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Unified reference model for smart manufacturing

Modèle de référence unifié pour la fabrication intelligente

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UNIFIED REFERENCE MODEL FOR SMART MANUFACTURING

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IEC 63339 has been prepared by IEC technical committee 65: Industrial-process measurement, control and automation in cooperation with ISO technical committee 184: Automation systems and integration. It is an International Standard.

It is published as a double logo standard.

The text of this International Standard is based on the following documents:

Draft	Report on voting
65/XX/FDIS	65/XX/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

“Manufacturing” refers to a range of human activities, from handicraft to high tech, and is commonly applied to industrial production, where raw materials and parts are transformed into finished goods on small to large scale by a series of interconnected processes. Smart manufacturing (SM) is an emergent characteristic of manufacturing achieved by digital technologies, gradually built up through digital transformation, combining diversity and uniformity, demonstrating continuous value delivery by a highly complicated collection of processes interacting on different time scales. In today’s manufacturing landscape, manufacturing is no longer characterized as a set of serial processes, but instead as a highly interconnected set of distributed processes that are able to cooperate on different time scales. A set of supervisory processes achieve coordination of these distributed processes using links that enable dynamic response to changing conditions in demands, supply, environment, energy and, other human or naturally caused probabilistic events. Since these probabilistic events are not known before occurrence, they often are disruptive and result in changing conditions.

The purpose of smart manufacturing is to accommodate those disruptive events, while supporting the introduction of new technologies and methods in a coordinated manner across the variety of customers, suppliers and stakeholders at various stages in the value chain.

Building upon the common knowledge and results found in IEC TR 63319 [8][1] – A meta-modelling analysis approach to smart manufacturing reference models, as depicted in Figure 1 – this document specifies the unified reference model for smart manufacturing (URMSM) to create purpose-specific domain and application reference models for smart manufacturing initiatives by specifying the necessary structure and terminology for expressing such models. The URMSM is applicable across the many domains and applications found within a manufacturing enterprise.

Smart manufacturing reference models (SMRM), which conform to the requirements of this document, provide SM standards developers and SM practitioners with better opportunities for implementing models of production systems and products that take full advantage of technological innovations. These innovations occur during:

- analysis and synthesis using models of manufacturing,
- application of new materials, processes and facilities for manufacturing,
- understanding the emergence of digital twin concepts and other smart manufacturing technologies.

The URMSM is not one model or one model visualization. The URMSM is the specification for a family of reference models that share structural and behavioural properties intended to promote interoperability.

NOTE Subclause 8.2 provides more information regarding relationships among models and derivation relations.

The URMSM brings together concepts from existing works, both standards and practice, to support the variety of existing reference models, the adaptation of existing reference models for new uses, and the emergence of new reference models, all of which take advantage of the evolution in manufacturing technologies.

[1] Numbers in square brackets refer to the Bibliography.

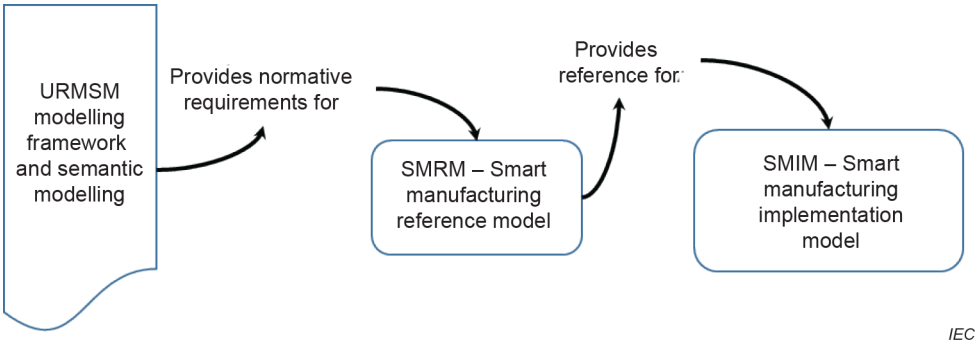

Figure 1 – Using URMSM

The model-based approach of the URMSM has two major structural components. The first is a modelling framework to support various arrangements of manufacturing elements into conceptual configurations deemed pertinent to domains of manufacturing enterprises. The second is the conceptualization of semantic models that reside within the modelling framework. A concise URMSM terminology supports both the modelling framework and the conceptual semantic models.

Since smart manufacturing is essentially a human conception of improved manufacturing technologies and practices, differences in interpretation of that concept can lead some practitioners to over-simplify the complicated nature of perspective and property interactions in today's manufacturing systems. Objectifying the notion of 'smart' for manufacturing is a challenge since developers and practitioners have been getting smarter about manufacturing for over 200 years already.

