M&S Workbench – A Foundation for a Modeling & Simulation Digital Engineering Ecosystem

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ABSTRACT

Department of Defense (DoD) organizations are challenged to compile and align Modeling and Simulation (M&S) information from a combination of data sources across multiple stakeholders. Aggregating useful data and analytics throughout program lifecycles is difficult because current practice typically relies upon static, disconnected, stove-piped sources of information. Digital Engineering (DE) is an emerging concept articulated by Deputy Assistant Secretary of Defense for Systems Engineering (DASD(SE)) designed to strengthen engineering discipline. It is an integrated, model-based approach to support the planning, design, operation, and sustainment of DoD programs.

With support from the DoD Modeling & Simulation Coordination Office (DMSCO), the M&S Workbench was developed as an open source, modular software tool that enables the development of a DE ecosystem—a digital environment for team collaboration based on authoritative sources of information.

This integrated M&S approach, supported by a digital engineering ecosystem, has been proven effective. The M&S Workbench is currently utilized by Program Executive Office Integrated Warfare Systems (PEO IWS) providing its M&S team visibility to hundreds of structured and unstructured data sources and "ground truth" collaboration throughout all phases of the systems engineering lifecycle. Key benefits of this approach are enhanced communication across the PEO IWS enterprise and increased confidence in delivering the best M&S outcomes within cost and schedule.

ABOUT THE AUTHORS

Ms. Pauline Johnson has over 20 years' experience providing customized technology solutions, managing technology support teams, and developing learning experiences. Currently, she contributes as a UX/UI designer to SimVentions' M&S team development projects, as well as supporting end users of deployed applications. Ms. Johnson has a Bachelor's of Science degree from San Diego Christian College.

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INTRODUCTION

Department of Defense (DoD) organizations are challenged to compile and align Modeling and Simulation (M&S) information from a combination of data sources across multiple stakeholders. Aggregating useful data and analytics throughout program lifecycles is difficult because current practice typically relies upon static, disconnected, stove-piped sources of information. Digital Engineering (DE) is an emerging concept articulated by Deputy Assistant Secretary of Defense for Systems Engineering (DASD(SE)) designed to strengthen engineering discipline. It is an integrated, model-based approach which supports the increasing complexities of planning, designing, operating, and sustaining DoD M&S programs.

In a 2009 internet published article titled, Competition and Innovation Under Complexity (Drezner, 2009), Jeffrey A. Drezner writes:
"*The products of the Department of Defense (DOD) acquisition process are perceived as becoming increasingly complex, emphasizing multifunction and multimission system configurations. Such weapon systems utilize network capabilities and systems-of-systems engineering and integration methodologies throughout their life cycles. The management and oversight of these complex programs have similarly become more complex. Changes may be needed in the organizations and procedures used to manage the development, production, and sustainment of these complex weapon systems.*"

