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# Model Curation: Requisite Leadership and Practice in Digital Engineering Enterprises

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## Abstract

Under the premise that model-centric engineering enterprises of the future will necessitate specialized competencies and leadership, ongoing research is investigating both model curation as a practice and model curator as a new leadership role. Specific needs and approaches for model curation have been generated through research investigation using primary and secondary sources. Four notional stages are used to frame the digital engineering paradigm shift, describing the characteristics of the enterprise and the respective leadership. This investigation suggests seven alternative forms for implementing model curation leadership roles and responsibilities, based on unique needs and organizational characteristics. Related research on human-model interaction, model-centric decision making, and model trust and integrity provide evidence of the importance of model curation for the envisioned future of digital engineering. Interim research findings have been shared with research stakeholders as a preliminary validation of needs, as well as capturing emerging practices related to strategic management of models.

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*Keywords:* model curation, model curator, model management, digital engineering, model-based, enterprise

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## 1. Introduction

As engineering practice becomes increasingly model-centric, models become highly valuable assets for designing, developing, maintaining and evolving systems. Model curation accordingly becomes a necessary functional role in digital engineering enterprises. This is a relatively new idea in the systems community, though significant progress has been made in maturing how models are managed, controlled and protected. The recently published the DoD Digital Engineering Strategy explicitly states that organizations must “formally develop, integrate and curate models” [1]. And, while the strategy does not use the term model curator, the strategy articulates many requisite leadership capabilities. Evidence shows that the systems community is beginning to embrace model curation as an essential element of digital engineering.

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### *1.1. Motivation*

Over the past five years, the Interactive Model-Centric Systems Engineering (IMCSE) research program has investigated various aspects of humans interacting with models and model-generated data, in the context of systems engineering practice. While model-based engineering initiatives are advancing technical aspects of models in the engineering of systems, IMCSE research advances knowledge relevant to human interaction with models and model-generated information. Participants in the 2015 IMCSE pathfinder workshop identified model curation as an important topic for investigation [2]. Ongoing IMCSE research [3, 4, 5] has revealed a number of driving factors for model curation and a curation leadership role at the enterprise level. Although reuse of models can have benefits, the reality is that legacy models are not widely used beyond their original purpose.

Rouse (2015) stresses that the wealth of existing models is often not used because of a lack of knowledge of these resources and the difficulty in accessing them [6]. Lack of access to models, mistrust of models, and perception of legitimacy of models are all barriers in model reuse and longevity. According to Reymondet et al. (2016), model expertise is largely resident in individuals, and the ability to select and compose sets of models is typically limited to the original use [7]. In many enterprises, modeling competency is distributed across individuals and organizations. Accordingly, lack of a centralized leadership authority results in models being owned and managed primarily at a local level. Modeling efforts are often duplicated across programs, and the individual programs may lack model experts preventing benefit from the collected wisdom of the enterprise [2]. Models have been employed for numerous purposes in recent years [8] and it is likely that digital engineering transformation may extend model use even further. A question arises as to whether a model curation function at the enterprise level could lead to more effective use of models and digital assets at all levels.

### *1.2. Curation Practice*

Reymondet et al. (2016) discuss a preliminary investigation into considerations for model curation in the engineering of complex socio-technical systems [7]. Maturing an approach for model curation for the engineering field can benefit from knowledge, practices and experiences from other fields of curation practice.

Museum curation (or curation in similar cultural/heritage institution) is a mature profession, with formalized practices and many academic degree programs. Some new aspects of museum curation emerge with the increasing use of technology in the display and preservation of objects. And, digital object curation is now an extension of traditional museum curation, given the many digitized and digital artifacts that may now be found in institutional collections. Section 4.1 discusses this role in more detail, as the field has many analogous activities that are envisioned for model curation.

