



BSI Standards Publication

A meta-modelling analysis approach to smart manufacturing reference models

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**A META-MODELLING ANALYSIS APPROACH TO SMART
MANUFACTURING REFERENCE MODELS**

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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 Technical Report is English.

In this document, meta-model concepts are described in Clause 6 and are identified as **italic*, that is, starting with an asterisk followed by the concept name in italic.

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.

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- withdrawn, or
- revised.

INTRODUCTION

The term "manufacturing" refers to a range of human activities, from handicraft to high tech, and is commonly applied to industrial production, in which raw materials and parts are transformed into products on small to large scale by a series of interconnected processes. In today's manufacturing landscape, manufacturing is no longer characterized as a set of serial processes, but instead as a highly complex set of processes interacting on different time scales, coordinated by a set of supervisory processes to dynamically respond to changing conditions in demands, supply, environment, energy, and other human caused or natural disruptive events.

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 a varied set of customers, suppliers and stakeholders at various stages in the value chain.

Both the IEC SMB and ISO TMB recognized the changing dynamics of manufacturing and the potential opportunities and benefits of developing a reference model for smart manufacturing for both the developers and the users of standards.

The objective of Smart Manufacturing Reference Model(s) (SMRMs) is the development of one or more than one unifying reference model of smart manufacturing to harmonize existing reference models for smart manufacturing. Objective details are described in Annex A.

The plan is to deliver the following outputs:

- 1) TR (Technical Report) A meta-modelling analysis approach to smart manufacturing reference models (this document);
- 2) IS (International Standard) Unified reference model for smart manufacturing (URMSM). (IEC 63339:2024, "*Unified reference model for smart manufacturing*" was developed concurrently; it was published on 2024-10-10).

A META-MODELLING ANALYSIS APPROACH TO SMART MANUFACTURING REFERENCE MODELS

1 Scope

This document uses a meta-modelling approach to identify commonalities among ten smart manufacturing reference models. Each reference model is placed into the context of the meta-model to facilitate analysis of both common and distinct features. Major smart manufacturing reference model topics are identified, and the reference models compared within each topic.

As part of the meta-modelling approach development, a collection of models differing in extent of abstraction characterizes the evolution of a particular smart manufacturing system from the meta-model through a unifying smart manufacturing reference model and successively less abstract domain models to a model for system implementation.

This document presents a range of issues and challenges for further work to specify a high-level smart manufacturing reference model that unifies the concepts and practices identified using the meta-model approach analysis of the smart manufacturing reference models.

2 Normative references

There are no normative references in this document.

3 Terms and 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 terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

NOTE Numbers in square brackets refer to the Bibliography.

3.1.1 business

series of processes, each having a clearly understood purpose, involving more than one person, realized 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 [1], 2.2]

3.1.2 life cycle lifecycle life-cycle

set of distinguishable phases and steps within phases which an entity goes through from its creation until it ceases to exist

[SOURCE: ISO 19439:2006 [2], 3.42, modified – added lifecycle and life-cycle alternatives]

3.1.3

manufacture

any or all of the steps in the design, procurement, screening, testing, production, storage, labelling, packaging or distribution of products and production systems

3.1.4

manufacturing domain

portion of a business dealing with the manufacture of products

3.1.5

meta-model

description of modelling elements for use in constructing models 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], 3.47]

3.1.6

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 may be a subset of a broader model.

[SOURCE: ISO 15704:2019 [4], 3.15, modified – added "simplified, purposeful" and "and relationships".]

3.1.7

reference architecture

set of common architectural elements for a particular domain and their general relationships usable to derive a specific architecture from it in order to fulfil a defined purpose within that domain

3.1.8

reference model

framework for understanding significant relationships among the entities of some environment, and for the development of consistent standards or specifications supporting that environment

[SOURCE: ISO 19165-1:2018 [5], 3.30]

3.1.9

smart

<manufacturing> significant progress in application of technology at a given time characterized by a) fundamental early adoption of novel procedures and processes in a new or already existing application domain, or b) fundamental change of already existing procedures and processes of an application domain

3.1.10

smart manufacturing

manufacturing that improves its 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 collaborates with other domains within enterprises' value chains

Note 1 to entry: Performance aspects include agility, efficiency, safety, security, sustainability or any other performance indicators identified by the enterprise.

Note 2 to entry: In addition to manufacturing, other enterprise domains can include engineering, logistics, marketing, procurement, sales or any other domains identified by the enterprise.

3.1.11

smart manufacturing reference model

SMRM

framework for understanding significant relationships among the entities involved in smart manufacturing, and for the development of consistent standards or specifications that support smart manufacturing

3.1.12

supply chain

set of organizations with linked set of resources and processes, each of which acts as an acquirer, supplier, or both to form successive supplier relationships established upon placement of a purchase order, agreement, or other formal sourcing agreement

[SOURCE: ISO/IEC 27036-1:2014 [6], 3.11, modified – deleted the notes to entry.]

3.1.13

system

combination of interacting elements organized to achieve one or more stated purposes

[SOURCE: ISO/IEC/IEEE 15939:2017 [7], 3.38, modified – deleted the note to entry.]

3.1.14

use case

technique for capturing potential functional requirements that employs the use of one or more scenarios that convey how the system should interact with the end user or another system to achieve a specific goal

Note 1 to entry: Typically use cases treat the system as a black box, and the interactions with the system, including system responses, are as perceived from the outside of the system. Use cases are popular because they simplify the description of requirements, and avoid the problem of making assumptions about how this functionality will be accomplished.

[SOURCE: IEC TS 62443-1-1:2009 [8], 3.2.132]

3.1.15

value chain

entire sequence of activities or parties that provide or receive value in the form of products or services

[SOURCE: ISO 27917:2017 [9], 3.1.4]

3.2 Convention used for term and definition selection

The terms and definitions in 3.1 result from an analysis of word and phrase frequency of use in the TR 1st draft and a belief that for the TR, common meaning for most terms are satisfactory. After reviewing the lexical analysis results, the terms in 3.1 were identified as of sufficient importance and frequency of use to justify definition. After reviewing candidate definitions and discussing the merits of various definitions, this subclause is the result.

Annex C describes the genealogy of the definition of smart manufacturing, and interpretations.

Meta-model concepts are described in Clause 6 and are identified as *italic*.

In subsequent works, particularly those involving SMRMs for specific domains or purposes, additional term definitions are necessary when common meaning is no longer satisfactory for the intended audience of the work.

