DIGITAL ENGINEERING INFORMATION EXCHANGE (DEIX)

High Level Concept (HLC) Document

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ABSTRACT

The purpose of this High-Level Concept (HLC) document is to describe a conceptual approach to exchanging engineering information required for model-based systems engineering (MBSE) in a global supply chain. The concept intends to offer an integrated MBSE approach that is an improvement over the disjointed, difficult to control, document-based approach to systems engineering. The members of the Digital Engineering Information Exchange Working Group (DEIX WG) base the conceptual model-based approach on the ongoing work. This DEIX WG is a collaboration between International Council of Systems Engineers (INCOSE), the National Defense Industry Association (NDIA) Modeling & Simulation (M&S) Subcommittee, and the Department of Defense, Office of the Under Secretary for Research & Engineering (DoD/OUSD(R&E)). The phrase model-based engineering (MBE) information is a subset of the "digital artifact." Digital artifacts are any combination of model data and meta-data that exchanged within a digital ecosystem. In a global supply chain where organizations may be both consumers and suppliers of products requiring engineering information, there is a need for governments, industries, and academia to offer, request, and exchange these digital artifacts for many activities during the lifecycle of complex systems. This exchange happens between various engineering disciplines as well as between acquirer-supplier relationships. The authors follow the management of digital artifacts from their creation to their consumption and all of the critical roles and functions that must interact to benefit from the exchange.

INTRODUCTION

As more disciplines and organizations move toward model-based engineering (MBE) approach, there is a growing need to share, cross-reference, integrate, and reuse, and extend models to digitally represent a total system model. In today's document-centric paradigm, exchanging digital models require some version of a create-convert-recreate cycle. For example, we create digital models using any number of software tools for a given discipline or industry. Next, we export to some version of an electronic-document or abstracted digital file standard. Finally, the recipient reconstitutes it into a digital model in their tool. This cycle increases cost, time, and compounds errors. The fact that industry and government also has a long history of using a document-based engineering approach that they must now convert to model-based digital artifacts compounds their problems with the disjointed use of models today. As such, industries have the added challenge of exchanging engineering information in new ways and while addressing issues like tool interoperability, language standards, workforce development, and cultural change, to name a few.

There were two workshops held at the 2017 International Council of Systems Engineers (INCOSE) International Workshop (IW) to address this challenge. These were the Office of the Secretary of Defense (OSD) led Digital System Model workshop and a U.S. Air Force lead Digital Thread workshop. The conclusion of these workshops leads to the creation of the Digital Artifacts Challenge Team at the INCOSE 2018 IW. The outcome of the digital artifacts challenge team was an understanding that exchanging these digital artifacts was a problem that spanned organizations' upstream and downstream global supply chains. As a result, the INCOSE, the National Defense Industry Association (NDIA) Modeling & Simulation (M&S) Subcommittee, and the Department of Defense, Office of the Under Secretary for Research & Engineering (DoD/OUSD(R&E)) chose to collaborate to resolve these problems. The complex challenge led to them partnering with INCOSE to create the Digital Engineering Information Exchange Working Group (DEIX WG). The concepts presented in the paper are the emerging thoughts and consensus from the members. The authors have written this paper to begin a dialogue with practitioners across international borders, industries, and disciplines.

THE VALUE OF THE DIGITAL ARTIFACT

In the MBSE domain, the digital artifact is graphical and non-graphical engineering information that professionals create, manage, and display within a set of digital technologies [1]. The use of digital tools and digital modeling to perform all engineering functions is what the U.S. Department of Defense (DoD) calls Digital Engineering [2], [3]. That is the digital artifact is an item created and managed in digital form, or "born digital [4]." These digital artifacts represent the creative engineering ideas of scientist, technologist, engineers, artistic-designers, and mathematicians (STEAM). The digital artifact is a universal set of digital forms that represent the STEAM professionals' thoughts [1]. It includes descriptive system model elements, mathematical models, geometric primitives, audio-visual files, database records, and other digital forms that capture ideas in ways that are represented in digital form but interpretable by humans. As such, digital artifact encapsulates the best representation of their data, information, knowledge, and wisdom (DIKW) from the STEAM professionals. In Figure 1, the notation 8 represents the DIKW as characteristics of the digital artifact. That said, there is no consensus that knowledge or wisdom exists outside of human cognition [5]; thus, for this discussion, the digital artifact is a representation of STEAM professionals' DIKW. As such, when parties share this digital artifact with others, their DIKW can be unpacked, interpreted, and consumed by other STEAM professionals. Thus, these digital artifacts serve as the token for value exchange. Those practicing MBE find value in the digital artifact when it provides innovative solutions to the practitioners' problems. As a token of value, its value increases as there is more of the creators' DIKW that applies to digital artifacts such that it solves STEAM professionals' most demanding problems.

