

# The State of Assessing Data Stewardship Maturity – An Overview

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## Abstract

*Data stewardship encompasses all activities that preserve and improve the information content, accessibility, and usability of data and metadata. Recent regulations, mandates, policies and guidelines set forth by the U.S. government, federal and funding agencies, scientific societies and scholarly publishers, have levied stewardship requirements on digital scientific data. This raised level of requirements has increased the need for a formal approach to stewardship activities that they support compliance verification. For any entity to meet or verify the compliance with the stewardship requirements, it is necessary to assess the current stage, identify gaps, and define a roadmap forward for improvement if necessary. This, however, touches on standards and best practices in multiple knowledge domains. Therefore, data stewardship practitioners, especially these at data repositories, data service centers or associated with data stewardship programs, can benefit from the knowledge of existing maturity assessment models. This article provides an overview of the current stage of assessing stewardship maturity for federally funded digital scientific data. A brief description of existing maturity assessment models and related application(s) is provided. This helps stewardship practitioners to readily obtain basic information about these models. It allows them to evaluate each model's suitability for their unique verification and improvement needs.*

**Keywords:** Data Stewardship, Maturity Matrix, Data Preservation, Data Accessibility, Scientific Data, Information Quality, Metadata

## 1. Introduction

Data stewardship “encompasses all activities that preserve and improve the information content, accessibility, and usability of data and metadata” (National Research Council 2007). Scientific or research data is defined as: “the recorded factual material commonly accepted in the scientific community as necessary to validate research findings.” (OMB 1999). Federally funded scientific data are generally cared for by individual organizations such as repositories, data centers, data stewardship programs or services.

U.S. laws, federal government mandates, policies and guidelines set forth in the last two decades have greatly expanded the scope of stewardship for federally funded digital scientific data. These directives include the following:

- U.S. Information Quality Act (US Public Law 106-554 2001, Section 515), also known as Data Quality Act;
- U.S. Federal Information Security Management Act (US Public Law 107-347 2002);
- Policies on Open Data and Data Sharing (OMB 2013; OSTP 2013);
- Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information (OMB 2002a);
- Guidelines on Ensuring Scientific Integrity (OSTP 2010).

In response to these governmental directives, federal and funding agencies have issued their own policies and guidelines (e.g., NOAA 2010; see Valen and Blanchat (2015) for an overview of each federal agency’s compliance with the OSTP open data policies.)

Recognizing the impact and challenges of changing digital environment, the National Academy of Sciences (NAS), together with the National Academy of Engineering, and the Institute of Medicine, have prompted the good stewardship of research data and called for transparency and data sharing to ensure data integrity and utility (NAS 2009). The Group of Earth Observations (GEO) has called for “full and open exchange of data, metadata and products” in its defined data sharing principles for its data collections to ensure the data are available and shared in a timely fashion (GEO Data Sharing Working Group 2014). Scientific societies and scholarly publishers, such as those involved in the Coalition on Publishing Data in the Earth and Space Sciences (COPDESS), have issued the position statement to call for data used in publications be “available, open, discoverable, and usable” (COPDESS 2015). The World Data Service (WDS) of the interdisciplinary Body of the International Council for Science (ICSU) requires its members to certify to maintain their membership by demonstrating their compliance to the WDS strong commitment to “open data sharing, data and service quality, and data preservation” (<https://www.icsu-wds.org/organization>; see also WDS Scientific Committee 2015). A set of FAIR (namely, Findable, Accessible, Interoperable, Reusable) data principles for scientific data management and stewardship has been formally defined and endorsed by stakeholders from academia, industry, funding agencies, and scholarly publishers (Wilkinson et al. 2016).