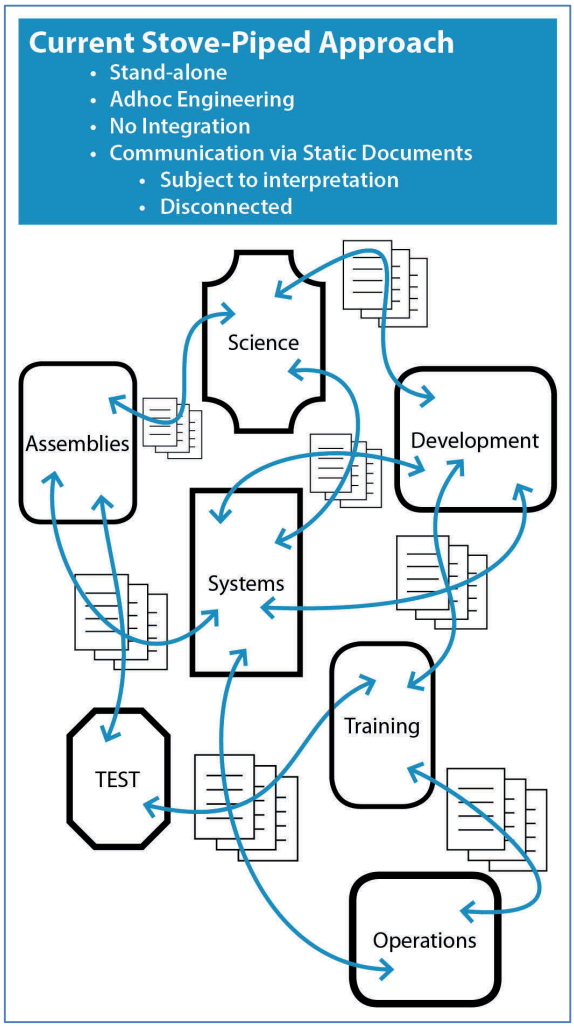

Figure 1 Stove-piped systems

CURRENT DAY CHALLENGES

The DoD, as well as organizations of all sizes, are finding themselves with overwhelming amounts of increasingly complex information, often locked away in silos—stove-piped models of different systems, created by different organizations, separated by different geographies and containing different data types—making it practically impossible to connect all of the dots and make sense of critical system information. Contributing to the challenge of increasing complexity is the current document-centric engineering process. Documents are not digitally shared across systems, organizations or stakeholders, and so become subject to interpretation by the reader. With information housed throughout many stand-alone systems, it is not possible to establish a single source of authoritative truth from which stakeholders and decision makers can rely upon to inform the decision process consistently, accurately, and timely.

Decisions made early in a system lifecycle may negatively impact a program downstream due to an incomplete understanding of a data model's intended use, or because of the inability to validate one data model against another similar, or possibly duplicate, model that might exist in a disconnected system. Further, stakeholders (especially stakeholders of large systems of systems) who are geographically distributed may have different or conflicting interests and priorities; programs may not share relevant data across engineering functions, which can lead to duplication of effort or work products that are not in step with one another; different methods to preserve knowledge are utilized from one program to another, or even within the lifecycle of a single system. All of these dynamics contribute to the challenges that put pressure on not only the decision makers, but also on the M&S practitioner.

There are additional factors contributing to the development challenges DoD programs face. Gartner research forecasts that the volume of data will grow at a rate of 800% over the next 5 years. 80% will be unstructured data (such as presentation files, instant messages, image files, or text documents, to name a few). The ability to utilize unstructured data within the current system engineering methodology is problematic but must be resolved. As system requirements continue to grow in size and complexity – the challenge to collect, manage, analyze, and interpret the large amount of data required by M&S stakeholders and system engineers grows proportionately arduous for the DoD.

A DIGITAL ENGINEERING ECOSYSTEM SOLUTION

Given the complexity of systems, the diversity of data, and the increasingly rapid changes that systems experience, it is reasonable to forecast that the complexity will continue to increase. As a solution, ODASD(SE) promotes digital engineering as a way to harness the power of information available to the Department to make data more useful and more readily accessible across systems.

Defense Acquisition University (DAU) defines a Digital Engineering Ecosystem (DEE), as an "interconnected infrastructure, environment, and methodology (process, methods, and tools) used to store, access, analyze, and visualize evolving systems' data and models to address the needs of the stakeholders."

While the DoD currently uses modeling throughout the acquisition lifecycle, it has been speculated that shifting to a dynamic, digital, model-centric ecosystem with a digital authoritative source of truth would be a key component to transforming the acquisition process. Creating a digital ecosystem that spans across various disciplines, and stretches throughout system lifecycles is not achieved by just implementing technology. Rather, it consists of a fuller solution that includes people, processes, and technology. Cross-functional teams dedicated to collecting, analyzing, and sharing M&S assets and data, along with senior-level stakeholders within organizations with a strategy for M&S resource management and established policy for M&S governance, are critical to insure that all groups comply with and contribute to the sustainment of the ecosystem. Supporting the needs of stakeholders, a DEE provides an accessible, collaborative pool of M&S information and assets to serve as "ground-truth" for making data-driven decisions. It is critical for those involved in the engineering process to identify and understand how every element impacts a design, in order to mitigate negative outcomes. Digital engineering also serves to preserve historical information throughout personnel changes, ensuring that key information survives beyond specific people occupying critical roles and positions.

