International Standard

ISO/ASTM 52951

Additive manufacturing — Data — Data packages for AM parts

Fabrication additive — Données — Paquets de données pour pièces de FA

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 261, *Additive manufacturing*, in cooperation with ASTM Committee F42, *Additive Manufacturing Technologies*, on the basis of a partnership agreement between ISO and ASTM International with the aim to create a common set of ISO/ASTM standards on additive manufacturing, and in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 438, *Additive manufacturing,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Additive Manufacturing (AM) processes follow many of the same manufacturing steps observed in more "traditional" manufacturing processes, from design to manufacture to inspection. As an advanced manufacturing process, AM introduces additional complexities to those steps within an AM workflow (illustrated in Figure 1). AM-specific information is necessary to specify, verify, and archive data related to parts that are manufactured using AM technologies. Key information associated with those steps includes relevant facility, operator, machine, process, material, postprocess, inspection and other information (see ASTM F3490).

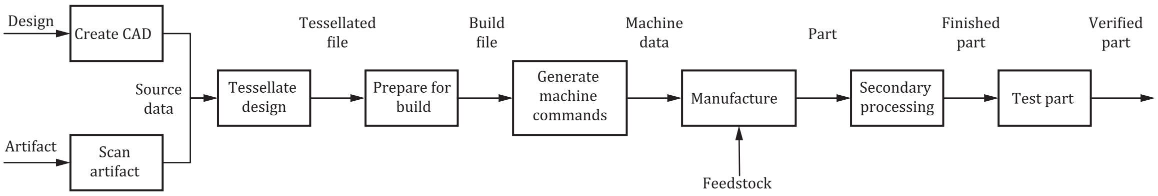

Figure 1 — Illustrative additive manufacturing workflow[1]

This document is developed on the premise that an overarching digital thread can represent the workflow of a part fabricated using an AM process, such as shown in Figure 1. This digital thread is comprised of the information requirements derived from various stages of fabrication, including design, manufacture, and inspection. By identifying and selecting specific information requirements from the digital thread (see Figure 2), a data package for a specific part can be developed for a specific application or scenario associated with each individual stage of the workflow. Data packages serve to provide an organization with a means to specify and organize part information requirements specific to a given application or scenario.