These governmental regulations and mandates, along with principles and guidelines set forth by funding agencies, scientific organizations and societies, and scholarly publishers, have levied stewardship requirements on federally funded digital scientific data. As a result, stewardship activities are extremely critical in ensuring the data to be: *scientifically sound and utilized, fully documented and transparent, well preserved and integrated, and readily obtainable and usable.*

This raised level of well-defined requirements has increased the need for a more formal approach to stewardship activities that they support rigorous compliance verification. To meet or verify the compliance with these requirements, it is necessary to evaluate the current stage, identify gaps, and define a roadmap forward for

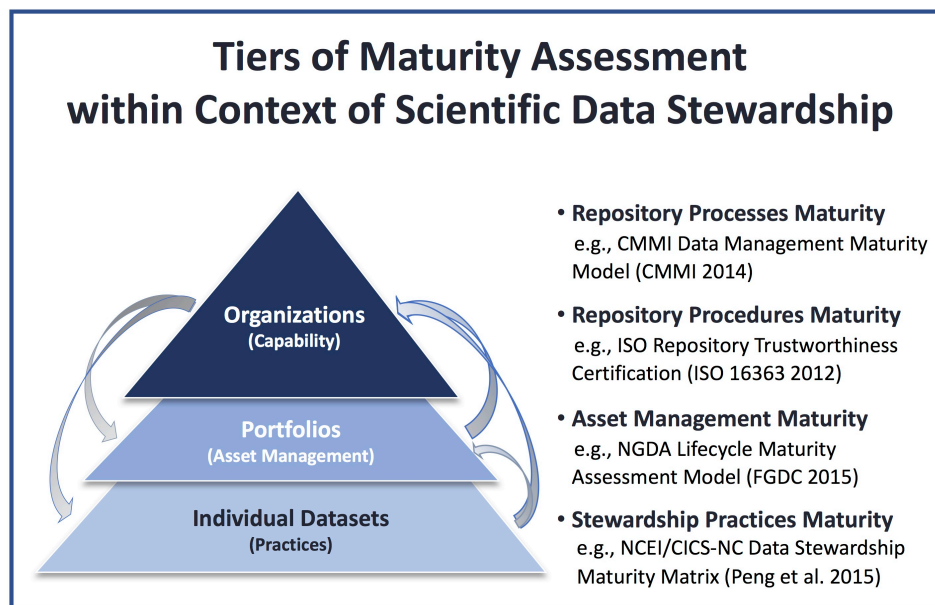
improvement if necessary. However, such an effort requires comprehensive cross-disciplinary knowledge and expertise, which is extremely challenging for any single individual. Therefore, data stewardship practitioners can benefit from the existence of maturity models and basic information about these models.

A maturity model is considered as a desired or anticipated evolution but in discrete stages for organizations or processes (Becker, Knackstedt & Pöppelbuß 2009). A maturity model can also be developed to evaluate practices applied to individual data products (e.g., Bates and Privette 2012; Peng et al. 2015). A number of maturity models have been developed and utilized to quantifiably evaluate both stewardship processes and practices (e.g., Mecca 2015; Peltz-Lewis et al. 2014; Bates and Privette 2012; EUMETSAT 2013; Peng et al. 2015; Thorne et al. 2015; Zhou, Divakarla & Liu 2016).

This article provides an overview of the current state of assessing the maturity of stewardship of digital scientific data. A list of existing or developing maturity models from various perspectives of scientific data stewardship is provided with a high-level description of each model and its application(s). This allows stewardship practitioners to further evaluate the utility of these models for their unique stewardship maturity verification and improvement needs.

## 2. Perspectives of Scientific Data Stewardship

Figures 1 and 2 display different perspectives of maturity within the context of scientific data stewardship. They highlight the inter-connectivity and dependency of different levels of stewardship activities within individual organizations and different types of maturity for scientific data products through the entire data product lifecycle.