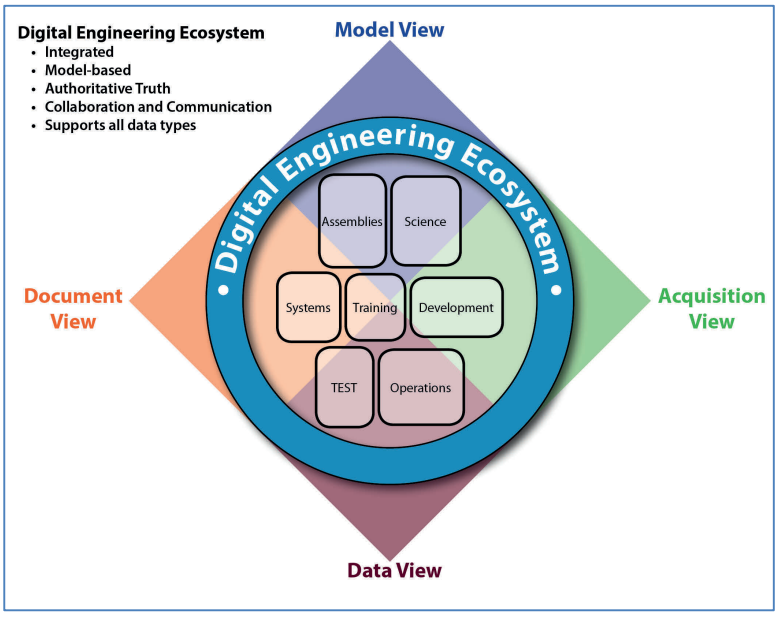

Figure 2 • A Digital Engineering Ecosystem

From a process perspective, a DEE streamlines the way programs collect, retain and share data. Visibility to methods and programs which need to share data across engineering functions, can potentially lead to the discovery of duplication of effort, or work products that are out of step with one another. In addition, programs and organizations may take varying approaches to preserving knowledge from program to program or among the phases of the acquisition life cycle for a given program. While varying techniques are employed today, by using a visual representation of the system, relationships between different parts of the system are easier to see and manage, and processes are exposed for analysis and potential modification. The goal is not only to better align strategies, reduce cost, lessen effort and minimize risk, but to also better execute all of the elements of an entire system lifecycle.

Digital engineering technology moves the DoD towards an integrated model-based approach through the use of standards-based digital environments (such as digital processes, methods, tools, and digital artifacts). While digital models themselves have been common in engineering since the 1960s, an integrated digital ecosystem extends beyond simply using independent digital models (such as E-CAD, MCAD, UML and SysML) by providing a data-rich environment. This environment shifts the DoD away from its document-centric approach to establishing a centralized and digital ground truth. Modulating to this integrated ecosystem enables engineering teams to more readily understand design change impacts, communicate design intent and analyze a system design before it is built. The digital engineering ecosystem covers the entire lifecycle of a system from concept to disposal. It reduces design time, improves quality, minimizes risk, and makes complex systems more understandable and affordable.

Digital Engineering Ecosystem Benefits

Based on our aforementioned discussion of the benefits and value of a digital engineering ecosystem, in summary, an ecosystem establishes a common reference across engineering disciplines, so that teams may more easily communicate and collaborate during the development process. Improved communication leads to greater efficiencies, improving time-to-deployment. Also, because a system model makes it easier to visualize interdependencies within a system, the risk of errors and quality assurance issues are reduced, especially when making system modifications.