For IEC work in a domain of similar complexity, the author of [41] summarizes "smartness" in the domain of Smart Cities as follows:

Smartness is an emergent characteristic of a system

- achieved by digital technologies,
- explicitly architected and engineered to reduce complexity,
- gradually built up through digital transformation,
- permanently demonstrating value delivery,
- combining diversity and uniformity,
- coordinating and cooperating between all the stakeholders.

Considering this characterization, the URMSM provides the means for creating reference models for smart manufacturing that enable emergence of more digitally oriented, engineered solutions for delivering additional value from manufacturing operations. The result is improved performance aspects with integrated and intelligent use of processes and resources in cyber, physical and human spheres to create and deliver products and services, which also collaborate with other domains within enterprises' value chains [13].

This document identifies a collection of criteria for arranging aspects of the smart manufacturing domain as reference models. The important relationships among manufacturing elements enable useful examination and derivation of practical designs in order to fulfil a defined purpose, and to maintain and improve the resulting system through methods for analysis and synthesis.

The URMSM provides insight into the modelling of aspects of manufacturing elements to consider when developing new elements. Smart support methods for conducting that development or modification can require an evolution from existing practice to a more unified model-based approach.

This document can be used to support the development processes of smart manufacturing, and to assure coherence and compatibility during the development of standards.

This document identifies ways to apply those aspects of manufacturing and the acumen essential to developing a smart manufacturing model for a particular industrial enterprise.

The URMSM goes beyond the representational features of manufacturing elements to enable examination of interactions among those elements through the use of models to address issues arising in the course of smart manufacturing initiatives.

Expectations regarding the outcome of a satisfactory URMSM are:

- enabling the examination of value within a value creation network;
- enabling a range of appropriate libraries such as use cases, interface definitions, models for semantics, information and data, and international standards as modelled views relative to modelling purposes for particular smart manufacturing situations;
- enabling representation as a multi-dimensional space composed from various collections of aspects to accommodate particular modelling purposes, such as aspects of production, aspects of product, aspects of smart technology, and their relationships over their respective life cycles;
- enabling assurance that information is consistently structured using standards for information, data and modelling languages, without ambiguous meaning, by applying semantic models and techniques;
- enabling efficient usability for the creation of tailored smart manufacturing models that address a stakeholder's particular concerns.

The URMSM supports all three modalities of interoperation (unified, integrated, and federated) that can co-exist within a modelling framework, albeit with varying extents of effectiveness and efficiency (see ISO 11354). Having a formal understanding of modelling frameworks enables more effective and efficient utilization of frameworks.

Clause 4 specifies extents of conformance to URMSM based upon meeting the requirements and recommendations in their entirety, as full conformance, or for particular subclauses, as partial conformance.

Clause 5 presents aspects of manufacturing commonly associated with 'smart manufacturing'.

Clause 6 presents modelling concepts essential for constructing suitable reference models in the domain of smart manufacturing.

Clause 7 establishes examination and derivation criteria for interoperation of aspects in manufacturing.

Clause 8 presents ways to use the URMSM to create purpose-specific reference models.

Clause 9 presents use cases for the URMSM and a progression of capability markers that indicate maturity in the application of the URMSM.

Clause 10 discusses ways to manipulate and use reference frameworks for extended analysis and synthesis for systems used in smart manufacturing.

Annex A presents concept areas of smart manufacturing.

Annex B provides a formal foundation for the URMSM approach including a modelling framework for URMSM.

Annex C provides an example figure of cascading reference models.

Annex D provides a summary of the meta-model for reference model analysis from IEC TR 63319 [8].

Annex E provides an introduction to the principles underlying semantic modelling.

Annex F provides a practitioner's modelling activity in a systematic usage of URMSM.

Annex G provides an extended example of the URMSM applied to a multi-dimensional manufacturing scenario.

UNIFIED REFERENCE MODEL FOR SMART MANUFACTURING

1 Scope

This international standard specifies the unified reference model for smart manufacturing (URMSM) using a terminology and structure, and establishes criteria for creating reference models, as specializations, that support smart manufacturing. The terminology and structure comprise a set of common modelling elements, their associations, and conformance criteria. These common modelling elements address aspects and perspectives of products and production and their lifecycle considerations.

The URMSM enables an approach for creating multiple models based upon a reference model that is sufficient for understanding significant relationships among entities involved in smart manufacturing (SM) and for the development of standards and other specifications.

The URMSM specifications in this document accommodate consistent, coherent, compatible specializations for relevant aspects of manufacturing systems consisting of equipment, products, and services within the domain of manufacturing. Provisions of this document are applicable for a new smart manufacturing reference model (SMRM) or elaboration of existing SMRM capabilities, for example, improving capabilities for analysis of opportunities and synthesis of technological advances, and improving interoperability of new and existing systems.