*Figure 1: Category of tiered maturity assessment within the context of scientific data stewardship and examples of existing maturity assessment models. The arrows indicate that the maturity at the initiation point can impact that of ending point. See the main text for a high-level description of each maturity assessment model listed in the diagram.*

The diagram in Figure 1 shows tiered maturity assessments from a top-down view. The top level represents an

organization’s processes while the lowest level represents the practices applied to individual data products of its data holdings. As indicated by the arrows in Figure 1, the maturity of organizational process capability can influence the maturity of portfolio management and individual data products, while the maturity of individual data products may reflect and can potentially impact the maturity of portfolio management and organizational process capability.

The quality of a data product and its associated practices throughout its lifecycle can impact its overall quality. As the overall quality of a data product, unfortunately, tends to be dictated by the lowest quality from any stage of its entire life cycle, it is important to take a holistic approach to ensure and improve the quality of a digital scientific data product. Figure 2 depicts the maturity assessment from this horizontal view, adopting four dimensions of information quality defined by Ramapriyan et al. (2017). These four dimensions of information quality are Science, Product, Stewardship, and Service. They correspond to the activities involved in the four different phases of the dataset life cycle: “1. define, develop, and validate; 2. produce, assess, and deliver (to an archive or data distributor); 3. maintain, preserve and disseminate; and 4. enable data use, provide data services and user support.” (Ramapriyan et al. 2017). We adopt this categorization of information quality dimensions for general scientific data products because they better reflect the differing roles and responsibilities of entities involved in the different stages of dataset lifecycle. These distinct roles often require different domain knowledge and expertise.

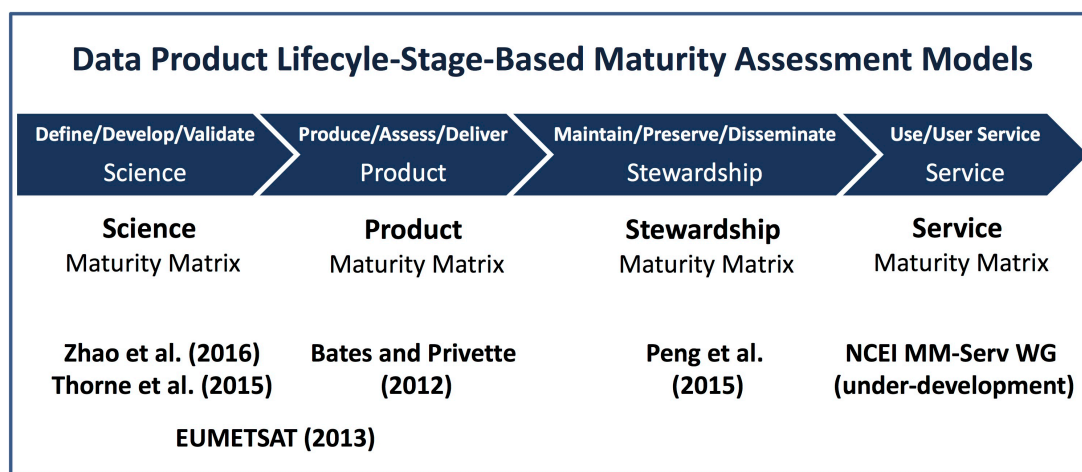


Figure 2: Category of data product lifecycle-stage-based maturity type and examples of existing assessment models in term of a matrix. See the main text for a high-level description of each maturity assessment model listed in the diagram.

A brief description of existing maturity assessment models, such as these highlighted in Figures 1 and 2, and their applications if available are provided in the next section.

### 3. Maturity Models Overview

#### a) Organizational data management maturity

Data management includes all activities for “planning, execution and oversight of policies, practices and projects that acquire, control, protect, deliver and enhance the value of data and information assets.” (Mosely et al. 2009).

McSweeney (2013) reviewed four leading business data management maturity assessment models and concluded that there is lack of consensus about what comprises information management maturity and a lack of rigor and

detailed validation to justify organization process structures. He called for a consistent approach, linked to an information lifecycle (McSweeney 2013).