When stakeholders, and others, have access to a digital, centralized, authoritative source of truth, there is improved understanding of data's intended use. Access to integrated technical data – such as overall information, program deliverables, test results and modeling data, can result in better decisions because they are traceable to the technical data and can be validated. Better informed decisions can avoid costly impacts to future development because the stakeholder can visualize and understand the impact of today's decision on tomorrow's system. Collaboration and improved communications – between stakeholders, engineering teams, and others – results in improved systems quality by fostering early requirements definition and facilitating the integrity of system design. Improved interaction across multi-disciplined teams can increase productivity, improve the ability to analyze the impact of requirement changes, and promotes the reuse of existing models. All of this contributes to minimizing risk and reducing cost.

PEO IWS CASE STUDY – PEOPLE, PROCESSES AND TECHNOLOGY

The Program Executive Office for Integrated Warfare Systems (PEO IWS) is one of the PEOs that reports to the Assistant Secretary of the Navy for Research, Development, and Acquisition ASN(RD&A). They are tasked with the development and acquisition of Navy platforms and weapons systems. PEO IWS also reports to the commander of the Naval Sea Systems Command (NAVSEA) for planning and execution of in-service support. Their mission is to "Develop, deliver, and sustain operationally dominant combat systems to Sailors." Over 120 programs and projects work together to meet this goal, including: Acquisition Category (ACAT) I Major Defense Acquisition Programs (MDAPs), Research and Development (R&D) projects, and Non-ACAT programs. The organization of the PEO enterprise is extensive, comprised of Element, Fleet Readiness, and Combat Systems Major Program Managers, as well as Major Engineering Development and Test Commands.

The importance of M&S in the acquisition, design, development, and test of complex weapon systems is widely accepted today. In the Memorandum "Application of Modeling and Simulation in Department of Defense Acquisition Programs", dated 21 March 2000, then USD(AT&L) J.S Gansler stated that "One of our top priorities is to reduce the costs and cycle times required to field new weapon systems. …we have stressed that we must make better use of M&S to improve the acquisition process, reduce costs, enhance T&E, and shorten the development times for our new systems. We are convinced that efficient use of M&S throughout the system life cycle will net great dividends in efficiencies."

Nearly seventeen years later, although many DoD Directives have provided high level guidance to organizations, on a practical level, organizations like PEO IWS struggle to manage the people, processes, technology, and data components of their Modeling and Simulation Resources.

Putting People First

The PEO IWS enterprise faced many challenges in managing the people associated with their M&S Resources. Multiple program and product lines, staffed by civilian government, military, and government contractors, often utilized common M&S, but with differing intended uses. For example, multiple weapons systems simulations might utilize a common threat model for performance assessment. Collaboration and communication was challenging because information was not centrally housed and accessible to all personnel supporting the programs and projects. Multiple weapons systems simulations might utilize a common threat model for performance assessment, but not all stakeholders had access to the model, and the threat model might be duplicated with slightly different parameters.