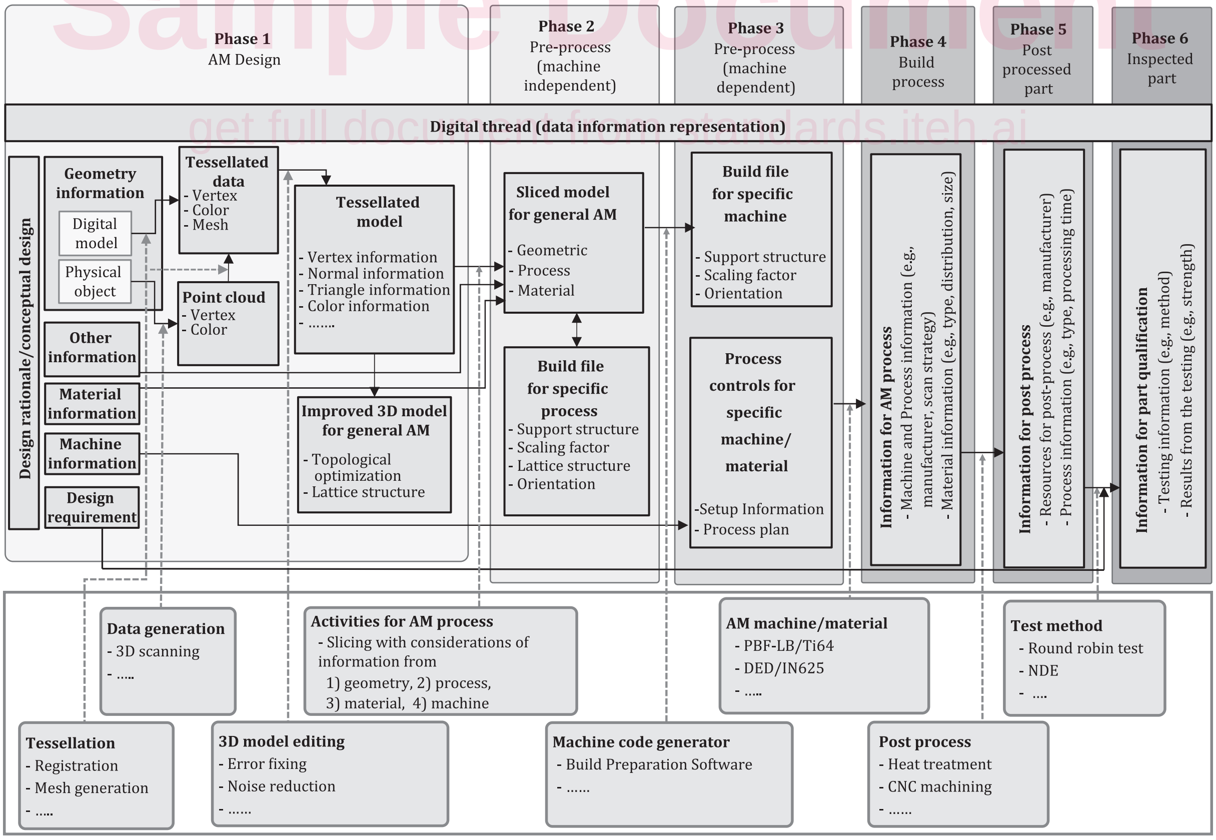

Figure 2 — Illustrative information requirements associated with data package development[1]

This document establishes a system to maximize an organization's flexibility when determining its data package requirements for various scenarios. The modularization of information requirements and their level of specificity supports the general, broad adoption of this document while also supporting specific organization needs and scenario requirements. In this sense, this document establishes principles for modular, multi-tiered information requirements to support the development of data packages for various scenarios with varying levels of control. Configuration management practices are used to identify acceptable representations, including file formats and file types, for given data package requirements.

To support part acceptance, this document establishes general principles for data package requirements, that, working in concert with data structure and configuration management, can be used to create a digital representation, or a "digital twin" of an additively manufactured part. A digital twin (see Figure 3) is developed by addressing the requirements of this document for a specific part and application scenario.

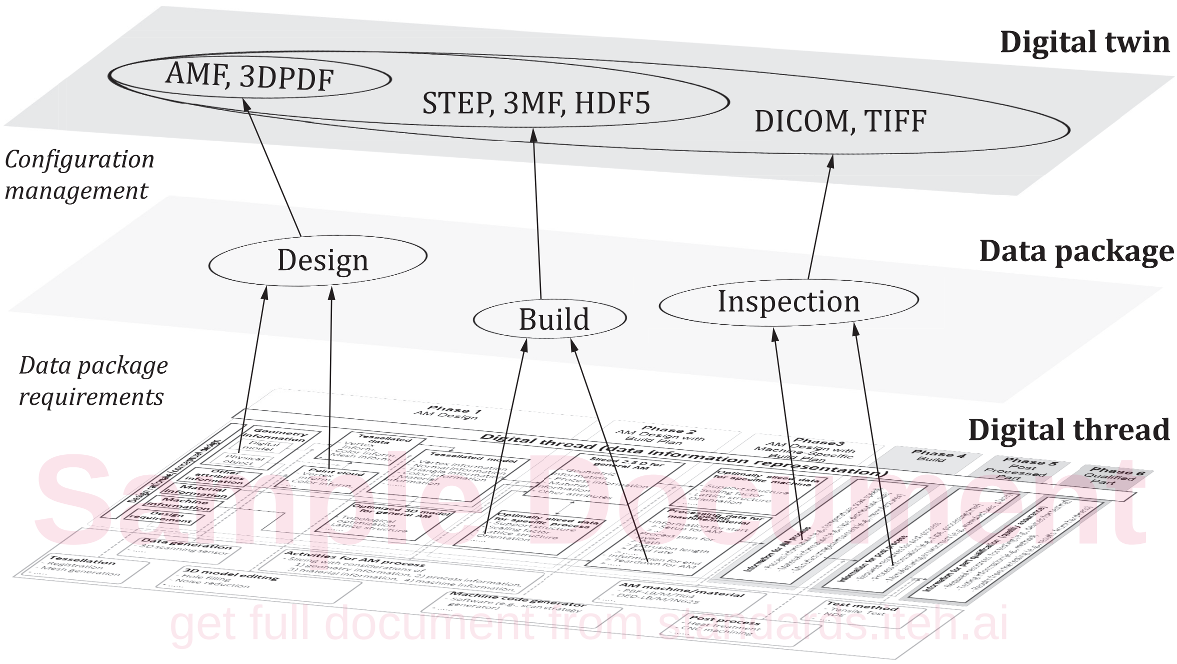

Figure 3 — The data package concept is central to the curation of additive manufacturing information