Following the CMMI principles and approaches, the CMMI Institute's Data Management Maturity (DMM) Model was released in August 2014. The DMM model is designed to cover all facets of data management and provides a reference framework for organizations to evaluate capability maturity, identify gaps, and provide guidelines for improvements across a project or an entire organization (CMMI 2014). The CMMI DMM model assesses 25 data management process areas organized around the following six categories: data management strategy, data governance, data quality, data platform & architecture, data operations, and supporting processes (CMMI 2014; Mecca 2015). It has been utilized by seven different businesses (Mecca 2015) and adopted by the AGU (American Geophysical Union) data management assessment program (Stall 2016).

The Enterprise Data Management Council (EDMC) Data Management Capability Assessment Model (DCMM) was released in July 2015 (EDMC 2015). DCMM defines a standard set of evaluation criteria for measuring data management capability and is designed to guide organizations to establish and maintain a mature data management program (EDMC 2015; Gorbail 2016). A detailed description and comparison of CMMI DMM and EDMC DCMM can be found in Gorbail (2016).

#### *b) Repository data management procedure maturity*

The trustworthiness of individual repositories has been the topic of study for the data management and preservation community for many years. Based on the OAIS reference model, ISO 16363 (2012) establishes comprehensive audit metrics for what a repository must do to be certified as a trustworthy digital repository (see also CCSDS 2012a). Three important qualities of trustworthiness are integrity, sustainability, and support for the entire range of digital repositories in three different aspects: organizational infrastructure, digital object management, and infrastructure and security risk management (ISO 16363 2012; CCSDS 2012b; Witt et al. 2012). A detailed justification for transparency is now recommended in the ISO 16363 repository trustworthiness assessment template.

Working with the Data Seal of Approval (DSA) and the Research Data Alliance (RDA), the WDS-DSA working Group developed a unified core trustworthy data repository requirements, namely the checklist, that can be utilized for certification of repositories at the core level (Edmunds et al. 2016) as a solid step towards meeting the ISO 16363 standards.

On the individual agency level, United States Geological Survey (USGS) has adopted the WDS-DSA checklist and begun to evaluate and issue the "USGS Trusted Data Repository" certificate to its data centers (Faundeen, Kirk, & Brown 2017). For organizations that do not wish to go through a formal audit process, utilizing these assessment template and checklist will still help them evaluate where they are and identify potential areas of improvement in their currently defined data management and stewardship procedures.

#### *c) Portfolio management maturity*

An organization may identify and centrally manage a set of core data products because of the significance of those products in supporting the strategy or mission of the organization. For example, under OMB Circular A-16 (OMB 2002b) "Coordination of Geographic Information and Related Spatial Data Activities," the Federal Geographic Data Committee (FGDC) designed a portfolio management process for 193 geospatial datasets contained within the 16 topical National Spatial Data Infrastructure themes (FGDC 2016). These 193 datasets "are designated as National Geospatial Data Assets (NGDA) because of their significance in implementing to the missions of multiple levels of

government, partners and stakeholders” (Peltz-Lewis et al. 2014). The first NGDA lifecycle maturity assessment (LMA) model was developed and utilized to baseline the maturity of the NGDA datasets (FGDC 2015). The LMA model assesses the maturity in 7 lifecycle stages of data portfolio management: Define, Inventory & evaluate, Obtain, Access, Maintain, Use & evaluate, and Archive (FGDC 2016). The assessments were mostly carried out by data managers and summarized with improvement recommendations for future LMA assessment to support portfolio management process in FGDC (2016). LMA assessment reports of NGDA dataset are available online at: [https://www.fgdc.gov/ngda-reports/NGDA\\_Datasets.html](https://www.fgdc.gov/ngda-reports/NGDA_Datasets.html) and maturity levels can be reviewed by an online tool at: <https://dashboard.geoplatform.gov> (user login may be required).