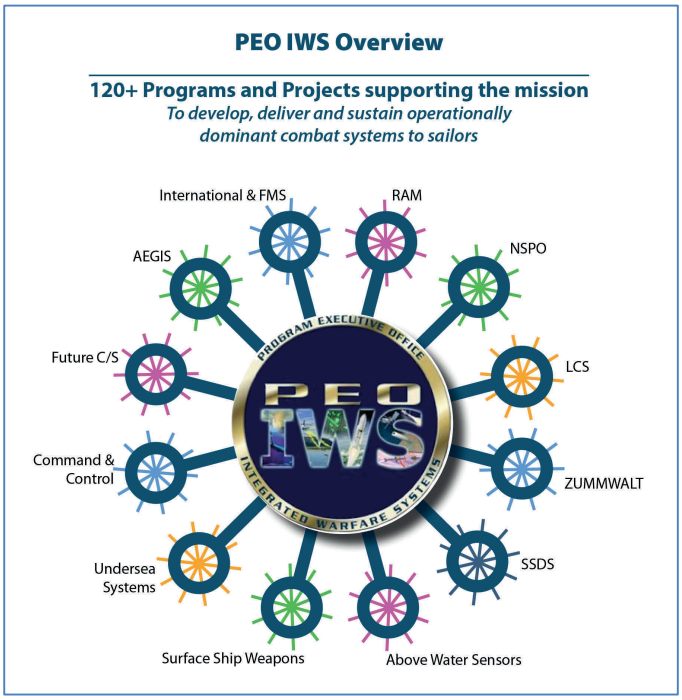

Figure 3 • PEO IWS organization is complex and robust

To address these challenges, the organization established a framework for the management and development of M&S and M&S based analysis. A community of interest (COI) was established, and ultimately, an M&S Integrated Project Team (IPT) was chartered. The IPT is composed of representatives from each directorate, or mission area, who assist in the coordination and standardization of M&S activities across the IWS enterprise for M&S assets used to support IWS programs. The establishment of the M&S IPT ensured that each directorate was appropriately represented. As the IPTs supported the organization and collaboration of people, it was discovered that the organizations' catalog of M&S resources were a varied combination of Government off the shelf (GOTS), Commercial off the shelf (COTS) and tactical hardware and software. There was no single tool to provide visibility into the vast amounts of existing M&S data to support high level decision makers and to facilitate and support M&S asset discovery and re-use, thereby reducing cost and minimizing risk, along with other benefits addressed earlier in this paper.

From People to Processes

The M&S IPT recognized that the accuracy of the M&S data and discovery of the data used throughout the greater organization was the key to its re-use. Developing sound processes to collect, gather and store data (as well as reporting out on the data) was challenging because much of the M&S data utilized by PEO IWS was not specifically developed by the organization itself, but rather was created by other government agencies or contractors. Further, ensuring that information was updated in a timely manner, given funding and schedule constraints, created roadblocks to defining and implementing successful processes over the lifecycle of projects and systems.

The Data Dilemma

The PEO IWS organization is faced with managing three types of data: structured data, unstructured data, and semi-structured data. Managing these data types presented challenges to the enterprise.

Structured Data
Structured data can be defined as any data that has an "enforced composition to the atomic data types" (Director of Administration and Management, May 3, 2013.) Structured data is well-defined. It is often found in relational databases or spreadsheets, which can easily be queried and reported through the hosting software program. The PEO IWS M&S community manages large quantities of structured data generated by various models, simulators, and live testing efforts. The data is collected in various file formats and stored at geographically diverse locations. Structured data is challenging because there is a of lack of availability to all who need access to the data; individuals may not have the technology needed to view or open certain data formats; data rights and contractual limitations may not provide for widespread access to the data; and lack of adequate data set descriptions may leave some structured data unsearchable and unknowable.

Unstructured Data
Unstructured data can be defined as "any data stored in an unstructured format at the atomic level" (Director of Administration and Management, May 3, 2013.) Computerized information, which does not have a data structure, that is easily readable by a machine and requires human intervention to decipher the data is unstructured data. Examples include (but are not limited to): e-mails, meeting minutes, PDF files, power point presentations, text messages, video files and system documentation text files. Unstructured data can contain dates and statistics within its files. The PEO IWS M&S community manages a multitude of unstructured data artifacts. They are generated during the utilization and management of M&S by the organization, but could also be created by others outside of an individual directorate. M&S verification and validation packages, organizational directives, meeting minutes from technical exchanges, integrated product team meetings, and focus group meetings are some of the examples of unstructured data that is created, managed and used by the enterprise. Many of the challenges to managing and accessing unstructured data are common to the challenges of addressing structured data, listed above: varying file formats, geographically diverse storage locations, lack of availability, lack of the right technology to view or open certain data formats, data rights, contractual limitations, and lack of adequate description of data sets may leave important unstructured data undiscoverable and therefore unknowable to decision makers.

Semi-structured Data
Semi-structured data can be defined as a type of structured data that lacks a data model structure. XML and other markup languages are often used to manage semi-structured data, commonly referred to as "metadata," by using tags or other types of markers to identify certain elements within the data. Many M&S practitioners are familiar with the concept of metadata. Metadata is information describing the characteristics about an entity's data, data activities, systems, and holdings. Discovery metadata is a type of metadata that allows data assets to be found using enterprise technology search tools. Because of the diversity of semi-structured data, the same challenges as stated above haunted the PEO IWS enterprise.