3.3 Abbreviations and acronyms

AIF RM	Alliance Industrie du Futur Reference Model
AMQP	Advanced Message Queuing Protocol
B2MML	Business to Manufacturing Markup Language
BPMN	Business Process Model and Notation
CCM	CORBA Component Model
CIMOSA	Computer Integrated Manufacturing Open System Architecture
CoAP	Constrained Application Protocol
CPI	Continuous Process Improvement
CPS	Cyber-Physical System
CRM	Customer/client Relationship Management
C4ISR	Command, Control, Computers and Communication of Intelligence, Surveillance and Reconnaissance
DCS	Distributed Control System
DFMA	Design for Manufacturing and Assembly
DMN	Decision Model and Notation
DoDAF	Department of Defense Architectural Framework
EA	Enterprise Architecture
EAETs	Enterprise Architecture and Engineering Tools
EAMS	Enterprise Architecting, Engineering and Integration Methodology
EDF	Électricité de France
EMLs	Enterprise Modelling Languages
EMs	Enterprise Models
EMOs	Enterprise Modules
EOS	Enterprise Operational Systems
ERP	Enterprise Resources Planning
FEAF	Federal Enterprise Architecture Framework
FMS	Flexible Manufacturing System
GEMCs	Generic Enterprise Modelling Concepts
GERA	Generic Enterprise Reference Architecture
GERAM	Generalized Enterprise Reference Architecture and Methodology
GFB	General Function Block (IVRA)
GIM	GRAI Integrated Methodology
GRAI	Graphs with Results and Actions Inter-related
HMI	Human Machine Interface
ICT	Information and Communication Technology
IFAC	International Federation of Automatic Control
IFIP	International Federation for Information Processing
IIC	Industrial Internet Consortium
IoT	Internet of Things
IIoT	Industrial Internet of Things
IIRA	Industrial Internet Reference Architecture
IMSA	Intelligent Manufacturing System Architecture

IVI	Industrial Value chain Initiative
IVRA	Industrial Value chain Reference Architecture
KVM	Kernel-based Virtual Machine
MEMS	Microelectromechanical Systems
NEMS	Nanoelectromechanical Systems
MES	Manufacturing execution system
MOM	Manufacturing Operation Management
MQTT	Message Queuing Telemetry Transport
NATO	North Atlantic Treaty Organization
NB-IoT	Narrowband IoT
OMG	Object Management Group
PEMs	Partial Enterprise Models
PERA	Purdue Enterprise Reference Architecture
PLM	Product Life cycle Management
PMML	Predictive Model Markup Language
POM	Production Operation Management (SSIF)
QIF	Quality Information Framework
RAMI 4.0	Reference Architecture Model Industrie 4.0
RESTful	Representational State Transfer based web services
SCADA	Supervisory Control and Data Acquisition
SCM	Supply Chain Management
SCOR	Supply Chain Operations Reference
SM	Smart Manufacturing
SM2	Smart Manufacturing Standards Map
SM2TF	Smart Manufacturing Standards Map Task Force
SMRM	Smart Manufacturing Reference Model
SMS	Smart Manufacturing Standards (NIST)
SMU	Smart Manufacturing Units (IVRA)
SOAP	Simple Object Access Protocol
SSIF	Scandinavian Smart Industry Framework
TOGAF	The Open Group Architecture Framework
URL	Uniform Resource Locator
URM-MM	Unified Reference Model – Map & Methodology

3.4 Conventions used for selected references

The ISA 95 standard from the International Society of Automation has been the base for the IEC 62264 (all parts), the ISA 95 model is included in IEC 62264 (all parts) and when a reference is made to ISA 95, the subject of the reference is found in IEC 62264. In technical literature they are often mentioned together.

The ISA 88 standard from the International Society of Automation has been the base for the IEC 61512 (all parts), the ISA 88 model is included in IEC 61512 (all parts) and when a reference is made to ISA 88, the subject of the reference is found in IEC 61512. In technical literature they are often mentioned together.

4 Smart manufacturing (SM)

4.1 Introduction to and vision of SM

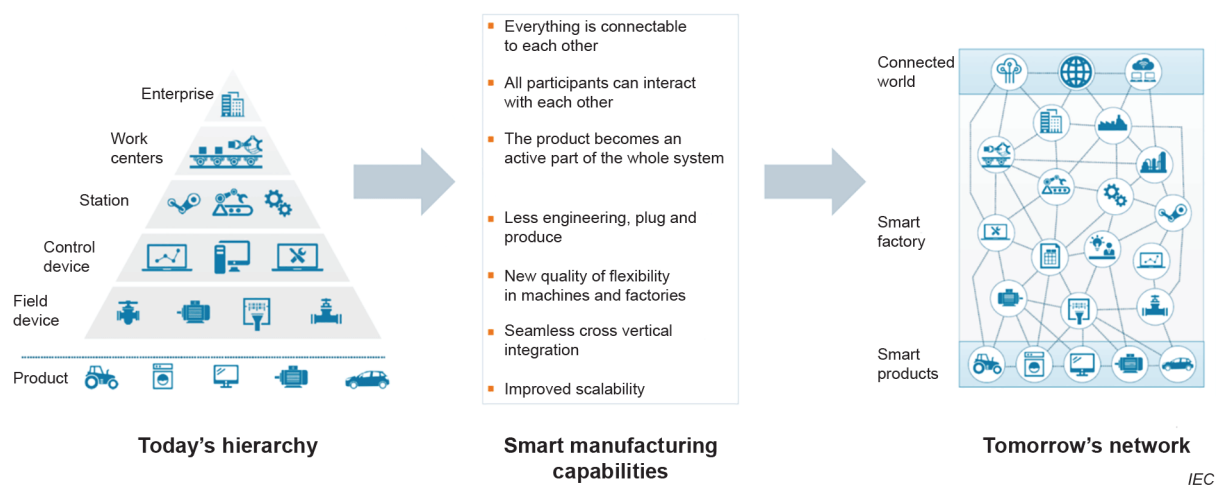
The manufacturing industry has utilized computer processing functionalities for many years; with the Information and Communication Technology (ICT) development, information is now available in a fundamentally new way. Data and computer processing power is now relatively inexpensive and easily available across organizations and life cycle phases, enabling new solutions based on new forms of digital information and communication. These new forms move industry towards perceiving digital information as capital, with the goal of using and exploiting information across traditional boundaries as successfully as possible.

Digital information reaches its full potential, when it is trustworthy, securely managed and possesses documented quality. These characteristics in turn require agreements on how to represent information in a standardized way with well-defined semantics and syntax to ensure unambiguous interpretation of shared information and avoid isolated islands of information.