A similar approach can be adapted to product portfolio management. For example, focusing on the product user requirements and impact, NOAA’s National Centers for Environmental Information (NCEI) developed product prioritization process and associated metrics to support an organization-wide product portfolio management process (Privette et al. 2017). They should be a part of an organizational data strategy that “ensures that the organization gets the most value from data and has a plan to prioritize data feeds and adapt the strategy to meet unanticipated needs in the future.” (Nelson, 2017). Data strategy needs to be complimentary to and aligned with organizational strategy. One can turn to Nelson (2017) for a set of key components when defining data strategy.

#### *d) Data product lifecycle-stages-based maturity assessment models*

Ensuring and improving data and metadata quality is an end-to-end process through the entire lifecycle of data products and shared responsibilities of all product key players and stakeholders (Peng et al. 2016a). As mentioned above, information quality is multi-dimensional and can be defined based on data product lifecycle stages (e.g., Ramapriyan et al. 2017). Therefore, defining maturity assessment models for different phases of data products may reflect better the different roles and knowledge required for assessments.

#### *i) Science Maturity Matrix (Define/Develop/Validate)*

The scientific quality of data products is closely tied to the maturity of observing systems, product algorithms and production systems. Under the Gap Analysis for Integrated Atmospheric ECV CLimate Monitoring (GAIA-CLIM) project, a measurement system maturity matrix has been developed (Thorne et al 2015). The measurement systems are categorized as: Comprehensive observing networks, Baseline networks, and Reference networks, based on the observing quality and spatial density (Thorne et al. 2015). This matrix aims to assess the capability maturity of the measurement systems in the following areas: Metadata, Documentation, Uncertainty characterization, Public access, feedback, and update, Usage, Sustainability, and Software (optional). The GAIA-CLIM Measurements System Maturity Matrix has been utilized by the GAIA-CLIM project to assess the geographical capabilities in the areas of data and metadata for ECVs (Madonna et al. 2016a; 2016b).

The maturity of algorithms measures the scientific quality of developing data products and helps establish the credibility of the data products. A data product algorithm maturity matrix (referred to as MM-Algo) has been developed by NOAA’s Center for Satellite Applications and Research (STAR) and applied to 68 products from S-NPP (National Polar-orbiting Partnership)/JPSS (Joint Polar Satellite System) as a measure of the readiness of the data product for operational use (Zhou, Divakarla & Liu 2016). The MM-Algo defines five stages of maturity levels for a data product in the areas of validation, documentation, and utility of the product: Beta, Provisional, Validated (Stage 1, 2, and 3) (Reed 2013).

The S-NPP/JPSS Cal/Val program has developed a readiness review process. The information on S-NPP/JPSS data product algorithm maturity including the timeline and associated calibration/validation findings is available at:

<https://www.star.nesdis.noaa.gov/jps/AAlgorithmMaturity.php>.

*ii) Product Maturity Matrix (Produce/Assess/Deliver)*

Utilizing a maturity matrix approach for individual Earth Science data products is pioneered by Bates and Privette (2012). Bates and Privette (2012) described a product maturity matrix (referred to as MM-Prod) developed by NOAA for satellite-based climate data records (CDRs). CDR MM-Prod provides a framework for evaluating the readiness and completeness of CDR products in six levels in the following six categories: Software readiness, Metadata, Documentation, Product validation, Public access, and Utility. It has been applied to about 35 NOAA CDRs (Bates et al. 2015). The assessments are performed mostly by the CDR data producers during the research-to-operations (R2O) transition process, and reviewed by NCEI CDR R2O transition managers. (The MM-Prod scoreboard for each CDR can be found at <https://www.ncdc.noaa.gov/cdr>.)

As standards defined in CDR MM-Prod, such as data format, are mostly defined for and implemented by NOAA's satellite climate data records program, it may need to be generalized for a broader application to digital environmental data products.