FROM PROCESS TO TECHNOLOGY

PEO IWS Technology Challenges
The PEO IWS organization faced many technological challenges related to the management and utilization of their M&S Resources. The lifecycle of combat systems (and the M&S that supports their lifecycle development), surpasses conventional systems by many years, and sometimes decades. The computing systems used by the organization are not homogenous. They are comprised of many different operating systems, connection types and differing hardware components. Government furnished equipment (some of which was purchased as part of a single buy at the initial acquisition of a system) is now required to function with commercial off the shelf products (COTS). The organization is challenged to manage not only the technology integration process, but to support supply chain management and the lifecycle needs of required hardware.

Another technological hurdle, that must be managed by the organization, is the information assurance (IA) requirements. These require organizations to integrate cybersecurity into the system engineering process. Understanding the IA requirements and applying the correct solutions to mitigate each cybersecurity requirement is critical, while at the same time it is challenging. When a COTS tool has not been vetted through the IA process, government organizations do not have the rights or even access to the code to make necessary alterations. This limits the COTS products that can be used when cybersecurity is a factor. Another technological challenge centers around following the DoD policy and procedure requirements for the Verification, Validation, and Accreditation (VV&A) of PEO IWS's M&S data. However, managing this VV&A information has also proven to be a challenge. When making

decisions based on the M&S used to support different activities (such as test and evaluation, system performance analysis, and milestone reviews), practitioners need to determine the VV&A status of a model, simulation, or data set, and understand its specific intended use. Existing GOTS and COTS tools lacked the ability to include this information in the data sets.

Technology Solution

As PEO IWS implements the DoD directives that compel organizations to make all data and metadata "discoverable, searchable, and retrievable" by using "existing commercial-off-the-shelf, government-off-the-shelf, open source software, and open standard solutions," the M&S IPT analyzed a GOTS tool developed to facilitate the capture of metadata about M&S. The IPT determined that the tool provided a strong foundation but required customization to meet their unique organizational needs.

A Customizable GOTS Tool

The Defense Modeling and Simulation Coordination Office (DMSCO) has a distinguished history of developing policies, standards, and tools to support improved development, collaboration, and application of M&S across the DoD. M&S policy and guidance documents support the principles articulated in the DoD Net-Centric Data Strategy (2003), which emphasizes making data visible, accessible, understandable, trusted, and interoperable. The Strategy also provided a concept for the communities of interest organized around specific domains such as M&S, logistics, and command and control. In support of these goals, DMSCO initiated an effort several years ago to develop the Modeling & Simulation Community of Interest Discovery Metadata Specification (MSC-DMS). This specification was a first for the M&S community and provided a common taxonomy to describe M&S information and resources. The MSC-DMS is based on the Extensible Markup Language (XML) and was developed to be compatible with the metadata specifications of other communities of interest. The approval of the MSC-DMS fulfilled part of the vision of the Net-Centric Data Strategy by providing a technical means for making data accessible, understandable, and interoperable.

The development of a metadata specification led to the subsequent development of a web-based software tool to enable users with an easy interface to manage, share, and collaborate on M&S data. Records composed of metadata are commonly called "metacards." The initial name for the software tool to support the creation, maintenance, and publishing of metacards was the Enterprise Metacard Builder Resource (EMBR) Portal. EMBR was developed as a Government-Off-The-Shelf (GOTS) tool and built using open source components. There are no proprietary restrictions to using EMBR. Exchanging data with other metadata catalogs and repositories is one of EMBR's strengths because its database was patterned after the MSC-DMS.