This document is not intended to prescribe interoperability considerations or data schemas of models. Standardization of content relative to models will be the subject of other standards and texts specific to those model domains.

2 Normative references

There are no normative references in this document

3 Terms, definitions, abbreviated terms, acronyms and conventions

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp/ui

3.1.1
aspect
labelled designation for a collection of concepts in a particular context

EXAMPLE functional, structural, information, security, availability, customer.

Note 1 to entry: An aspect is often expressed as a view across one or more model for a manufacturing system.

Note 2 to entry: Elements of an aspect can have functional, non-functional or other kinds of descriptors.

Note 3 to entry: The identification of an aspect is often the result of prior knowledge, experience and practice in the domain to which the aspect applies.

3.1.2
aspect interaction
relationship between two or more *aspects* (3.1.1) where one aspect influences or is influenced by the presence of another aspect

Note 1 to entry: Influence includes but is not limited to dependence and control.

3.1.3
business
series of processes, each having a clearly understood purpose, involving one or more person, realised through the exchange of information and directed towards some mutually agreed upon goal, extending over a period of time

[SOURCE: ISO/IEC 15944-20:2015, 2.2]

3.1.4
complex
<context>
decision situation characterised by unordered decision variables, and ill-defined categories, criteria and dependencies

3.1.5
complicated
<context>
decision situation characterised by enumerated decision variables, and well-defined categories, criteria and dependencies

3.1.6
concern
matter of relevance or importance to a *stakeholder* (3.1.20) regarding a manufacturing system or element thereof

Note 1 to entry: Stated concerns are useful when relevant to the purpose of the modelling effort and refer to specific rather than categorical difficulties, problems, or requirements.

Note 2 to entry: Concern expression takes many forms, including among others: as questions about features or characteristics, as a keyword label for many related matters, and as expected quality attributes of the manufacturing system or its products and services.

[SOURCE: ISO/IEC/IEEE 42010:2011, 3.10, modified – added "regarding a manufacturing system or element thereof”]

3.1.7
dimension
coherent collection of *aspects* (3.1.1) relevant to a *manufacturing domain* (3.1.12)

Note 1 to entry: The coherence requirement of the dimension can result in a collection of aspects that are unordered, partially ordered, fully ordered, or related in some other manner, or not ordered in any way (see 6.4 on dimensional coherence for further information).

3.1.8
element
tangible or intangible constituent of a manufacturing system or of a product

Note 1 to entry: A constituent can range from atoms of raw material or logical constructs or items of information through manufacturing models or equipment and entire factories, plants or supply chains and added value networks to finished goods, and software and services.

Note 2 to entry: While the term as defined has broad meaning, designation of a specific meaning for an element of manufacturing or manufactured product includes an adjective to constrain the meaning appropriate to that particular manufacturing element.

3.1.9
facet
framework composed of one or more dimension(s) (3.1.7)

Note 1 to entry: Composition rules for coherent dimensions distinguish facets from other modelling frameworks.

Note 2 to entry: The location at which dimension aspects intersect are containers for models representing each pf the intersecting aspects.

3.1.10
granularity
extent of detail or specificity

Note 1 to entry: The possible extent ranges from coarse to fine.

3.1.11
life cycle
lifecycle
life-cycle
set of distinguishable phases and steps within phases that an entity goes through from its creation until it ceases to exist

Note 1 to entry: The phases of a nested enterprise can be steps within the life cycle of the containing enterprise.

Note 2 to entry: The use of the terms 'phase' and 'step' does not imply any prescribed temporal ordering of activity types. The term 'life history' chronicles instance occurrence of activities.

[SOURCE: ISO 15704:2019, 3.12, modified – addition of lifecycle and life-cycle alternatives, and Note 2 to entry]

3.1.12
manufacture
any or all of the activities in the design, procurement, construction, commissioning, deployment, screening, testing, production, storage, labelling, packaging or distribution of products and production systems

3.1.13
manufacturing domain
portion of a *business* (3.1.3) dealing with the *manufacture* (3.1.11) of products

3.1.14
meta-model
description of modelling elements for use in constructing *models* (3.1.15) pertaining to a domain

Note 1 to entry: A meta-model is always relative to the model in which its modelling elements appear.

[SOURCE: ISO 19440:2020, 3.47]

3.1.15
model
simplified, purposeful representation of certain entities and their characteristics and relationships either (a) using a formalism, or (b) using an established or ad hoc modelling paradigm, approach, or technique

Note 1 to entry: An ad hoc model is more difficult to implement using an established design technique.

Note 2 to entry: A model can be a subset of a broader model.

[SOURCE: ISO 15704:2019, 3.15, modified – addition of "simplified, purposeful" and “and relationships]