A CDR production system maturity matrix, which is originated from the CDR MM-Prod but adapted for the CDR production system, has developed under the COordinating Earth observation data validation for RE-analysis for CLIMAtE ServiceS (CORE-CLIMAX) project (EUMETSAT 2013). The CORE-CLIMAX production system maturity matrix assesses whether the CDR can be sustainable in the following six categories: Software readiness, Metadata, User documentation, Uncertainty characterization, Public access/feedback/update, and Usage. It has been applied to about 40 EU data records of essential climate variables (ECV), including satellite, in situ and re-analysis data products (EUMETSAT 2015). It is utilized by the Sustained, Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM) project of World Meteorological Organization (WMO) to monitor development process (Schulz et al. 2015). The CORE-CLIMAX production maturity matrix is the first maturity model that dedicates an entire category to data uncertainty. To some extent, it measures production process quality control capability, as well some aspects of science and product maturity.

*iii) Data Stewardship Maturity Matrix (Maintain/Preserve/Disseminate)*

A scientific Data Stewardship Maturity Matrix (DSMM, referred to as MM-Stew) was developed jointly by NCEI and Cooperative Institute for Climate and Satellites - North Carolina (CICS-NC), leveraging institutional knowledge and community best practices and standards (Peng et al. 2015). MM-Stew takes a similar approach to Bates and Privette (2012), but with a different scale structure. MM-Stew defines measurable, five-level progressive stewardship practices for nine key components: Preservability, Accessibility, Usability, Production sustainability, Data quality assurance, Data quality control/monitoring, Data quality assessment, Transparency/traceability, and Data integrity (Peng et al. 2015).

Over 700+ Earth Science data products were assessed utilizing MM-Stew, mostly carried out manually by NOAA OneStop Metadata Content Editors as a part of the OneStop-ready process, (e.g., Ritchey et al. 2016, Hou et al. 2015; Peng et al. 2016b). The OneStop Metadata team, working with the NOAA Metadata Working Group, has developed the workflow and best practices to implement MM-Stew assessment ratings into ISO 19115 collection-level metadata records (Ritchey et al. 2016; Peng et al. 2017). These MM-Stew ratings are integrated into the OneStop data portal and used for discovery and search relevancy ranking. The ISO collection-level metadata records are integrated into NOAA and other catalog services. The detailed justifications for each of OneStop-ready data products are captured in a data stewardship maturity report (DSMR). A tool has been developed by the OneStop

project to systematically generate draft DSMRs with a consistent layout for both figures and DSMR (Zinn et al. 2017). An example of a citable DSMR can be found in Lemieux, Peng & Scott (2017). Both persistent and citable DSMRs and ISO collection-level metadata records can then be readily integrated into or linked by other systems and tools, for example, to be used for improved transparency and enhanced data discoverability and usability. (Links to the MM-Stew related resources including examples of use case studies and ISO metadata record can be found in Peng (2017)). This quantitative and content-rich quality descriptive information may be used in decision-making process to support data asset management (e.g., Austin and Peng 2015).

The MM-Stew is designed for digital environmental data products that are extendable and publicly available. This may limit its usage to certain types of data products in specific key components, e.g., data products from one-off research cruises for the Production Sustainability component.

Utilizing the MM-Stew, the Data Stewardship Interest Group under Committee on Earth Observation Satellites (CEOS), led by the European Space Agency, has started to develop a harmonized DSMM (Albani 2016). This harmonized DSMM is to be utilized in the Earth Observation domain and integrated with CEOS data management principles and preservation principles (Maggio 2017).

*iv) Data Use/Services Maturity Matrix (Use/Services)*

Unlike product services in business sector, which are quite mature, the scope of digital scientific data use/services is still evolving. In its levels of services, the National Snow and Ice Data Center (NSIDC) defined a variety of services that can be provided for a data product and described factors that could affect the amount of work required for each individual dataset in six categories: Archival, Metadata, Documentation, Distribution, USO (User Support Office) Infrastructure, and USO Support (Duerr et al. 2009). This list of services levels is designed to provide mechanisms for assessing and providing quantitative guidance on how much effort is required to provide the level of services that is needed for the data product in its current state.