As EMBR's adoption increased and more organizations began using it to manage their M&S holdings, it became clear that a tool by itself was inadequate to foster the sharing and reuse goals articulated in DMSCO policies and strategy. A new concept emerged called "Local Control – Enterprise Discovery." This concept acknowledges the long-standing problem of "stove-piped" data repositories that lack capability for sharing of data with authorized users. "Local Control" appreciates the idea that individuals and teams are at the heart of knowledge sharing and that they are grouped generally by functional discipline, such as M&S, system test, or threat analysis. Local teams have the best and most current domain knowledge and, as a result, are more apt to share data and collaborate. However, local teams are generally reluctant to share their knowledge when they are not in control of which data are shared or unsure how that data will be used. Therefore, a tool developed to foster increased collaboration must also permit teams to control which data are published and also be given an opportunity to describe the context of the M&S resource using metadata. "Enterprise Discovery" is facilitated when local teams are provided with a secure, easy to use tool to manage their M&S holdings and publish selected data records to a trusted centralized catalog.

An Emerging Digital Ecosystem

The successor to EMBR is the M&S Workbench, which supports the concepts of operation described above and also enables the development of a DE ecosystem—a digital environment for team collaboration based on authoritative sources of information. The Workbench, also a GOTS tool, was built using a modular design approach to minimize the cost of sustainment also enable the development of new features without rework of the core application. As teams within organizations utilize the Workbench, customizations can be accommodated to support the unique data taxonomies and workflows of each functional domain.

Some current implementations of the Workbench are deployed to cloud vendors such as Amazon Web Services, which has been fully accredited by the DoD to host sensitive, but unclassified data. This cloud-based approach enables geographically distributed team members easy access to M&S resources and collaboration with the team. Current areas of research for future capabilities include development of the Workbench for classified data and users.

Implementing the Customizable GOTS Tool – The Workbench

Using the M&S Workbench, the PEO IWS M&S Portal (the Portal), is an interactive web-based application specifically tailored to meet the needs of the IWS M&S community. The Portal allows IWS directorates to manage M&S use, oversee re-use, and provides a centralized, authoritative basis for true collaboration. It provides a framework for metadata within the DoD common lexicon and enhances M&S asset, usage, project, and personnel discovery. The Portal standardizes the format of resource entries for reuse, sharing, and reporting. It also includes multi-level access control to support reporting IWS M&S resources to the greater Department of Navy and DoD audiences.

The Benefits of the Customized M&S Workbench Solution

Building on the foundation of the GOTS tool, the IPT developed unique types of resource metacards to create a simple, but meaningful structure. Along with the custom fields, each of the metacards contains the required elements of the MSC-DMS schema, ensuring compatibility and the ability to share M&S information beyond the PEO IWS organization, to the Department of Navy (DON), the Navy Modeling and Simulation Office (NMSO), and additional DoD domains. Lead representatives from warfare product codes serve as lead custodians of certain types of metacards while lead representatives from integrated combat system codes serve as lead custodians for project metacards. This process encourages the creation of project metacards for Enterprise-level M&S and cross-program M&S use.