The vision of SM has products self-aware as a part of the automation solution, and technologically advanced devices capable of computational work and autonomous decision-making. Self-improving, adaptive decision support systems interact with humans in the socio-technical interoperation between all the actors and resources involved in product design, manufacturing and operation. Outcomes of processes are measured, analysed and used to predict and adjust plans; reality is reflected in digital models that learn based on outcome; and manufacturing resources are intelligent and communicate securely with each other and products in the process. Further, the availability and combination of information create new services and ecosystems for collaboration [10]¹.

4.2 SM characteristics and differences from conventional manufacturing

Many distinct SM functions are already implemented, often partially implemented and isolated, on a more or less proprietary technological basis, and with a significant need of engineering efforts. One big difference now is the improved ICT capability and affordability for a wide range of stakeholders, enabling information to be captured, analysed and shared. Connectivity among resources allows all of them to be more aware and intelligent. SM can also be seen as the transition from a centralized to a distributed system paradigm, where components and actors interact in the factory regardless of hierarchy levels (see Figure 1).



SOURCE: [11], used with the permission of the authors.

Figure 1 – Example of transition from centralized to distributed system paradigm

¹ Numbers in square brackets refer to the Bibliography.

To reach the features of flexibility, scalability and less engineering, some of the intelligent uses of processes and resource capabilities considered are:

- trustworthy communication, e.g. secure connectivity, message privacy;
- self-integrating resources, e.g. autonomous negotiation, situation awareness, safety;
- change resilience, e.g. adaptable configuration, graceful failure recovery;
- computational efficiency, e.g. data stream analytics, updatable semantics;
- service composition, e.g. functional transparency, on-line assembly;
- model-based development, e.g. stakeholder viewpoints, model views;
- model-based operation, e.g. digital representation, simulation.

These capabilities form the basis for SM characteristics that differ from conventional manufacturing:

- **Autonomous networking:** Networks of manufacturing resources that are autonomous and capable of controlling themselves in response to different situations.
- **Servitisation:** Manufacturing capability results from supplier-based integration of production systems and devices with value adding services often provided in real-time and based on analytics of measured data.
- **Intrinsic built-in product features:** The smart products are self-aware, can be uniquely identifiable in their respective contexts and are located at all times. A smart product knows how it can be made optimally. Smart products can communicate with other entities using explicit agreements and clear policies exist about what to communicate to whom, and when.
- **Enhanced product/production flexibility:** The design, configuration, ordering, planning, production, operation and recycling phases incorporate individual customer and product specific features. New production methods, such as 3D printing, Artificial Intelligence and mobile robots support lot size 1 with the economy of mass production.
- **Environmental sustainability:** Improved and precise management in logistics, manufacturing, and maintenance results in lower use of energy and materials, and lower waste and pollution while improving resilience to constantly changing situations.
- **Scalable, flexible, distributed manufacturing:** Manufacturing at point of use enables new and innovative utilization of manufacturing supply chains to meet market demands.
- **Affordability for small and medium enterprises:** Decreased cost enables smaller stakeholders to benefit from the technologies and being partners in value networks.
- **Flexible work organization and new value creation:** New business models and intercompany value networks emerge throughout life cycles arising from the ability to share and control digital representations.

4.3 Essential concepts and enabling technologies for SM

4.3.1 SM categories

Manufacturing methods and enabling ICT technologies evolve continuously and more or less in parallel. Thus, three distinct categories are used to describe the SM methods and technologies: generic methods, their applications in the manufacturing domain, and the enabling ICT technologies.

4.3.2 Generic methods

Generic methods are based on ICT and are applicable in many domains; they can include:

- Standardized digital representations of physical entities interconnected in an information framework that provide an integrated view of lifecycles (digital twin and digital thread [12]).
- Measures for analysing and aggregating large volumes of data into information.
- Measures for automating reasoning and decision making.

- Industrial internet of things with infrastructure for interconnecting distributed entities, inside and outside of the organization.
- Information standards, both traditional standard information models and emerging communication protocols based on service-oriented architectures.
- Fast, functionally safe, available communication networks with robust, secure communication infrastructure to assure safety, privacy, self-configuration and ease of use.
- Mechatronic systems where physical and software components are deeply intertwined (CPS).

4.3.3 Applications in the manufacturing domain

Methods based on ICT, combined and applied in the domain of manufacturing, are listed below.

- Digital factory: digital technology to model, communicate and operate the manufacturing process. It supports the design, the configuration, the monitoring and the control of a production system.
- Microelectromechanical systems (MEMS): technology of microscopic devices, particularly those with moving parts, which merges at the nanoscale into nanoelectromechanical systems (NEMS) and nanotechnology.
- Advanced robotics and smart machines: autonomously operating, communicating, adaptive and possibly learning systems able to solve problems and make decisions independent of people when allowed.
- Human-machine interaction: design and implementation of robotic systems interacting with humans have a specific concern for the safety and well-being of the human workers who interact with the advanced robotic systems and smart machines.
- Smart sensors: integration of physical sensing devices and associated electronics/software to provide functions beyond those necessary for generating a correct representation of a sensed quantity.
- Additive manufacturing: various processes in which material is joined or solidified under computer control to create a three-dimensional object.
- Predictive maintenance: Sensing and analysis of measured data for systematic detection of trends and prediction of incipient faults to prevent failures from occurring.

4.3.4 Information and communication technologies

Many recent and emerging technologies under the rubric of ICT are impacting opportunities for SM. The technologies briefly described below will continue their evolution and can emerge with new labels in the future; they include:

- Edge computing: methods for optimizing computing systems by placing control in applications/services that directly contact the physical world, rather than in central nodes.
- Artificial intelligence: methods to make computer systems able to perform tasks normally requiring human intelligence, related to automated planning and reasoning, recognition of patterns, knowledge representation and learning.
- Big data: technologies addressing data sets that are so large and complicated that traditional data-processing application software is inadequate for management and utilization of the data.
- Cloud computing: technology that enables ubiquitous access to distributed and shared pools of system resources and services with minimal management effort.
- Augmented Reality (AR): interactive experience of a real-world environment whose elements are "augmented" by computer-generated perceptual information.
- Virtual reality (VR): interactive immersive computer-generated experience taking place within a simulated environment.