Digital curation was the subject of recent investigation by The National Academies. The resulting published report stresses the importance of “active management and enhancement” in digital curation, and discussed the importance of preparing the workforce [9]. The study concluded that digital curation is unique in regard to “the immense and ever-increasing quantities of material to be curated, the need for active and ongoing management in a context of continually changing uses and technology, and the great diversity of organizational contexts in which curation occurs.” Digital objects include such things as files, images, and video. Many of the challenges inherent in digital curation also pertain to model curation. Rusbridge et al. (2005) outlined a vision for digital curation that “embraces and goes beyond that of enhanced present-day re-use, and of archival responsibility, to embrace stewardship that adds value through the provision of context and linkage: placing emphasis on publishing data in ways that ease re-use and promoting accountability and integration” [10].

Data curation is about lifecycle maintenance of data, with the goal of preservation for use, for example, research data and census data. In particular, there is an emphasis on maintaining the value of data throughout its lifespan. With rise of big data and data science the field takes on a greater importance in many types of organizations. Data warehousing is an example of long-standing approach that falls under data curation. With increased digitization of objects such as paper-based reports, lines between digital curation and data curation are less distinct. However, digital objects are not always data per se; data curation may also deal with non-digitized data. [11]

Social curation focuses on collaborative sharing of Web content organized around one or more particular themes or topics. Duh et al. (2012) define social curation as “the human process of remixing social media content for the

purpose of further consumption” [12]. Potter and Gilje (2015) state curating (as a verb) suggests at least “... collecting, cataloguing, arranging and assembling for exhibition and displaying” [13]. Speaking to the act of curating at the individual, rather than institutional level, they note that verbs used to credit an author such as ‘written’, ‘edited’, or even ‘created’... don’t capture all the self-representational activities or practices in digital culture that the verb ‘curated’ does”. Curating a digital space is “not only about writing or creating within it but also collecting, distributing, assembling, disassembling, and moving it across different stages.” Social curation has implications for model curation, suggesting the importance of viewing curation at multiple levels from individual to enterprise. It also points out the importance of taking a situational viewpoint as part of curation activity.

In the field of engineering, Patel et al. (2009) examined curation of CAD engineering models, noting some specific challenges. The first is that “the information to be dealt with are diverse and particularly complex, including product geometry, finite element analysis models, manufacturing process models, etc.” Another challenge is engineering organizations need to communicate that information to a wide range of different stakeholders, each with different information needs and access rights.” They note that the purpose of the information may be varied. Their work primarily focuses on technical strategies for curation; but these authors also say “there is a need for best practice guidelines and cost-benefit models to aid in choosing appropriate curation strategies since the business of deciding a suitable path is non-trivial and contingent on many factors.” [14]

## 2. Model curation

The paradigm shift to digital engineering is heading toward a situation where models are becoming increasingly valuable and ultimately may have equal/greater value than physical assets. Models exist at all levels of an enterprise (individual, program, business unit, enterprise) but rarely are these managed as an enterprise collection. Of course, there is a need to distinguish between the models that can be elevated to the enterprise collection (deemed of value and quality to be used across the enterprise) and worthy of distribution outside the enterprise (by exchange, loan, sale...), and those models that are suitable for use at a local level (highly specialized, insufficient maturity for reuse, designed to be used for quick studies, etc.). It is not expected that all models that are useful will be destined to become enterprise-level models. Further knowledge and specific criteria need to be developed to effectively determine which models will be most suitable for reuse across programs and of value at the enterprise level.

With the increasing use and reliance on models and digital artifacts [15], enterprises need to re-examine the leadership that enables digital engineering effectiveness. The knowledge and expert insights on challenges and needs in model-centric enterprises, discovered in this research, have led to exploration of a model curation role appropriate to addressing these. Model curation (including curation of engineering data) is proposed as necessary at both the program level and the enterprise level.

The DoD SE Digital Engineering Fundamentals states “responsibility of planning and coordinating programs’ use of models, simulations, tools, data, data rights, and the engineering environment belongs to the program manager; the performance of the actual tasks may be delegated to the program systems engineer and other program staff as appropriate” [16]. In addition to program-level curation, enterprises will benefit from an enterprise-level leadership role to enable strategic management and control of models and digital artifacts.

