independent. Also, it is important to note that there is no 3D printing capability in SPIDERS.

7.3.2 Option 2

A more decoupled configuration would begin with a separate SPIDERS schema dedicated to NAMKDS. If portability is the primary concern, it could also be served up by a separate APEX application. These are non-functional changes that would be transparent to the user but worthy considerations if the NAMKDS application is to be cloned and implemented in multiple environments. This would also provide a separation of data that can be managed via Oracle schema users. Although this requires new back-end infrastructure, separating database objects via schema will ultimately make it easier to lock down NAMKDS data without affecting existing SPIDERS data. It is worth noting that this configuration would likely incur additional expenses regarding maintenance and possibly licensing.

7.3.3 Option 3

A third option for NAMKDS is to develop a stand-alone system for NAMKDS. This option provides the functionality but requires the development of an entire system including getting an Authority to Operate (ATO). This incurs more cost since no leveraging of infrastructure is needed.

7.3.4 Option 4

A final choice may be to add NAMKDS functionality as a module to another existing logistics software system (not SPIDERS) to leverage the equipment and parts information in the database of a logistics system. The 3D printing of items is equipment related. The most significant task in establishing a 3D file sharing system is not the 3D aspect but integration with databases of equipment and parts data. The marriage of 3D printing metadata is most closely related to logistics data. It is important to note the DLA owns this kind of data and information.

7.4 Organization

The organizational structure to manage NAMKDS environment will mature during *Block 1* activities.

7.5 Lifecycle Cost (LCC)

The NAMKDS LCC includes the cost to develop or augment a Navy IT system, printer costs, print media costs, training costs, and NAMKDS O&M costs (Table 6). An annual estimation is presented that has inherent inaccuracy due to assumptions. Regardless, an estimate is made that will likely represent the first five years. After that time a new cost assessment will have to be made since the infrastructure will require a refresh of equipment and software.

Table 6. Initial LCC

YR	Cost Item	Cost	YR total
1	Dev NAMKDS (= 10 developers)	$250,000/dev	$2.5 M
1	NAMKDS SW	$750,000	$0.75M
1	3D printers (= 2,000)	$750	$1.5M
1	3D print media (= 10,000 spools)	$50	$0.5M
1	Other costs (unknown other related costs)		$1.0M
1	**YEAR ONE TOTAL**		**$6.25M**
2	Dev NAMKDS (= 10 developers)	$250,000/dev	$2.5 M
2	NAMKDS SW (support)		$0.15M
2	3D printers (= 2,000 more)	$750	$1.5M
2	3D print media (= 30,000 spools)	$50	$1.5M
2	**YEAR TWO TOTAL**		**$5.65M**
3	**YEAR TWO TOTAL**		**$5.65M**
4	**YEAR TWO TOTAL**		**$5.65M**
5	**YEAR TWO TOTAL**		**$5.65M**