- Business intelligence: strategies and technologies used for the data analysis of business information, for example reporting, online analytical processing, data mining, business performance management, and benchmarking.
- Secure computing: methods and technologies such as block chains, that aim for secure and resistant storage by managing data as a growing list of records, called blocks, linked using cryptography.
- Wireless Wide-Area Network (WWAN): communications with short (sub millisecond) response latency and high (over 10 Gb/s) transmission speeds to enable real-time interactions among many automated mobile agents.
- Low-Power Wide-Area Network (LPWAN): long-range communications at a low bit rate that is considered useful for private sensor- and smart device networks; its low power enables sensors operated on a battery with data rate ranges from 0,3 kbit/s to 50 kbit/s per channel.
- Ethernet extensions for Time-Sensitive Networking (TSN): agreements on time synchronization, processing and forwarding of communication packets, and selection of communication paths, to realize low latency and high availability in the presence of traffic with very diverse requirements, on the same media, and in a common way.
- Software Defined Networking (SDN) and Network Functions Virtualization (NFV): technologies enabling the communication networks to become programmable and agile by distributing the communication intelligence towards control nodes instead of physical routers.

NOTE Many other examples of initiatives differentiating smart manufacturing are available [13], [14], [15].

5 Smart manufacturing reference model (SMRM)

5.1 Need for a SMRM

An SM system is a complex system of systems, where many collaborating, competing and possibly conflicting systems are connected in federated or integrated ways, or both. The system development and maintenance activities are also complex and require appropriate standardized interfaces and harmonized business processes to reduce that complexity. Modelling provides systematic methods supporting the whole life cycle of system development, usage and retirement, allowing all the SM benefits while managing the complexity. An SMRM thus provides a framework for preparation of interoperability as well as guidance for architecture derivation and system design. To summarize, SMRM can be used by SM system developers and users to support the development process, and by SM standard developers to ensure coherence and compatibility in the developed body of standards.

5.2 Objectives in more detail

The primary objectives for SMRMs are:

- 1) guidance and support for the development and use of standards for SM;
- 2) guidance and support for the development of SM systems.

An SMRM is a reference for standard mapping activities. The objectives of standard mapping serve the development of standards by:

- understanding of the scope and definition of SM;
- support to locate existing standards;
- identification and promotion of the development of interoperable sets of standards;
- identification and closure of gaps in standards;
- identification of overlaps and determination and selection of solution;
- minimizing the number of standards used;
- identification of sub-sets of a standard for the rapid conversion of partial contents for SM.

The objectives of SMRM for SM system development are:

- support to identify the scope of SM systems;
- support to develop SM systems utilizing existing standards;
- support to configure SM systems as open eco-systems by combining multiple sub-systems;
- support to optimize processes in SM covering full value-chains;
- support of standardized interfaces between the product and the production systems at all phases of life cycle.

5.3 SMRM focus

By establishing a common set of entities and relationships, SMRM provides guidance towards the specification of aspects of manufacturing, from conceptualization of a manufacturing system through its retirement or disposal, and of products within the domain of manufacturing.

SMRM identifies those aspects of manufacturing and intelligence to apply when developing an SM model for a particular industrial enterprise.

5.4 Reference modelling

Modelling is a very effective approach to systematize system development and operation activities by use of advanced information technology. A reference model provides insight into the aspects of a system to consider when developing a new system or modifying an existing system and provides mechanisms for conducting that development or modification. Reference models provide a common basis for the development of individual systems and enable their interpretation as a whole system by reuse of the common characteristics of the individual systems.

SMRM specifies relevant aspects of manufacturing with appropriate abstraction, including their constituent activities, processes, resources and information, and their relationships. Starting from a general SMRM, models that are more specific can be derived in a systematic manner for achieving the target system configuration and implementation.

Clarification and standardization of SMRM at various abstraction levels are necessary to improve development processes efficiency by reusing constituent assets in system development and operations. SMRM can also be used as a guide for effective use of existing standards and finding gaps for missing standards.

5.5 Usage of a reference model: the OSI model

The Open Systems Interconnection model (OSI model) [16] [17] is a well-known example of a reference model that had an enormous beneficial effect on the development of advanced communications.

5.6 SMRM harmonization needs

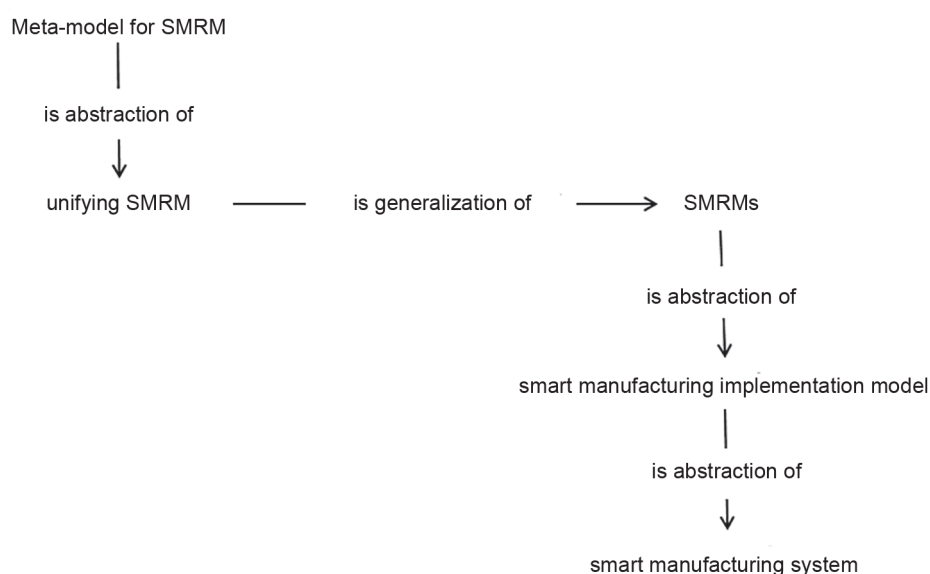
SM systems are developed worldwide, leading to many possible system representations and reference models, each intended for various purposes. As shown in Figure 21, the numerous submissions from different national bodies, technical committees and organizations clearly indicate the diversity of contributions for SMRMs and expose the need to harmonize those models in order to achieve a unified and general understanding about SM systems.

To begin this harmonization, an analysis was conducted on the contributions for SMRMs and the result revealed several common and essential features of them in both graphical form and textual content. Because these features of the various SMRMs often use different representational styles, i.e. structural arrangements and terminology, a "meta-model" concept is proposed to represent these features uniformly with an abstract language applicable for expressing the common concepts and relationships of various individual SMRMs.

5.7 SMRM abstraction stack

The meta-model for SMRM is for use when specifying the unifying SMRM. In Figure 2, the unifying SMRM is a unifying model applicable across many domains, which can be resolved from a generalization of SMRMs of particular manufacturing domains. The unifying SMRM can also be used to create very purpose specific SM models, again by specializing the SMRM first to create a reference model for the particular purpose and then using that specialization. Instantiation of the elements of a specialized SM model results in an implementable model for a particular SM initiative.

Figure 2 shows the SM abstraction stack.