At the enterprise level, it is envisioned that there may be an executive curator leadership role, similar to an executive museum curator. The 2017 study by the US Interagency Working Group describes seven challenges that organizations may encounter in infusing digital model-based engineering [17]. The challenges imply new or strengthened leadership capabilities, many that relate to a curation-type role, as well as re-examining basic leadership capabilities under the digital paradigm. These capabilities have potential to address many cited challenges related to organizational and cultural hurdles, contractual and data management practices, security for authoritative source of truth, and others. And, the 2018 DoD Digital Engineering Strategy [1] explicitly states model curation responsibilities as part of the digital engineering strategy.

Overall, a model curation function (performed by key individuals and/or a group of individuals) will have the objective of sustaining highest possible benefits and outcomes from the collective set of model assets using formal curation practices. Extending from the various types of curation roles and activities of other fields, the model curator’s role is envisioned to include many significant responsibilities, achieved with support of various personnel.

### 3. Model curator

A formal definition of a model curator in the digital engineering context is a designated professional role entrusted with the ownership, tracking and use of model collection objects, and possessing designated authorities for managing and controlling models. Model curators may exist at a “local” program or business area level, involving responsibilities such as selecting and maintaining the set of models for a specific program or laboratory purpose. The curator plans and manages model version upgrades, works with model software developers on specialized needs, and organizes training for program staff. The program/business area curator supports enterprise-level model assessments and activities, and performs model trade-offs and model software selections.

At the enterprise level, the model curator (or curation function) would set and administer model-related policies and practices. The curator ensures models and related documents are authenticated, preserved, classified and organized accordingly with model metadata standards. The curator may own the data management for models and related information, or oversee the ownership by other individuals or organization. As needed, a curator would meet with individuals and teams, who will create, use and re-use models, helping to determine a useful classification of both individual models and sets of models. In an enterprise with an executive-level model curator, the program/business area curators would recommend models for consideration for the enterprise collection. The model curator possesses deep, current knowledge of models, model trades, composability practices, etc. A curator may orchestrate demonstration of model-based capabilities to support bid and proposals, and convene panels of program-level model leaders for making strategic and operation decisions. The model curator originates and maintains model pedigree for the program-owned model assets, as discussed further in section 5.1.

The curator has strategic responsibility for digital engineering infrastructure and technologies, and has a responsibility to follow new developments related to methods, standards and toolsets for digital engineering. A key role involves recommending appropriate points for upgrading/replacing infrastructure, working in conjunction with program leadership and model experts.

### 4. Envisioning an executive leadership role

Our research indicates that a unique enterprise-level role for model curation may be necessary in future digital engineering enterprises [4]. The digital paradigm has led many enterprises to establish new leadership positions, e.g., Chief Digital Officer (CDO). Typically the CDO is a change agent for all things digital, with primary focus on creating business opportunities. Chief Data Officer (CDO) and Chief Analytics Officer (CAO) are other newer executive roles. These roles, however, are not sufficient for enterprises that depend upon digital engineering, as the focus is somewhat different. Roles such as CDO and CAO may likely co-exist with a model curation executive role. As engineering enterprises undergo transformation, leadership roles can be expected to evolve over time respective to the extent to which models are central to the enterprise’s mission. Table 1 shows a notional description of leadership approach and enterprise characteristics respective to digital engineering transformation.