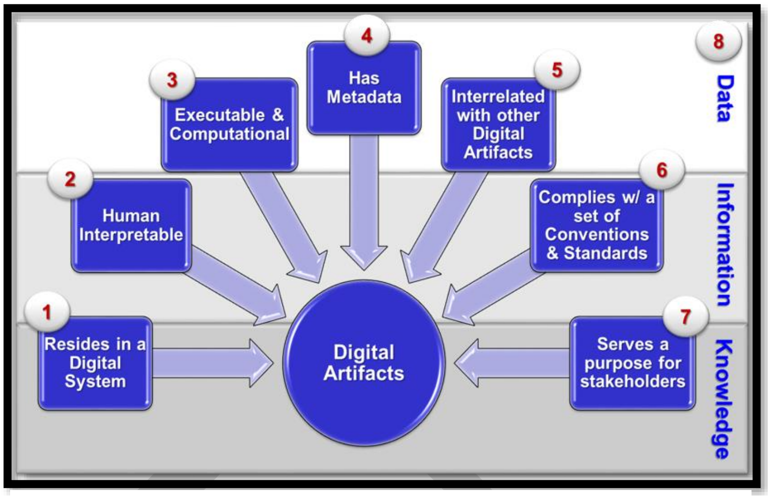

Figure 1: The eight characteristics of a digital artifact

THE DIGITAL ENGINEERING ENVIRONMENT AS GENERATOR FOR DIGITAL ARTIFACTS

As diverse STEAM professionals practice MBSE, they are continually learning and adding new knowledge to evolve their digital artifacts. The authors refer to these evolving digital artifacts as unpublished. The unpublished digital artifacts are available to the enterprise as determined by its governing rules. For example, the unpublished digital objects may follow a governance process that uses algorithmic rules for peer-reviews, management reviews, and workflow processes before the organization approves and publishes it for external stakeholders. Here, the STEAM professionals are checking-in and checking-out digital artifacts within a digital engineering environment. The digital engineering environment is a set of interconnected information, communication, and software

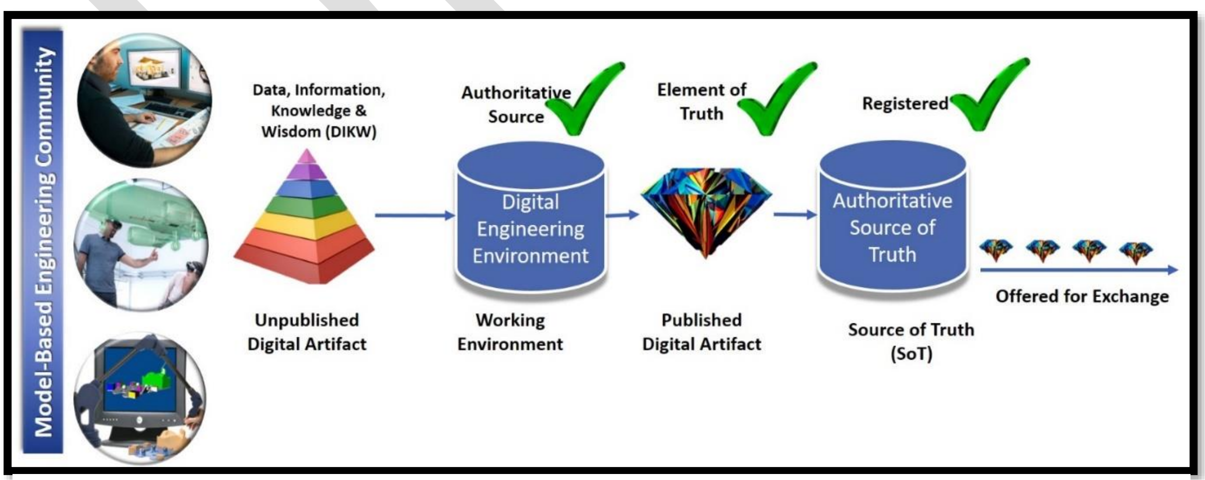

Figure 2: The transformation of DIKW to Digital Artifacts that are available to stakeholders.