IEC

Figure 2 – SMRM abstraction stack

The meta-model for SMRMs is detailed in Clause 6. Examples of mapping it to some of the submitted specific SMRMs are used for explanation and validation of the meta-model in Clause 7.

6 SMRM meta-modelling approach

6.1 General

The intent of the meta-model is to provide a meta-language for representing concepts and relationships to be used by standards developers as they identify and document a SMRM. The meta-model specified here is an abstraction of the concepts and relationships evident in the contributions for SMRMs. Because the meta-model needs to be useful for discussing this wide range of models, the meta-model is rather abstract and imprecise, sometimes stretching our conventional word meaning to extend coverage for different situations. The concepts of meta-modelling are described in Annex D.

Use cases are a critical approach to understanding the ways in which processes, information, resources, and organizations operate for successful manufacturing today and in the future. In addition to capturing the utility of use cases, using guides similar to those created using IEC 62559 (all parts) [18], the meta-model utilizes concepts from ISO/IEC/IEEE 42010 [19] and ISO 15704:2019 [4].

6.2 Objectives

The objectives of defining a meta-model for the SMRM aim to:

- capture the essence of each contribution for SMRM;
- integrate discussion points articulated by participants over the course of many meetings;
- avoid using terminology lacking consistent use among the contributions for SMRM;
- provide a consistent representation for SMRMs;
- include concerns of both standards developers and standards users;
- provide information for both technical and marketing presentations.

6.3 Assumptions, constraints and guidance

6.3.1 Assumptions

The following assumptions result from discussions and a need for a concise way to characterize aspects of SM.

- 1) Contributions provided by experts representing national standards bodies form the basis for the meta-model.

NOTE 1 This assumption also includes a very general notion of model, which can be formally defined or informally conceived.

- 2) The specificity of the meta-model is constrained by the need of the unifying SMRM to allow for the wide variety of content types in the SMRMs.

NOTE 2 Since a reference model will likely be specialized for a domain or purpose, flexibility in content is essential. The number of aspects expected for SM is very large, approaching uncountable.

- 3) Model coherence with intended purpose requires an expressed commonality among constituent modelling elements and alignment to purpose.

NOTE 3 To efficiently examine and represent different collections of SM aspects, each collection needs to be coherent, i.e. each collection has at least one expressed feature common to each of its constituents, which binds them into a meaningful collection.

- 4) Collection of information elements does not imply ordering of information elements.

NOTE 4 Placing aspects into a collection based upon some common features does not necessarily impart an ordering of those aspects within that collection. As a practical matter, most collections of the submitted SMRMs do have at least a partial ordering of constituents for at least one common feature, but many collections have partial ordering for several common features.

- 5) The meta-model consists of language concept specifications (as detailed in 6.4.2) and propositions relating those concepts to each other (as detailed in 6.4.3).

NOTE 5 While the formal meta-model is a textual expression of concept specifications and the propositions among them, a visualization is possible using a variety of drawing tools. However, visualization can fail to capture the particulars of the meta-model, i.e. text is still necessary to explain some consequences of the meta-model representation.

6.3.2 Constraints

The following constraints result from discussions and a need for a concise way to characterize aspects of SM.

- 1) Meta-language concept terms and relationship labels are used consistently.
- 2) Expressed concepts and relationships do not conflict with the contributions for SMRMs.

6.3.3 Guidance

The following guidance results from discussions and a desire to link the meta-model to established practice.

- 1) Develop the meta-model using guidance from ISO/IEC/IEEE 42010 [19] and ISO 15704:2019 [4].
- 2) Introduce new terms, not used by contributions for SMRMs, for critical concepts.
- 3) Keep the "picture" relatively simple, e.g. ignore relationship cardinality, and use short labels while using a limited number of concepts and relationships.

6.4 Concepts

6.4.1 General

Concepts and their relationships are the primary items abstracted from the contributions for SMRMs as they pertain to the meta-model based upon the guidance.

The meta-language concept terms are starred and italicized. The meta-model concepts are modelling elements used in the meta-language that is the meta-model.

6.4.2 Concepts of the meta-model

6.4.2.1 **Smart_Manufacturing_domain*

The **Smart_Manufacturing_domain* consists of those entities and processes that are the subject of this document.

6.4.2.2 **stakeholder*

A **stakeholder* is either a developer of a reference model, i.e. **stakeholder* (standards developer), or a user of a reference model to craft their own particular SM model, i.e. a **stakeholder* (SM practitioner). One individual can have **stakeholder* roles as standards developer and SM practitioner.

6.4.2.3 **perspective*

A **perspective* is the orientation of a **stakeholder* within an SM domain, where each **stakeholder* or group of **stakeholders* has its own **perspective* arising from their knowledge, expertise, responsibility, authority and accountability relative to a SM effort. Since the meta-model distinguishes two groups of **stakeholder*, two different primary **perspectives* occur because of the different orientations. The **perspective* (SM practitioner) is the origin of one or more **use_case*, the purpose of which is to explain a specific collection of **concern* (practitioner) relative to SM, and the **perspective* (standards developer), as the holder of the modelling expertise, is the origin of one or more **viewpoints*.

6.4.2.4 **use_case*

A **use_case* is a specification of **stakeholder* (SM practitioner) needs based upon a SM scenario, which identifies a situation, relevant concerns regarding that situation, and desired outcomes.

NOTE Since an **aspect* is an expression of a **viewpoint* and a **viewpoint* is an expression of a **use case*, a **use case* is conceptually a basis for a SM **aspect*.

6.4.2.5 **concern*

A **concern* is a subject that results from a **perspective* or **use_case*. Since the meta-model distinguishes two different **perspectives*, there are two corresponding sets of **concerns*. The **concern* (standards developer) generally relates to the means and methods for specifying a coherent **viewpoint* that captures all relevant **concerns* for assuring that a well-known set of **concerns* within the relevant domain are included. The **concern* (SM practitioner) generally relates to more domain specific and purpose specific information, methods, and expectations for modelling outcomes, often where a **use_case* provides an explanation of a group of associated **concern* (SM practitioner).

6.4.2.6 **viewpoint*

A **viewpoint* is a collection of **concerns* and specification of one or more kind of models or methods for providing necessary and sufficient information content for expressing the harmonization, understanding and resolution of those **concerns*, most often by the projection of **model_content* as an **aspect* of a SM domain. The **viewpoint* concept has two elaborations, one as **viewpoint* (simple) for use in specifying **concern* resolution for which a single **model_kind* can be used to project a **view* satisfying the **viewpoint* (simple) specification. The second, designated as **viewpoint* (complicated), is for use in specifying **concern* resolution that requires more than one **model_kind* from which projections need to be composed to satisfy the **viewpoint* (complicated) specification. For both situations, **viewpoint* (simple) and **viewpoint* (complicated), the resulting resolution is designated as an **aspect*, which is an expression of the **viewpoint*.