In transitioning from a design to a manufactured part, the AM digital thread progresses through many digital representations including: CAD design, simulation, tessellated geometry, sliced geometry, build file, part with build data and part with evaluation data. At each of these stages, the digital provenance of the part is evolving, with its digital twin maturing from the generation of new data at every stage. As a digital representation of the intended physical counterpart, the digital twin provides important insight into the state of the part through its design to product transformation. When accepting a final part, it is important to have confidence in the processes used in the fabrication of the part, since differences in implementation can mean different parts. The digital twin provides an important resource from which confidence can be gained but can create its own uncertainty if not well-defined and well-understood, with the requirements identified in the data package.

Clause 4 outlines the general procedure to be followed for an organization to develop a customized data package, from identifying information requirements to adopting configuration management practices. Clauses 5 to 10 outline the data requirements across the AM workflow. Clause 11 provides the specific configurations to meet specified organizational requirements.

Key concepts used and discussed in this document include data package, data package requirement, digital thread, digital twin, modular components, configurability, configuration management, capability (e.g. software, equipment, facility, operator) and criticality (part or application).

Additive manufacturing — Data — Data packages for AM parts

1 Scope

This document specifies the methods, parameter sets and models to develop and utilize a data package for a part created using AM technologies (AM part). This document is applicable to the information requirements associated with workflow of the fabrication of an AM part, from design to acceptance. Peripheral information related to entities such as organization, facility, operator, security, and others is addressed for sake of completeness; but is not the focus of this document and can be defined elsewhere. This document provides the means to develop an organizational or application-specific data package for the communication between and amongst the designer, the manufacturer, and all acceptance authorities, among other potential stakeholders.

This document does not impose a plan of execution to produce an AM part, though a digital thread is provided to establish a referenceable information workflow.

The requirements set forth in this document are based on the fabrication of a part using the PBF-LB/M (powder bed fusion-laser based/metal) process. While specific details directly relate to PBF-LB/M, generalized workflow requirements can be related to any AM process.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO/ASTM 52900, *Additive manufacturing — General principles — Fundamentals and vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO/ASTM 52900 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
AM data package, noun
set of information associated with an AM part, instantiated data package requirements that should confirm established configuration management practices

3.2
AM digital thread, noun
digital component of the design to product transformation workflow of an AM part

3.3
AM workflow, noun
process applied to realize the design to product transformation of an AM part, including any acceptance procedures

3.4
AM workflow stage, noun
specific sub-process within the larger *AM workflow* (3.3) that aligns with an activity associated with the production of an AM part

3.5
configuration, noun
collection of an item's descriptive and governing characteristics that can be expressed in functional and physical terms

Note 1 to entry: This represents the requirements, architecture, design and implementation that define the version of the system and its components.

3.6
configuration management, noun
process for establishing and maintaining consistency of a product's performance, functional and physical attributes with its requirements, design and operational information throughout its life

3.7
digital provenance, noun
aggregation of data and information that can be used to provide the history of the design, fabrication, processing, testing, and acceptance of an AM part

4 Significance and use

Part design, manufacture, inspection and procurement can be relatively complex when AM processes are used. Complexities of AM processes can create variabilities in AM parts; therefore, the specification of additional process and workflow information is desired at times. Variabilities in AM processes and workflows create challenges in the common specification interpretations of AM processes. This document provides the methods, supported by a reference workflow and information flow, on which AM parts can be consistently specified and interpreted for part design, manufacture, inspection, and procurement.

Additive manufacturing workflows come in varying levels of complexity, and the processes can be controlled and specified at varying levels of detail. When adopting AM processes, explicit communication is vital to satisfy organization objectives. Data packages provide an organization with the means for communicating details about a part or a design. Under-specification can lead to loss of fidelity in the fabrication of AM parts, while overspecification can lead to improper execution by underqualified personnel. Identifying the correct requirements at the proper level of specificity is essential to successful delivery and acquisition of AM parts.