Table 1 Leadership approach evolves as enterprise transforms to model-centric enterprise (notional)

<b>Transformation Stage</b>	<b>Leadership Approach</b>	<b>Enterprise characteristics include...</b>
<i>Model Use Throughout Program</i>	“Local” model management	Limited reuse of models Organization embraces importance of models Models are primary artifacts replacing documentation
<i>Model Reuse Across Programs</i>	Enterprise model management	Model-centric enterprise culture Models are reused across programs Digital engineering as standard practice
<i>Systems with “Digital Twin”</i>	Enterprise-level curation role	Digital engineering culture throughout enterprise System “digital twin” maintained through lifecycle Enterprise practices for models (modularity, composability)
<i>IP Inversion in Enterprises</i>	Curator as top tier executive	Models/Digital Twins are key deliverables Model are valuable IP, sold, exchanged, loaned Innovations emerge from composability of models

#### 4.1. Chief Model Curation Officer (CMCO)

With the advancement of digital engineering there will naturally be increasing demand for leadership and management of models. An executive leadership role will become important as enterprises achieve their transformation objectives, notionally termed a Chief Model Curation Officer (CMCO). This role is envisioned as a designated professional, authoritative role – at the executive level of the enterprise - entrusted with the ownership, tracking and use of enterprise model-based assets (models and digital artifacts). The role of the CMCO does not negate the need for model ownership and management at the local (program) level. Not all models are suited for a collection-level asset, and many models will be the result of maturation of a local-level asset (e.g., developed on a particular program or in a research project).

The CMCO is envisioned as having an enterprise-level leadership role that focuses on the strategic management of the enterprise collection of models and digital assets. As mentioned in section 2, the curator of institutional collections, such as museum curator, offers an analogy for the proposed responsibilities of the model curator. The museum curator's role is an essential one where highly knowledgeable curators oversee collections of artwork and historic items, with support from archivists who appraise, edit, and maintain permanent records and historically valuable documents. Specialists and technicians are also involved in various capacities. The museum curator has deep knowledge of the collection, with responsibility for putting together purposeful special exhibits. The CMCO is envisioned to have a similar executive-level role overseeing the enterprise-level model collection, as well as having strategic responsibility for composing sets of models for special purpose. An example of special purpose is a model-based demonstration of new system capability in support of a competitive bid or market opportunity.

A primary role is managing and overseeing the enterprise collection of model-based assets. The CMCO has responsibility and authority for model accessioning, that is the formal process for accepting and recording a model as a collection object in the model portfolio. Accessioning addresses the legal, IP and ethical issues in model acquisition and development. Additionally, de-accessioning is a key responsibility, as the formal process of removing a model as a collection object from the enterprise level model portfolio. As part of accessioning, the CMCO has enterprise-level authority for model acquisitions. Model acquisition is the formal act of acquiring a model through an arrangement with the model owner (e.g., through purchase, trade, or other business transaction). The acquisition of models may be necessary to obtain models of supplier-developed products, as well as to acquire models when it is not practical to develop them internally due to time limitations or skill limitations. Similarly, there may be a desire to acquire models as part of a research and development contract with an external provider.

Once a model is accepted into the enterprise level collection, the CMCO ensures cataloging is performed. This is a formal process of making a model available for use through recording it in a catalog or directory, and tracking it throughout the model lifecycle. The CMCO ensures the effective capture of descriptive metadata, which is contextual data about the model object(s). Metadata documents characteristics of models, and is used for indexing, discovering, identification. Metadata provides user discovery of, access to, and management of a model. Similarly, the CMCO ensures that every enterprise-level model has original and current model pedigree maintained. Model pedigree is defined as model-associated information that describes model origin, development process, originators and developers, assumptions, expert knowledge, model enhancements, investment costs, versions, change history, etc. Model metadata is essential for model integrity, and model pedigree provides basis for judging model trust.

Enterprise-level models are acquired through the purposeful elevation of program-level models, as well as through the purchase of models from suppliers or other enterprises, or borrowing these on a term-limited basis. The CMCO may also loan models to other enterprises. Model loan is defined as the act of temporarily acquiring a model through an agreement whereby the model owner agrees to share the model with the model acquirer for a specified time and specified terms (e.g., terms of use, remuneration, etc.). Such an arrangement may require significant negotiation and validation of fit for purpose of the model to be acquired.