technologies internal to an enterprise is a Suite of integrated tools/software that STEAM professionals use to accomplish their jobs and share between functions [6]. The digital engineering environments enable a larger digital engineering ecosystem such as Internet-based, cloud-based, device agnostic, technologies that allow organizations to engage with external stakeholders [6]. The digital engineering environment supports the unique requirements of each discipline that has a role in producing goods and services for its enterprise. Thus, it enables a digital thread that connects multidisciplinary engineering information across the lifecycle [7], [8], [9]. There is also a digital thread for the digital systems model that controls and aligns the relationships and interplay between the digital artifacts from the various disciplines as they mature during the lifecycle [10], [7]. Thus, maintaining a record of metadata about all the digital artifacts that represent the components of the digital system model. As such, the digital engineering environment provides the technological infrastructure that provides the digital capabilities to share digital artifacts within an enterprise.

THE AUTHORITATIVE SOURCE OF TRUTH TO CERTIFY AUTHENTICITY OF DIGITAL ARTIFACTS

The digital engineering environment may contain a single repository, a partitioned repository, or a federated set of repositories for digital artifacts that are ready for use by others beyond the creators. The authors define these digital artifacts as publishable. A governing entity within the enterprise will decide when and how they publish digital artifacts. The published artifacts should be associated with an authoritative source of truth (ASoT) before a broader community of stakeholders uses them to ensure credibility and coherence. Figure 2 shows this progression from DIKW created by STEAM professionals and the transformation to digital artifacts available to stakeholders. A governing body must first establish the repository for the published digital artifacts as the system of record (SOR) to meet the criteria for an ASoT [8]. The enterprise will most likely have different SOR's for any given type or class of digital artifacts. To be registered by the authoritative source of truth, that SOR must be legitimate in that it meets some standard of integrity. Again, the enterprise's governing body must define this standard of integrity for its SOR's. Standards of integrity may include levels of access control, historical metadata on modifications, controls for modifying records, and others.

Furthermore, the digital artifacts within the SOR's must meet some criteria of truth [8]. The governing body must determine these criteria of truth for each type or class of digital artifacts in its enterprise. For any digital artifact that meets criteria of truth and its owners hold in a legitimate SOR; then, the owners can register it in the authoritative source of truth. This ASoT may be a pointer in a federated software system, or it may be a single repository with all published and registered digital artifacts. The physical instantiation of the ASoT is at the discretion of the enterprise's governing body. Once they have a designated digital artifact with the ASoT, it is available for sharing with other stakeholders or systems.

PRESENTING DIGITAL ARTIFACTS COMPLIANT WITH DIGITAL VIEWPOINTS

The enterprise that has publishes its digital artifacts registers them in its authoritative source of truth can now offer those digital artifacts to stakeholders in a digital engineering ecosystem. The ASoT provides some assurance to a broader community that they can receive the most trustworthy digital artifacts that an enterprise has to offer. That stakeholder may be within the enterprise or external to the enterprise. The stakeholders are a diverse set, the variety of digital artifacts are plentiful, and there are numerous digital technologies available to view these digital artifacts. As a result, the combinatorial options are endless making it difficult to standardize a set of digital views that accommodate a majority of the stakeholders. To address this challenge, those requesting digital artifacts and those offering digital objects must have a standard way of describing what they want. Thus, we need a digital viewpoint model with familiar syntax and semantics for describing which digital artifacts, how they should assemble them, and which presentation technologies stakeholders have available for viewing [9], [10]. Figure 3 represents a possible construct for using digital viewpoint models to provide digital views. By using a digital viewpoint model, it assures those offering and requesting digital artifacts they see what they need to make decisions and complete follow-on tasks. Thus, when exchanging digital artifacts within a digital engineering ecosystem, the participants in the global supply chain may have a more contractually binding way of defining the form and function of the digital artifacts for exchange. These exchange of digital artifacts with the proper information exchange requirements allows requestors to use them to form their digital system models, digital threads, and digital twins.