In its tiered scientific data stewardship services, NCEI defined six levels of stewardship services that could be provided to individual data products (see Figure 4 in Peng et al 2016a). Level 1 stewardship service preserves datasets and provides basic search and access capability for the datasets. With increased levels of stewardship services, more capabilities in scientific quality improvement, enhanced access, and reprocessing are provided, resulted in being authoritative records in Level 5 and providing national and international leadership in Level 6.

The Global Climate Observing System (GCOS) ECV Data and Information Access Matrix provides data and information access to the WMO GCOS ECVs (e.g., <https://www.ncdc.noaa.gov/gosic/gcos-essential-climate-variable-ecv-data-access-matrix>). The Global Ocean Observing System (GOOS) defines three maturity level of the observing systems in the following three different aspects: Requirements processes, Coordination of observations elements, and Data management and information products. Three maturity levels are: Concept, Pilot, and Mature. The system performance is evaluated and tracked based on a series of metrics, including Implementation, Performance, Data delivery, and Impact metrics. More information on the GOOS framework can be found at: [http://goosocean.org/index.php?option=com\\_content&view=article&id=125&Itemid=113](http://goosocean.org/index.php?option=com_content&view=article&id=125&Itemid=113)

A use/service maturity matrix for individual digital environmental data products is under-development by the NCEI Service Maturity Matrix Working Group, in collaboration with the Data Stewardship Committee of Earth Science Information Partners (ESIP). The preliminary maturity levels for data monitoring and user engagement have been shared with the ESIP community for community-wide feedback (Arndt and Brewer 2016).

## 4. Summary

Recent U.S. laws, federal government mandates and policies, along with recommendations and guidelines set forth by federal and funding agencies, scientific organizations and societies, and scholarly publishers, have levied stewardship requirements on federally funded digital scientific data. This raised level of requirements has increased the need for a more formal approach to stewardship activities that they support rigorous compliance verification. To help data stewardship practitioners, especially these at data centers or associated with data stewardship programs, this article provides an overview of the current state of assessing the maturity of stewardship of digital scientific data. A brief description of the existing maturity assessment models and their applications is provided. It aims at enabling data stewardship practitioners to further evaluate the utility of these models for their unique verification and improvement needs.

Generally speaking, one could utilize

- the CMMI DMM model if the focus is on assessing and improving organizational processes or capabilities;
- the ISO 16363 model if the focus is on assessing and improving organizational infrastructure or procedures;
- the data product lifecycle-stage-based maturity models if the focus is on assessing and improving practices applied to individual data products.

For any organization, it is beneficial to assess and improve its effectiveness of data stewardship using a holistic approach. Doing so will help ensure that processes are well-defined and procedures are well-implemented using the community best practices.

Given the multi-dimensional and incremental stages of these maturity models, they are not only practical in assessing the current state, identifying potential gaps, and defining a roadmap forward to a desired level of maturity from a certain stewardship perspective. They are also offering the flexibility of allowing organizations or stewardship practitioners to define their own process capability requirements or data product maturity levels with a progressive, iterated improvement process or to tailor these models to a particular organizational process area, such as data quality management; or a particular practice applied to individual data products, such as verifying data integrity.

Increased application of these maturity assessment models will help demonstrate their utility and improve their own maturity. This is also beneficial in establishing the need and developing a community consensus on best capturing and integrating quality descriptive information consistently in metadata records or in citable documents for both machine and human end-users. Doing so helps ensure that quality information about federally funded digital data products are findable and integrable, which in turn helps ensure that the data products are preserved for long-term use.

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## DISCLAIMER

The description of maturity assessment models in this article is for information only. It does not claim to be complete. Any entity (person, project, program, or institution) is encouraged to do its due diligence and make the use decision based on its own unique needs. Any opinions or recommendations expressed in this article are those of the author and do not necessarily reflect the views of NOAA, NCEI, or CICS-NC.

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