The CMCO plays a key role in the development of digital demonstrators. A digital demonstrator (or, model demonstrator) is a composed set of models with interactive interfaces for the purpose of demonstrating context-specific systems capability. Demonstrators enable a modeled system to be experienced by an individual through conveying cogent information and where possible, use of interactive interfaces and augmented intelligence. The CMCO has knowledge to guide selection of appropriate models in the collection that are available for a digital demonstrator. In the future, digital demonstrators may likely be an integral part of the systems innovation process.

The CMCO performs as the executive process-owner for model-centric environments and digital engineering implementation strategy, and assessing modeling competency within the workforce. Specific responsibilities may be designated to individuals within the enterprise, or to external contractors or suppliers where necessary and appropriate. Accordingly, the CMCO provides governance for data/model repositories, data rights, intellectual property agreements, etc., and ensures model pedigrees are truthful and effectively maintained. The CMCO guides selection of modeling platforms, and adoption of/ compliance to modeling standards. The CMCO owns and manages model risk and opportunity at the enterprise level, and may oversee model capability assessments.

The particular organizational form for implementing a chief model curation officer role may vary based in situational factors and the current state of transformation. Knowledge gathering and semi-structured interviews with executives inform the seven proposed alternative forms for an enterprise to execute the role and responsibilities of an enterprise model curator function (Table 2). Over time, studies are needed to understand how effective these forms are for various enterprises, and under which conditions one might chose the form [4].

Table 2 Proposed organization forms for enterprise level model curation leadership

Form	Description	Chief Model Curation Office (CMCO) Organizational Form – under what conditions
<i>Centralized – Top Tier</i>	CMCO is a top tier exec reporting directly to CEO	High performing model-centric engineering enterprise or enterprise that has a very aggressive goal to become one. Culture has fully embraced model-centric engineering across entire enterprise, and believes model leadership is key to competitive advantage and innovation.
<i>Centralized – Dotted Line</i>	CMCO has “dotted line” reporting CEO	The enterprise is rapidly becoming a high performing digital engineering enterprise. The CMCO needs enterprise level authority to implement strategic decisions, but enterprise is not ready to make CMCO a full member of the executive management team.
<i>Franchised</i>	Enterprise units have CMCOs, with common policies	For very large enterprises with varied cultures within enterprise units, it can be difficult to have one top-tier CMCO. In a franchised form, CMCOs are appointed in each enterprise segment reporting to its top executive, conforming to enterprise defined policy and role.
<i>Collaborative</i>	Virtual CMCO role via collaborative committee	Enterprise does not wish to appoint a CMCO at this time, but recognizes need for model curation. An appointed collaborative committee is “virtual CMCO” as a strategy-setting and oversight body. May be preferred in enterprise comprised of newer acquisitions with strong heritage culture and processes.
<i>Dual Hat</i>	CMCO is one of two roles played by an executive	An enterprise that is working toward becoming a model-centric enterprise but still uses legacy approaches; not ready to appoint enterprise CMCO. A dual hat form, while challenging to perform, enables enterprise to allocate specific curation responsibilities to an existing leader (CIO, CTO, CDO).
<i>Delegated</i>	CMCO tasks delegated to one or more individuals	Similar to “dual hat” but role is not specifically delegated; responsibilities are delegated as add-ons to an existing role, or to the responsibilities of a standing committee. This implementation is weaker than dual hat, but does acknowledge these as MC responsibilities, as a precursor to a formal role.
<i>Outsourced</i>	CMCO role is performed by an external hire	Temporary hiring of an outside CMCO may be only option available to an enterprise that recognizes need for MC role but does not have expertise or capacity to staff from within. May also be a form used by an enterprise that is not convinced of value of CMCO, but wants to have trial implementation.

## 5. Model curation enablers

Model curation will benefit from myriad enablers such as defined lexicon, templates, and standards. Three important enablers that are under investigation are discussed below.