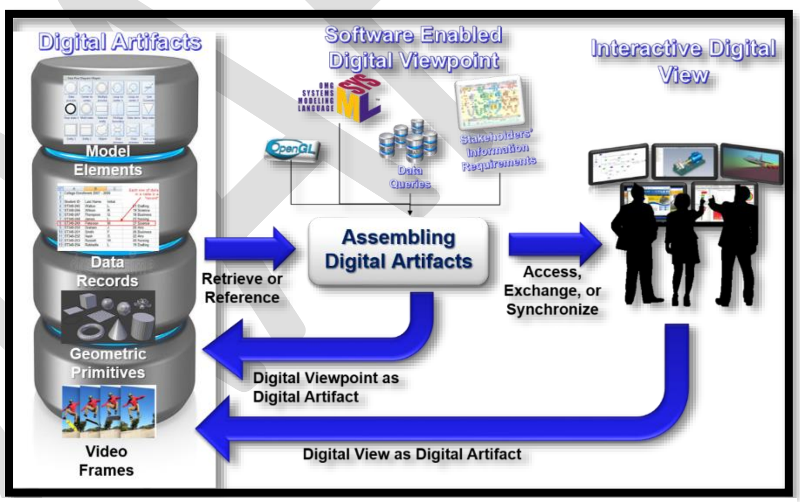

Figure 3: The process to convert digital artifacts to digital views for stakeholder consumption

DIGITAL ENGINEERING FRAMEWORK

All of the digital artifacts are assembled and used to form what Reid and Rhoades [11] call the digital framework. This digital framework includes the digital system model (DSM), digital thread (DTh) and the digital twin (DTw). To distinguish this from the generic uses of the term, the authors will refer to it as the digital engineering framework (DEF). The DEF allows all the digit artifacts, digital viewpoints, and digital views hang together cohesively to enable an end-to-end digital engineering enterprise. To understand the DEF, the authors will define the components and their interaction.

First, the digital system model (DSM) is a digital representation of engineered systems that include descriptive, analytical, and computational models developed and used by systems engineers and the specialty engineers [10], [14], [15], [16]. The DSM fully represents the total system and provides the system owner with all the information they need to manage the system as it evolves over the system lifecycles as represented by a digital thread. Next, the digital thread (DTh) is an enterprise analytical framework that shares authentic, multidisciplinary engineering digital artifacts between predecessors and successor states during the system lifecycle [17], [7], [9]. Where nodes represent the various states on the DTh such as the as-conceived state, as-designed state, as-built state, and so on [8]. Also, there must be digital threads at subsystem levels, assembly levels, and parts levels of the system hierarchy that align with the DSM as it evolves along its own DTh [10]. Finally, the Digital Twin (DTw) forms the 3rd leg of the DEF. The DTw is the as-built or as-maintained states of the digital thread (DTh). It uses the best available digital artifacts from the DSM and the DTh at the as-maintained states [14], [10]. To simulate its physical twin, the virtual twin needs the system data logs from those physical systems as well the integrated, multiple physics, multistage, and probabilistic models from the DSM and the DTh [18]. These elements form the digital engineering framework that allows the digital artifacts that work cohesively and comprehensively.

THE DIGITAL ENGINEERING ECOSYSTEM ENABLES SEAMLESS EXCHANGES BETWEEN ENTITIES

The digital engineering ecosystem may involve an Internet-accessible, digital engineering environment that allows the exchange of digital artifacts from an authoritative source of truth to a stakeholder-network [6]. The community governing the digital engineering ecosystem may make it permission or permission-less, with private or open transactions, or multipurpose or single purpose. Ideally, rules-based algorithms derived from governing bodies' decision processes can direct the digital engineering ecosystem. Thus, the digital engineering ecosystem allows exchanges per mutual agreements between parties. Participants in the digital engineering ecosystem can use digital viewpoints to request and offer digital artifacts within the digital engineering ecosystems. With advances in model-based software development, the digital viewpoint model may write the code to present the digital view to the requesting stakeholder. Also, with digital viewpoints serving as smart contracts that define what parties agree to exchange and capture those exchanges in ledgers across the ecosystem. Thus, increasing the security and verifiability of the digital artifacts exchanges and any associated data rights or intellectual property rights. The transactions may include keys to convert black-box digital artifacts into white-box digital artifacts given proper permissions were authorized. With these and many other rules and digital technologies, the digital engineering ecosystem offers the participants a way to exchange MBE information seamlessly and securely to accommodate a variety of stakeholders.