NOTE The meta-model resists the temptation to use "complex" to designate the alternative to "simple" because a modelling paradigm rarely is able to address a "complex" situation with the precision expected for a solution to a manufacturing problem. Most "complex" situations are not decomposable into "simple" situations for effective modelling while "complicated" situations can always be decomposed. Therefore, a "complex" **viewpoint* is treated as an imprecise **viewpoint* (simple) for the purpose of identifying a suitable **model_kind* and resulting **view* and **aspect*.

EXAMPLE A **viewpoint* (simple) specifies only one **model_kind*, e.g. an information model, from which the specified view is projected; but the viewpoint can specify several views and become a **viewpoint* (complicated) if all of the specified views projected from the information models are not suitable for composition based upon common elements. A **viewpoint* (complicated) can also specify more than one **model_kind*, e.g. an information model, a process model that uses elements of the information model, and a simulation that provides an execution trace for the process model in operation; these **model_kinds* can be difficult to compose into a single representation, e.g. a dashboard monitoring the process.

6.4.2.7 **model_kind*

A **model_kind* is a modelling paradigm for expressing concepts and relationships among concepts. The specifier of a **viewpoint* selects a **model_kind* suitable for creating a **model*, which, when populated with information, is suitable for projecting a **view* that satisfies the **viewpoint* specification or identified part of the specification. Modelling paradigms range from information models, through simulation models, to conceptual sketches.

6.4.2.8 **model*

A **model* is a specification or representation of concepts and the relationships among those concepts often based upon a formal syntax and semantics for the words or symbols used. This formality enables disparate **models* to be integrated or composed into single specifications or representations.

6.4.2.9 **model_content*

The **model_content* of a **model* is the collection of labels and values assigned to concepts in the **model* as information provided by instantiation of the **model*. **Model_content* can be static (e.g. result of database query), or dynamic (e.g. a real-time trace of values resulting from a simulation).

6.4.2.10 **view*

A **view* is the projection of **model_content* information for the specific purpose of resolving a **viewpoint* (simple) specification.

6.4.2.11 **aspect*

An **aspect* is a **view* or a composition of more than one **view*, where each **view* of **model_content* can be the result of projection from a **model* created using a different **model_kind*. Each **aspect* is usually given a label indicating the specific purpose or topic of the **views* from which it is composed. **aspect* is the foundational concept for understanding a SM domain.

6.4.2.12 **aspect_collection*

An **aspect_collection* is one or more than one **aspect* grouped into a labelled collection. An **aspect_collection* is most meaningful when a relationship among the meanings of the various **aspects* in the collection exists and is articulated for reference. **aspect_collections* provide the basis for representation of the SM domain for a particular purpose.

6.4.2.13 **aspect_collection_coherence_rule*

An **aspect_collection_coherence_rule* constrains or places a criterion rule upon an **aspect_collection*, e.g. ordered or unordered, possessing a common characteristic, sorted by a semantic relationship. **aspect_collection_coherence_rules* bind the individual **aspects* into a representative whole.

6.4.2.14 **alias_label*

An **alias_label* is an alternative designation for **aspect_collection* frequently used by **stakeholders*. The two most common alternatives are **alias_label* (dimension) and **alias_label* (axis).

NOTE Other concepts likely have common alternative designations as well.

6.4.2.15 **facet*

A **facet* is a specification of one or more **aspect_collection* intersecting orthogonally such that some of the intersecting **aspects* from different **aspect_collections* have meaning for a SM domain and contribute to achieving the purpose for which the **facet* exists. When the **facet* has more than one **aspect_collection*, i.e. the **facet* is multi-dimensional, only certain sub-dimensionality can make sense to SM. The purpose of the meta-model is to facilitate the understanding of those sub-dimensionality that make sense to SM.

6.4.2.16 **facet_composition_rule*

A **facet_composition_rule* constrains or places a criterion upon the juxtaposition of **aspect_collections*, usually pertaining to intersection of specific **aspects* as **model_content_purpose* derived from **views* of SM. **facet_composition_rules* bind the individual **aspect_collections* into a representative whole.

6.4.2.17 **model_content_purpose*

The **model_content_purpose* is the information available at the intersection of **aspects* within a **facet* for SM. These intersections are a conjunction or blending of **aspects* and thus of **viewpoints* and the **concerns* those **viewpoints* entail. Often the content of the intersection leads to interpretation for desired effects.

6.4.2.18 **other_domain*

An **other_domain* is a place holder for collaborators with an SM domain, e.g. engineering, logistics, marketing, procurement, sales. For a particular SM domain, the collaborating **other_domains* can be very specific.

6.4.3 Proposition of the meta-model for SMRM

The full meta-model consists of the concepts described in 6.4.2 and the list of propositions given below. An underlined phrase links two concepts to form a proposition of the meta-model.

- 1) **Smart_Manufacturing_domain* is collaboration with **other_domains*;
- 2) **Smart_Manufacturing_domain* for a particular purpose is represented by one or more than one **facet*;
- 3) **facet_composition_rule* is constraint for **facet*;

- 4) **facet* is one or an intersection of more than one **aspect_collection*;
- 5) **aspect_collection* is conceptualization of one or a collection of more than one **aspect*;
- 6) **aspect_collection_coherence_rule* is constraint for **aspect_collection*;
- 7) **model_content_purpose* is an **aspect* within or interaction of **aspects* within a **facet*;
- 8) **aspect* is expression of **viewpoint* (complicated);
- 9) **aspect* is one or a composition of more than one **view*;
- 10) **view* is expression of **viewpoint* (simple);
- 11) **view* is projection of **model_content*;
- 12) **model* is container for **model_content*;
- 13) **model_kind* is language for **model*;
- 14) **model_kind* is selection by **viewpoint*;
- 15) **viewpoint* is capture of **concern*;
- 16) **use_case* is explanation of **concern* (SM practitioner);
- 17) **viewpoint* is expression of **use_case*;
- 18) **perspective* (SM practitioner) is origin of **use_case*;
- 19) **concern* (SM practitioner) is result of **perspective* (SM practitioner);
- 20) **perspective* (SM practitioner) is orientation of **stakeholder* (SM practitioner);
- 21) **stakeholder* (standards developer/SM practitioner) is participant in **Smart_Manufacturing_domain*;
- 22) **perspective* (standards developer) is orientation of **stakeholder* (standards developer);
- 23) **perspective* (standards developer) is origin of **viewpoint*;
- 24) **concern* (standards developer) is result of **perspective* (standards developer);
- 25) **aspect_collection* is known by **alias_label* (dimension/axis).