### 5.1. Model and data pedigree standards.

Model pedigree was first described by Gass & Joel in 1980 as “model demographics” [18], and the term pedigree was subsequently used by Gass. A pedigree contains all of the information about a model, its origins and use over time. Gass & Joel state the purpose is to “enable the decision maker to determine the model’s status with respect to past achievements, theoretical and methodological state of the art, and the expert advice that went into its development” [18]. While model documentation is typically developed, the pedigree may contain information not always included in model documentation. Model pedigree provides non-technical information concerning the model origins, extensions and applications. Given that IMCSE research on model-centric decision making has shown that trust is a key determinant in use of models [19], a pedigree provides information that engenders trust. Model pedigree plays an important role in human trust and acceptance of models for decision-making and for potential

reuse [4]. Accordingly, a proposed new enabler for model curation is a model pedigree standard. This standard would define the content and use of pedigrees, and specify how and when the pedigree is updated over time. Content creation and update authorities would be included in the standard.

NASA has defined and uses data pedigree and input pedigree in Modeling & Simulations (M&S) efforts. NASA Standard 7009A [20] cites data pedigree and input pedigree as two of eight credibility factors for Modeling & Simulation. Data pedigree is defined in the standard as “A record of traceability from the data's source through all aspects of its transmission, storage, and processing to its final form used in the development of an M&S” [20].

NASA associates data pedigree with M&S Development, and input pedigree with M&S Operations. Input pedigree is defined as “A record of traceability from the input data's source through all aspects of its transmission, storage, and processing to its final form when using an M&S.” Further, the NASA Standard notes that “changes from real world source data may be of significance to its pedigree” [18]. It specifies four levels for data/input pedigrees in terms of credibility assessment levels. A model pedigree standard may benefit from using a similar scale. While data pedigree and input pedigree share some common content with model pedigree, there are unique aspects that must be addressed in each standard.

### *5.2. Model curator competency profile*

A desired enabler for the model curator role is a competency profile. There is potential to build on the significant progress by the systems community in developing competency models and frameworks for systems engineering, including the recently published INCOSE Competency Framework [21]. Further research is needed to identify the knowledge, skills, abilities and behaviors that would be unique to the model curator role. Other fields of curation have done significant work on competencies, for example, [9, 22, 23]. Further investigation is ongoing to identify and gather knowledge that has been generated that may be useful to consider in the model curation context.

### *5.3. Model curator reference map for vulnerability assessment*

A model curator will need new or adapted tools for accomplishing the various responsibilities for this role. One of these relates to managing the risks and vulnerabilities that arise through new digital environments, infrastructure and the digital engineering practice and culture. While vulnerability analysis of systems is standard practice, examining vulnerabilities related to the enterprise itself is less common. Related ongoing research is investigating the use of Cause-Effect Mapping (CEM) as a mechanism for better enabling program managers and system engineers to anticipate and respond to programmatic vulnerabilities as related to digital engineering practices and model-centric environments [24]. A reference map resulting from the work shows promise for considering the cascading vulnerabilities and potential intervention options. A future goal is to develop such a reference map for the model curator, providing visibility into enterprise-level vulnerabilities, especially cybersecurity [25].

## **6. Summary**

Curation practices promote formalism and provide for the management, control and active enhancement of models and digital artifacts. This paper shares progress on investigation of model curation practice and a proposed model curator role, responsive to digital engineering transformation. Several selected enablers to support model curation are discussed. The underlying research motivation and its relevance are further elucidated by issue of the DoD Digital Engineering Strategy [1]. As with all transformation, true engagement of leadership with a compelling vision is a prerequisite for gaining the trust and buy-in of the workforce that underlies the ultimate success of the future digital engineering enterprise. In light of growing strategic importance of models for the future of engineering, a unique new role of a model curator becomes an imperative. This role is practically important to oversight of digital engineering across the enterprise, and strategically important to championing workforce and culture transformation. While digital engineering involves adaptation of existing practices, discovering novel methods and unprecedented ways of doing things is necessary. Existing infrastructure that enterprises depend upon for the engineering of systems also must evolve. There is a growing recognition of the need for model curation in digital engineering enterprises [2, 5], and accordingly many areas for continued research investigation [5, 7, 25, 26].

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