THE SERVICES TO ENABLE DIGITAL ENGINEERING INFORMATION EXCHANGES

With the creation of a digital engineering ecosystem to provide seamless and secure transactions for exchanging digital artifacts, their various services that participants can offer to give the digital views based on the digital viewpoint. These services are represented in Figure 4 and include the following [6]. First, there is the service of providing the requestor access to the original digital artifacts. The requestor has remote or on-site access to their digital views, and it assures them it's the most current version; while, the offerer has control of the digital artifacts and its providence. Another service for sharing digital views is the synchronization of static, dynamic, or interactive digital views that update as the source of digital artifacts changes. This service for digital presentations allows the owners of the digital artifacts to manage the configuration of digital objects while providing the stakeholders with the most current as-of-date versions. There is also a service to produce replicas of the digital artifacts in a digital view by exchanging files. This approach requires independent configuration control of the source and replicated digital objects providing the digital views. Each of the services offers ways to offer digital views to requestors. That said, each service has its costs and benefits. However, it does give the participants in the exchange to express a preferred method to see the digital views of any set of digital artifacts.

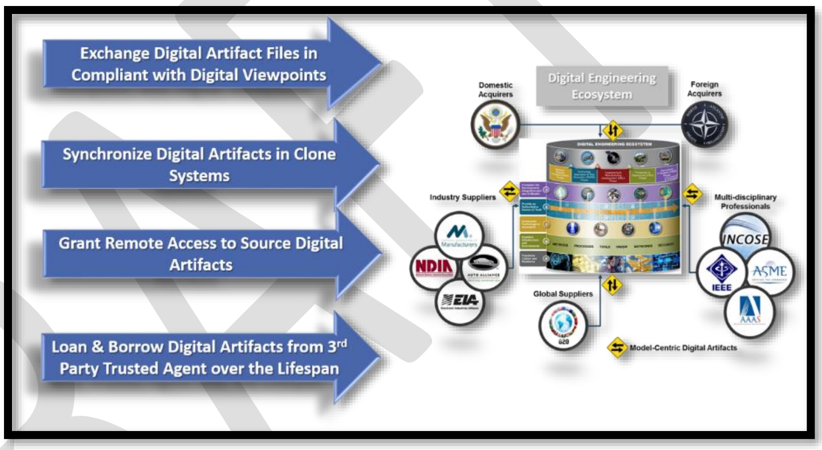

Figure 4: The components, roles, and services possible for the Digital Engineering Ecosystem.

A VISION FOR DIGITAL ENGINEERING ECOSYSTEMS

This concept should serve as a template for digital engineering ecosystems. The achievement could lead to digital engineering ecosystems that might support global supply chains, national innovation systems, or geographically dispersed enterprises. These digital ecosystems would be different digital engineering ecosystems based on engineering communities for any given knowledge domain, technology platform or important systems to reduce complexity [11]. The reason the product-based organizations need digital ecosystems focused on engineering its optimization of process and product innovations resulting from its reliance on a sharing of information between industry, academic, and customers for inventive ideas. In the future, with AI advancement we can even harness this ecosystem to forecast future engineering issues, innovations, or both. The digital engineering ecosystem is in contrast to the industry's increasing use of business digital ecosystems to increase productivity and brand loyalty from its customers. Although the motivations are different, the technologies are the same.

However, to achieve the benefits, organizations that rely on technologies may need to overcome its cultural inertia to implement digital engineering ecosystems. The organizations need to accomplish the essential activities to achieve a digital engineering ecosystem. First, it must develop the right technological infrastructure to create digital engineering environments that can participate in these digital engineering ecosystems. Second, their digital engineering ecosystems would need to have the means to securely offer, request, and exchange digital artifacts from an authoritative source of truth. Third, they would need to provide the types of services to assemble digital artifacts according to agreed digital viewpoints such that stakeholders receive their preferred digital views. Finally, they would need appropriate governance, cultural transformation, and standardized MBE methods and techniques to ensure reliable and repeatable exchanges. That said, the art of the possible is achievable by accomplishing the actions above. All of these actions support the goals for the Digital Engineering Information Exchange Working Group (DEIX WG).

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