This document establishes a system to facilitate the identification of individual and subsets of information requirements across this workflow to communicate desired levels of provenance for a given application or scenario. The information requirements set forth at each workflow stage are only imposed when a specific data-package configuration has been called into place. An organization shall identify a specific data package and configuration-management plan to specify how selected requirements are to be met for a given application or scenario.

This document establishes the concept of modularity to support various scenarios in which a data package can be required. The requirements put forth by individual modules may not be inclusive, and these modules can be extended and adopted as the organization sees fit. Different combinations of modules can be developed to satisfy various application scenarios as outlined in Clause 5. Different levels of control within each set of requirements can be specified based on capabilities of relevant organizations and individuals, as detailed in Clause 5 and Annex A.

This document supplements existing data package practices with AM-specific considerations and does not support requirements that can be put in place by an organization for parts manufactured with other manufacturing processes; nor does it replace other standards that can be used to satisfy data package requirements of non-additively manufactured parts. This document will leverage and reference existing standards where appropriate.

This document gives guidance on the concept of a “digital twin” for completeness to relate the digital thread, data packages, and configuration management. Digital twin is not a focus of this document, however, and thus development of one is not required to meet outlined specifications. For a broader understanding of digital twin concepts and related standards (e.g. ISO 23247 series and other standards under development by ISO/TC 184/SC 4 and other committees), please refer to those respective standard documents.

5 Method for data package development

5.1 General

The method for creating an AM data package consists of 5 separate steps. This clause provides the necessary guidance to create a customized data package to meet specific organizational or application requirements:

a) identifying application scenario and associated data package requirements;

b) using modules for data package configuration;

c) determining level of specificity by setting requirements control;

d) establishing configuration management practices;

e) creating a data package.

These steps are detailed in the following subclauses.

5.2 Identifying the application scenario and associated data package requirements

Depending on the scenario or application that a data package is being developed for, the requirements can vary significantly. Therefore, the configuration of data packages will depend on the context for which they are being developed. This context can be one of three data package application scenarios:

— Acquisition - this scenario occurs when an AM part is to be sourced from an outside party to meet a pre-existing specification and the acquiring organization has a need to communicate specifics about the design, fabrication, and testing of the AM part to the outside party.

— Manufacture in house - the scenario occurs when an AM part is to be fabricated within an organization and communication between design, manufacture, testing, and acceptance is needed.

— Verification only - this scenario occurs when an AM part faces unique acceptance requirements (either in house or external) but no further design or process communication is needed.

The three scenarios are further delineated based on the use history of the part to be fabricated:

— Prototype - this scenario occurs when a part is still progressing through design and manufacturing iterations and final specifications have not yet been determined.

— New part- this scenario occurs when a fully documented version of the AM part does not exist, and the part is being fabricated to specifications for the first time.

— Existing part - this scenario occurs when full specifications for the fabrication of an AM part exist, and these specifications are to be used in fabrication of additional AM parts.

The three scenarios are further delineated based on the maturity of the part to be fabricated:

— Expeditionary - this scenario occurs when a part is being developed for individual or small use-case scenarios.

— Developmental - this scenario occurs when an AM part has not yet reached full production status and additional specifications are needed.

— Production - this scenario occurs when an AM part has fully matured into production status and any implications associated with its fabrication are well understood and documented.

5.3 Using modules for data package configuration

Once the appropriate scenario has been chosen and effectively delineated, the information elements associated with the scenario can be identified. These information elements, identified through appropriate modules, determine what information will be required in the data package configuration.

11.1 provides suggested configurations of modules for each of the above scenarios in three separate tables. Users of this document can choose to adopt a suggested configuration or simplify or expand on a configuration. The final configuration of the data package requirements requires the user to identify the specific modules to be satisfied (see Figure 4).

The data package requirements associated with each module are provided in Table 2 through Table 19. How requirements are explicitly satisfied shall be agreed upon by involved parties, and levels of specificity allows for adjustments of these requirements (high, medium or low). The provided requirements provide a baseline for configurable data packages but are not meant to be inclusive. Additional requirements can be added as needed.