6.5 Meta-model for SMRM visualization

A depiction of the meta-model for SMRM is shown as Figure 3. In Figure 3, some concept labels are abbreviated to fit presentation constraints for readability.

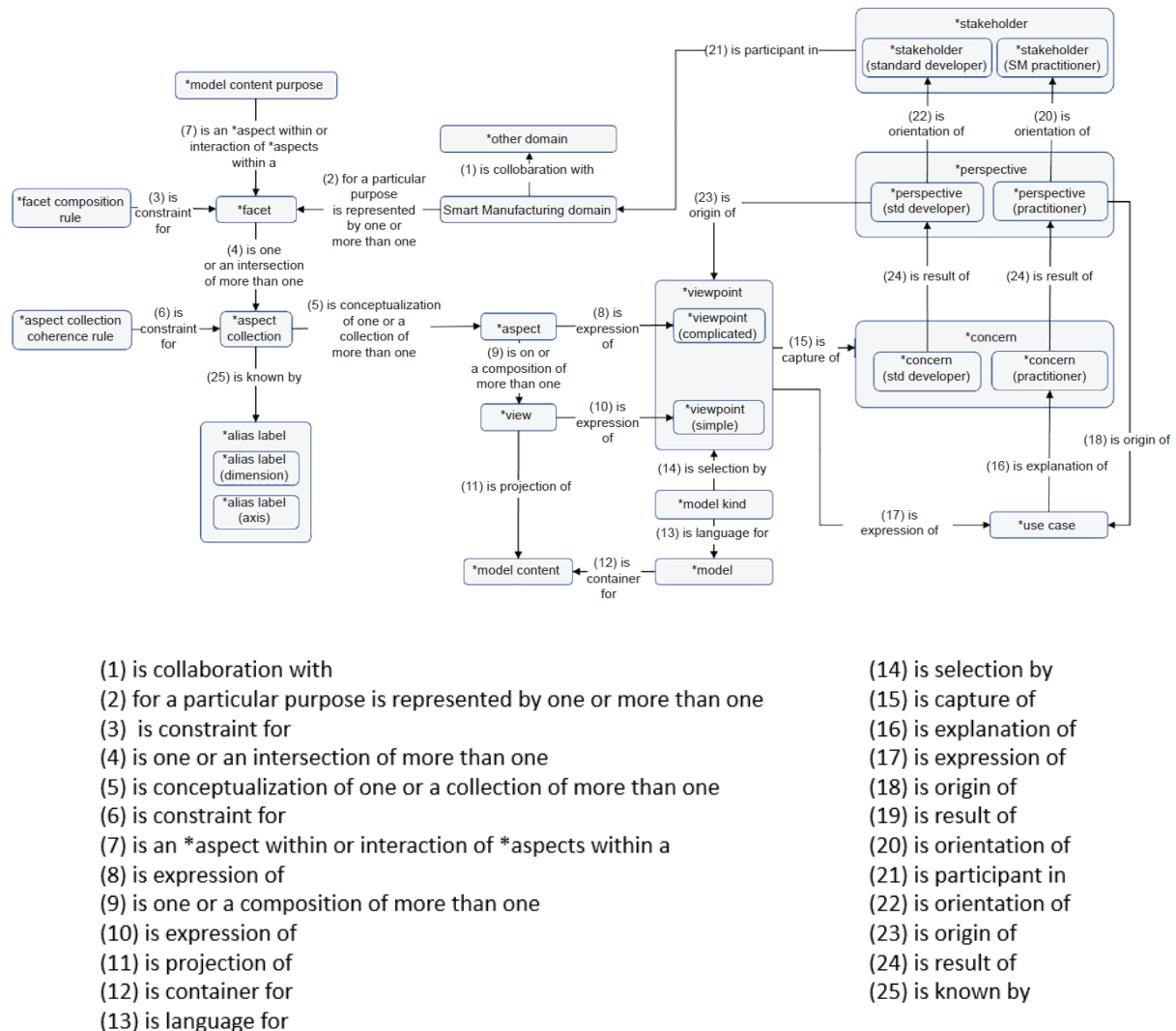


Figure 3 – Meta-model for SMRM

6.6 *Facet_composition_rules and *aspect_collection_coherence_rules

The critical necessity for using the meta-model is clearly specifying the rules governing the composition of a **facet*, i.e. appropriateness of included **aspect_collections*, and the coherence rules for each included **aspect_collection*. These rules are not part of the meta-model, but rather, they are statements about the SMRM, which provides the primary guidance for assembling modelling outcomes into representational form for the purpose of display and examination of interactions.

These rules need to be restrictive enough to constrain **aspect_collections* and **facets* within semantically relevant boundaries yet flexible enough to accommodate known examples of SMRMs. Since many different conceptualizations for SMRMs exist already, care is necessary in selecting the cohesion and composition rules for a particular modelling effort to avoid conflicting rules within the rule set.

To enable the creation of useful SMRMs or instances thereof, the SMRM effort needs to decide what kind of rules apply, both for the **facet* composition, i.e. which **aspect_collections* to

include, and for each **aspect_collection*, i.e. what constitutes the coherence rule set to which the **aspect_collection* conforms.

The **aspects* within an **aspect_collections* need to have coherence, i.e. a binding together based upon some common feature, semantic model or modelling purpose that is described as part of the documentation. One approach to identifying the extent of binding is to use an N2 (N-squared) diagram technique that provides a way to specify both existence of and extent of interaction between **aspects*. Other approaches can be just as effective.

However it is accomplished, the rules by which an **aspect_collection* is created need to be specified.

The **aspect_collections* of a **facet* need to be composed orthogonally so that meaningful examination of interactions between intersecting **aspects* can occur. The orthogonality provides for each **aspect* of one **aspect_collection* to intersect all **aspects* of the other **aspect_collections* in the **facet*. The utility of a **facet* lies in examining and understanding these intersections.

**facet* composition not only determines the **aspect_collections* to intersect but it also determines the way in which the **facet* appears to the user. For example, SSIF has a transparent 3D space so that the user "sees" the three surfaces furthest from them and thus the "inside" of the intersecting **aspects_collections*, while RAMI [20] [21] and IMSA [22] have an opaque 3D space so that users "see" the three surfaces closest to them and thus the "outside" of the intersecting collections. Both perspectives require annotations to identify particular intersections of **aspects*.