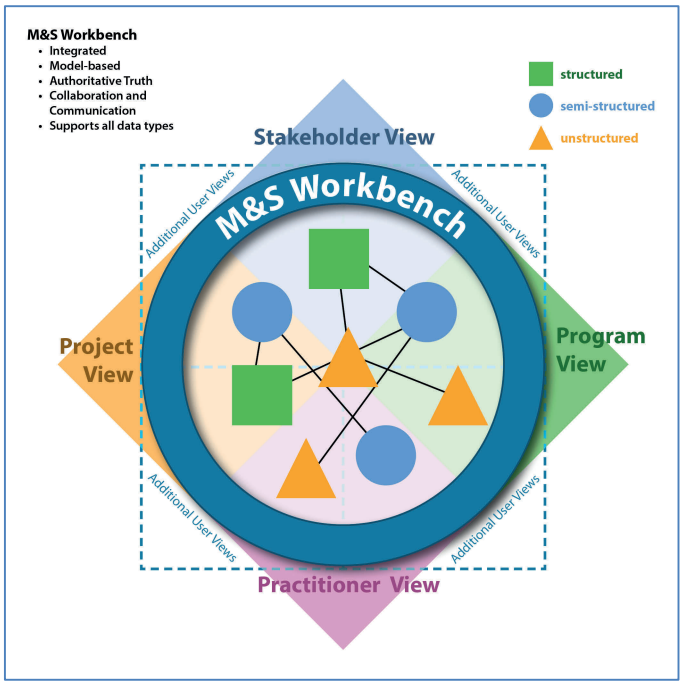

Figure 4 • The PEO IWS Workbench Portal

Meeting the challenges of unstructured data, pages capable of accepting dynamic data sets are included in the IWS M&S Portal. These pages provide the COI with a common area to collect and review unstructured data sets. The IPT uses these pages to store meeting minutes, DoD, DoN, and PEO IWS Instructions, and briefings presented at Technical Exchange and Working Group meetings. Users can view the files and download copies to their local machine. Using the M&S Portal to store unstructured artifacts has led to increased efficiency, collaboration and communication, as COI members no longer have to track down the data custodians of references that they are seeking.

The Portal has also been structured in such a manner that data (metacards) has differing access levels. Resources are accessible by some or all members of a particular directorate, by the entire PEO-IWS organization, or to the external community. Not only does data have differing access levels, the ability to control access was given to the IPT lead representatives. They have the responsibility for personnel within their organization, approving new accounts, assigning access to the tool, and access to records within the tool. The IPT lead representatives control and maintain the overall accountability settings for their data.

The IWS M&S Portal includes fields, determined by the IPT, that are required to provide a user an understanding of the data sets' intended use, the timeliness of the data, and its verification and/or validation status. The current Portal is an unclassified system that has limits on distribution level of information that can be included. The Portal is a web-based (cloud hosted) application, allowing IWS members and outside-entities, who have been granted access, the ability to access the information in the portal regardless of the user's geographic location. User access to the system is protected in accordance with DoD information assurance requirements, but supports collaboration and provides the

authoritative source of truth for all stakeholders, regardless of their geographic location. While there are no technological constraints to uploading data to the Portal, the only limitations in the Portal are the result of data rights, data classification, and contractual limitations, which are outside the purview of any technology system.

Case Study Conclusion

The Portal is a versatile tool being utilized by the PEO IWS organization to support the utilization of M&S resources and data for the lifecycle engineering of major programs and projects. The ecosystem of M&S resources allows the M&S IPT to create a complete picture of the M&S utilized for individual projects, combat systems, and major platforms. The Portal captures metadata to monitor areas where business processes and resource investments require management attention. By understanding what resources are available, what components are currently funded, and alerting program managers to data rights issues, the Portal assists the PEO IWS organization in the development of investment strategies and effective utilization of scarce resources to fulfill the mission of the organization: "Develop, deliver, and sustain operationally dominant combat systems to Sailors."

A DIGITAL ENGINEERING ECOSYSTEM FOUNDATION SUMMARY

The DoD challenges explored in this paper are shared by most all M&S resource practitioners. Developing and utilizing a Digital Engineering Ecosystem provides more systems engineering depth without increasing costs. It helps organizations achieve unprecedented levels of systems understanding while facilitating collaboration and communication between participants. Decision Makers and stakeholders have a common tool to provide early insight into decisions, and the authoritative source of truth provides a higher confidence in decisioning, enabling traceability back to validated data sources. Overall, a digital engineering ecosystem reduces risk of errors, data duplicities and minimizes quality issues as changes are implemented across systems, large and small. By further providing visibility of appropriate data to the right personnel, knowledge capture and transfer across departments and organizations, and throughout personnel changes no longer is a liability to the enterprise.

M&S resource management is critical to successfully leveraging ideas and innovations across organizations. PEO IWS demonstrates that it is critical to have a senior-level champion in the organization with a strategy for M&S resource management and established policies for M&S governance to successfully develop cross-functional teams dedicated to collecting, analyzing and sharing M&S assets and data. It is also necessary in order to implement an accessible, collaborative tool to collect M&S information and assets to serve as "ground truth" for making data-driven decisions.

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