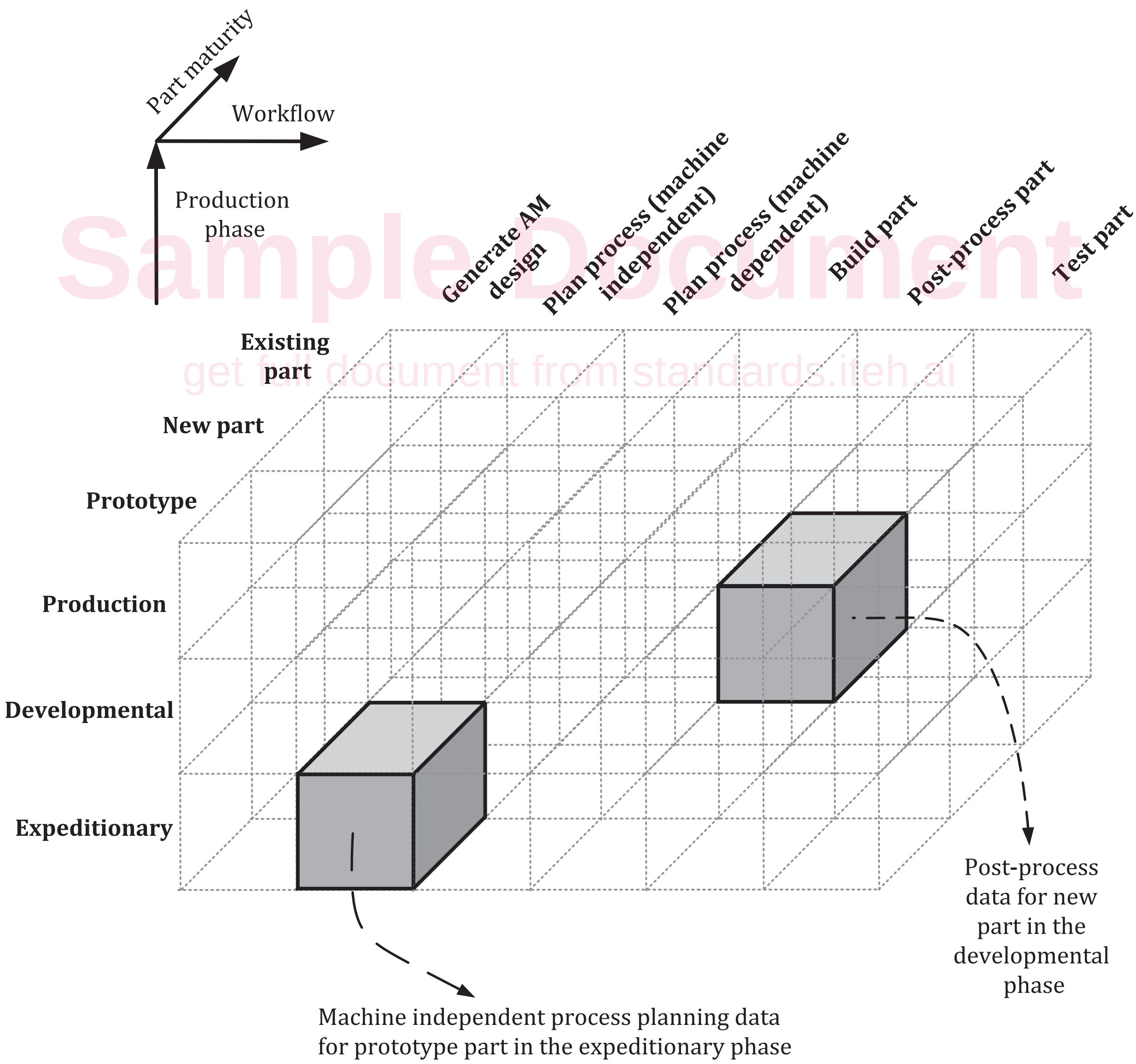

Figure 4 — Configurable "blocks" of data within the AM workflow
(Highlighted spaces are examples of data package configurations (Adapted from Reference [2]))

5.4 Determining level of specificity by setting requirements control

The configuration of data package modules depends on the scenario. The specified amount of control will depend on the criticality of the application scenario and the capability of stakeholders.

The information requirements within each module are satisfied using a multi-tiered approach to establishing a level of specificity. Each tier adds an additional layer of specificity necessary to satisfy the requirements of the data package. This document adopts a three-tier approach: low, medium, and high. High has the most stringent data requirements, thus providing the most explicit control, while low leaves more of the implementation up to the performer. The selection of low, medium, or high control is dependent on assessed capabilities of a performer in respect to stakeholder requirements. This designation is adopted throughout the data package tables provided in Clauses 6 to 9. As the three tiers are traversed, and new data requirements are added, the amount of control over each stage increases. Control refers to how much of the data requirements at each stage are specified and shall be met, as opposed to the relaxation of some requirements based on the capabilities of the performer. Low control is associated with the least number of requirements, while High control will specify maximum available requirements.

The amount of control desired for a stage is influenced by two critical factors: criticality and capability. Highly critical parts will require the highest levels of control, while less critical parts can have less stringent control requirements. For instance, at the design stage, if the geometry is critical, the designer should have the most control. However, if geometry requirements can be relaxed, it can be better to let pre-process performers determine final requirements.

The capability refers to the experience or capacity of the performer. The performer can refer to designer, operator, technician, or procurement specialist. The capability of the performer can also refer to the quality and capacity of the performer's equipment. High-capability performers are expected to have the experience needed to execute a high level of control over the process. Such performers are expected to follow and meet all detailed requirements, to provide skilled input, and to meet acceptance requirements with minimal guidance. Low capability performers can need additional specifications in order to perform their expected duties, and they should not be asked to play critical roles in the fabrication of critical parts.

Table 1 provides a part versus performer capability map, where recommendations are made on the level of guidance, or control, that should be expected based on the criticality of the part and the capability of the performer(s). See Annex A for examples on how Table 1 is adopted.

Table 1 — Part versus performer capability maps the level of control to the criticality of the parts and the capability of the performers

	High capability	**Medium-High capability**	**Medium capability**	**Medium-Low capability**	**Low capability**
High critical	Medium control	Medium to high control	High control	Not recommended	Not recommended
Medium-High critical	Medium to low control	Medium control	Medium to high control	High control	Not recommended
Medium critical	Low control	Medium to low control	Medium control	Medium to high control	High control
Medium-Low critical	Low control	Low control	Medium to low control	Medium control	Medium to high control
Low critical	Low control	Low control	Low control	Medium to low control	Medium control

Capabilities are considered as:

— High capability: expertise is possessed in by the individual or organization responsible for manufacturing the final part. High capability implies that the performer has the ability to meet designated requirements and has access to all necessary equipment and information to do so.

— Low capability: familiarity with AM processes is present, but the performer can possibly not have the knowledge or experience needed to execute to the highest levels. Some equipment is available to the performer, but stringent requirements cannot be met.

— High control: the design and manufacture of the part has been developed under careful consideration. The performer shall meet detailed part, process, and inspection requirements in order for any deliverable to be deemed acceptable.

— Low control: the design of the part is of utmost importance, but the manufacture of the part is left primarily to the performer. The expectation is that the performer will have the capability and know how to manufacture the part to meet design and performance requirements without explicit instructions.

— High risk: generally, this implies that failure to meet any part requirement can result in catastrophic failure. Risk levels are to be determined by the organization.

— Low risk: generally, this implies that failure to meet one or more part requirements can still result in a serviceable part. Such failures can lead to inconveniences that can be overcome with replacement parts or with sub-optimal performance. Risk levels are to be determined by the organization.

The high, medium and low control levels are used throughout the document from Table 2 to Table 19. The suggested level of control is indicated by an “X” for each set of attributes. Annex A provides example scenarios where different levels of control may be desired.

5.5 Establishing configuration management practices

Configuration-management techniques (see Figure 5) are required to control and manage data within the AM production cycle, effectively constructing a digital twin from data provenance. As a physical AM part traverses this lifecycle, the associated digital twin will undergo many digital transformations that mirror the various lifecycle functions - from a raw design to a qualified product. Configuration management begins early in the product design phase and aims at ensuring that the design intent is realized by monitoring and controlling the subsequent processes. A configuration management plan

— defines the allowable representations on which requirements can be met,

— identifies allowable formats and configurations,

— establishes consistency in how data are captured and represented,

— provides consistent evaluation and qualification across AM part families.

The application of configuration management shall aim at reducing impermissible and unintended changes and monitor/record the permissible changes. For example, increasing the component wall thicknesses in the CAD (computer-aided design) digital twin to compensate for material removal in post-processing stages can potentially disrupt an AM part’s definition. Format changes, such as converting the CAD digital twin into an AM machine-readable format, is another process-driven modification that can influence the design intent of the component. Since such examples can influence the design intent of the component, they should be managed carefully. Figure 5 outlines a scenario where a configuration plan is iterated through.

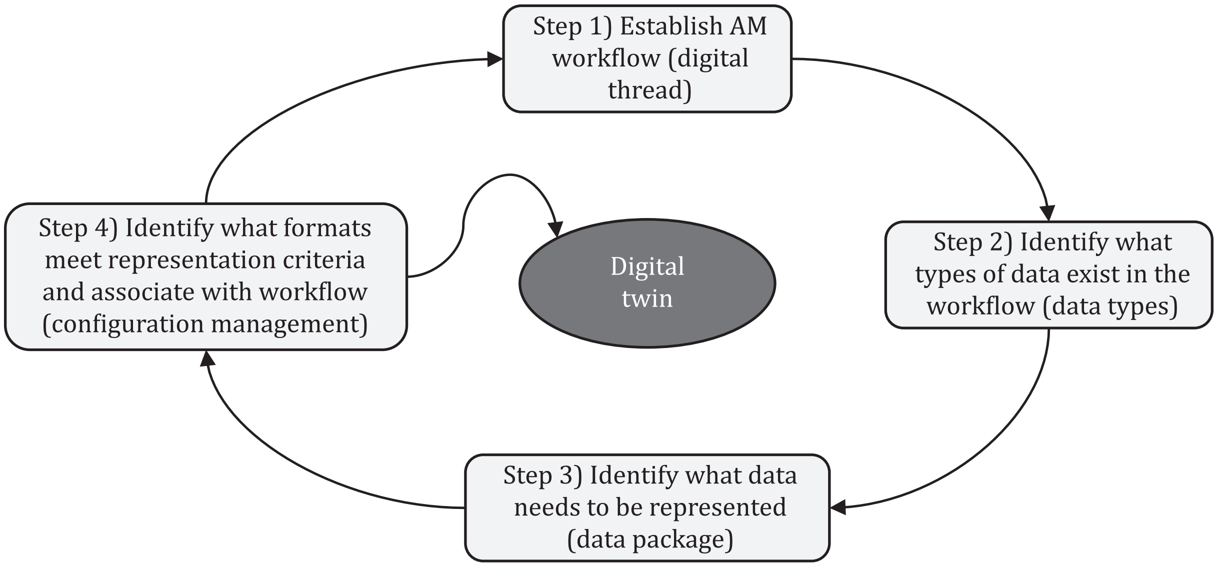

Figure 5 — The approach for establishing configuration management for AM production (Adapted from Reference [2])

Configuration management practices should be outlined as a configuration management plan. Configuration management for AM should be planned during the earliest project stage. Procedures should be developed for managing the configuration of the design and relevant data through to its disposal and throughout the design-to-product transformation. Given the complexity of AM processes and the variability in how these processes can be realized, additional considerations should be made for configuration between organizations to ensure each organization's approach and coding schemes are consistent and compatible. Configuration management plans should make the following considerations:

— Configuration identification - identification of Configuration Items (CI) requires the knowledge of which items influence the integrity of the component data as well as which data items are required for compliance consistency. All CIs and associated AM formats should be assigned an identifier and revision controlled.

— Configuration control (process required to change a CI and re-baseline it) - configuration control can be defined as "a systematic process that ensures that changes to released configuration documentation are properly identified, documented, evaluated for impact, approved by an appropriate level of authority, incorporated, and verified"[3]. In documenting a CI change, critical information to be captured includes the nature of the configuration change, the identification of previous and current states of the configuration item, and any data transformation and losses.

— Configuration status accounting (traceability) - the configuration data shall be stored in a manner that allows for configuration status retrievals. This allows for the component's full digital provenance to be accessed when required anywhere along its digital thread, from design to build to inspection.

— Configuration verification and audit - configuration baselines shall be periodically audited to verify their contents and ensure conformance. This involves a functional and physical verification of the component configuration.

Configuration-management standards and handbooks such as SAE EIA-649, ISO 10007 and MIL—HDBK-61B define the configuration management process in five key functions as depicted in Figure 6. Annex C provides an example of a configuration management scenario.