These rule sets are not part of the meta-model itself. The SMRM articulates these rule sets in three ways: 1) as mandatory sets for **aspect_collection* coherence and **facet* composition; 2) recommended sets for **aspect_collection* coherence and **facet* composition; and 3) optional sets for **aspect_collection* coherence and **facet* composition.

Rules can range:

- 1) from time ordering for life cycle **aspect_collections*;
- 2) to nesting of **aspect_collections*;
- 3) to higher order **facets* with more than 3 **aspect_collections* to disjoint partitioning of **aspect_collections*;
- 4) to avoidance of one **aspect* appearing in more than one **aspect_collection* of a **facet*, etc.

6.7 Utilizing the meta-model concept of use case

6.7.1 General

Practitioners often utilize the concept of use case to articulate stakeholder concerns based upon their particular perspectives. This subclause describes the relationships involving a **use_case* and the role **use_cases* exhibit in the meta-model of SMRM. This description is the result of analysis on relationships among related components of multiple different reference models.

Figure 4 depicts segments of the meta-model as distinct areas. On the left are the representational features, in the centre are the modelling content features, and on the right are the **stakeholder* related features to be handled by the modelling activities. Among those **stakeholder* related features are the **use_cases* that originate from **stakeholders* expressing **concerns* from their respective **perspectives*.

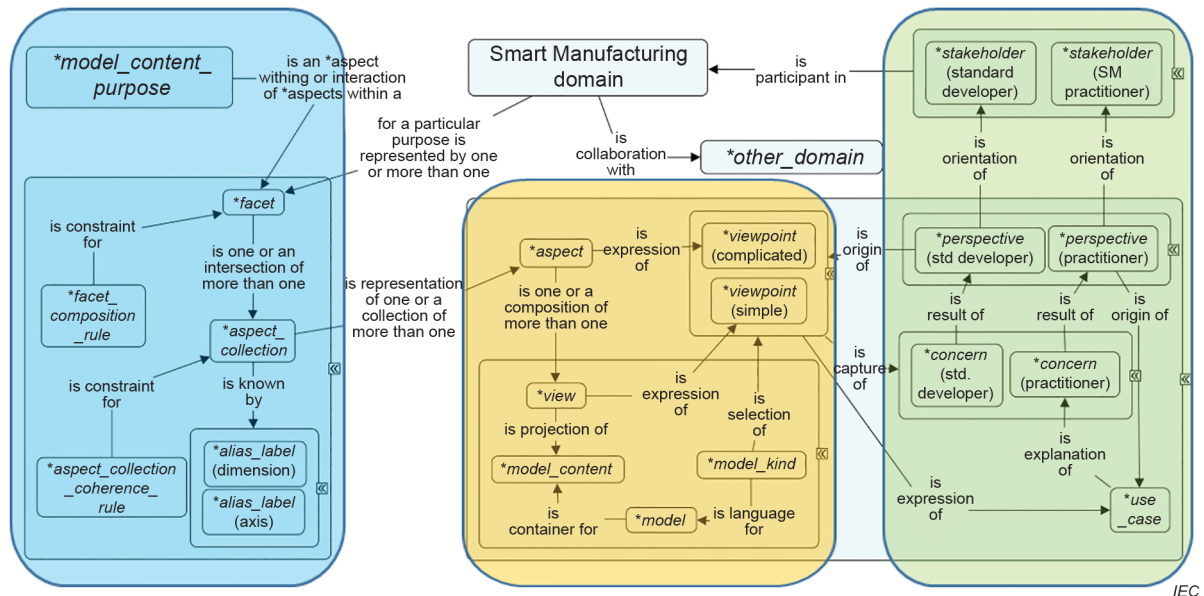


Figure 4 – Segments of the SMRM meta-model

6.7.2 *Use_cases for articulating concerns

While the **perspective* of a standard developer does result in specific concerns, their expression is generally through the **viewpoints* they create to capture the full set of concerns, including those articulated by SM practitioners.

Through analysis of SM views and use cases, the following observations help to align the meta-model with actions modellers can take to align **stakeholder* based concerns with modelling components in a SMRM. The examination of ISO/IEC/IEEE 42010:2022 [19] results in the following assumptions for clarifying relationships among reference model, use-case, and so on:

- "Views and use-cases" could be interpreted as the relation among concern, viewpoint, and view.
- There is a relation between "concern, viewpoint, and view" and SMRMs.

Accordingly, the relationships between **concerns* and **use_cases* are shown in Figure 5, where a **use_case* can cover a single or multiple **concerns*, and multiple **use_cases* could cover the same **concern(s)*. Ideally, combinations of **use_cases* and **concerns* form one or more disjoint sets, thus reducing the overlap in the resulting **viewpoints* and clarifying the distinct **views* from the specified **model_content*.

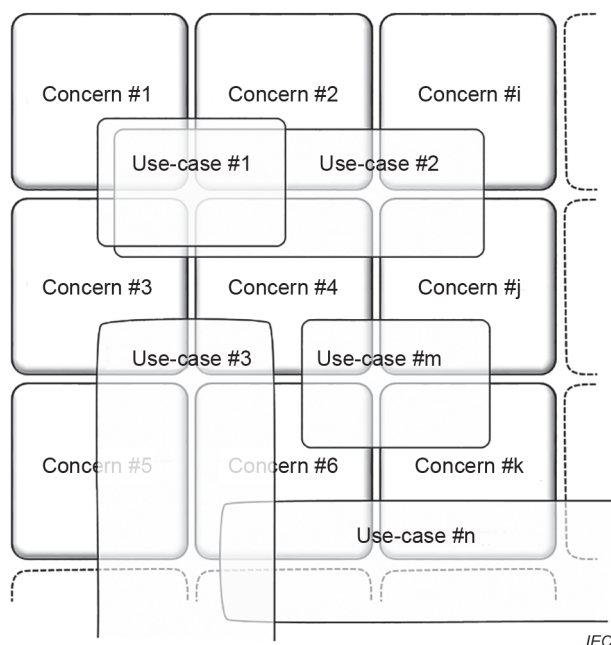


Figure 5 – Relation between typical concerns and use-cases on SM

6.7.3 *Viewpoints capture concerns and specify views

Figure 6 depicts the generation of simple **views* from models specified by **viewpoints*, as **aspects* of a "View" **aspect_collection*. This **aspect_collection* is captured as a vertical axis by several specific SMRM representations, e.g. RAMI and IIC. Each **view* carries **model_content* into the intersections with the **aspects* of other **aspect_collections*. In most situations, the **viewpoint* draws not only **concern* information from a **use_case* but also **use_case* proposals or required means and mechanisms for addressing those **concerns* as **model_content*.

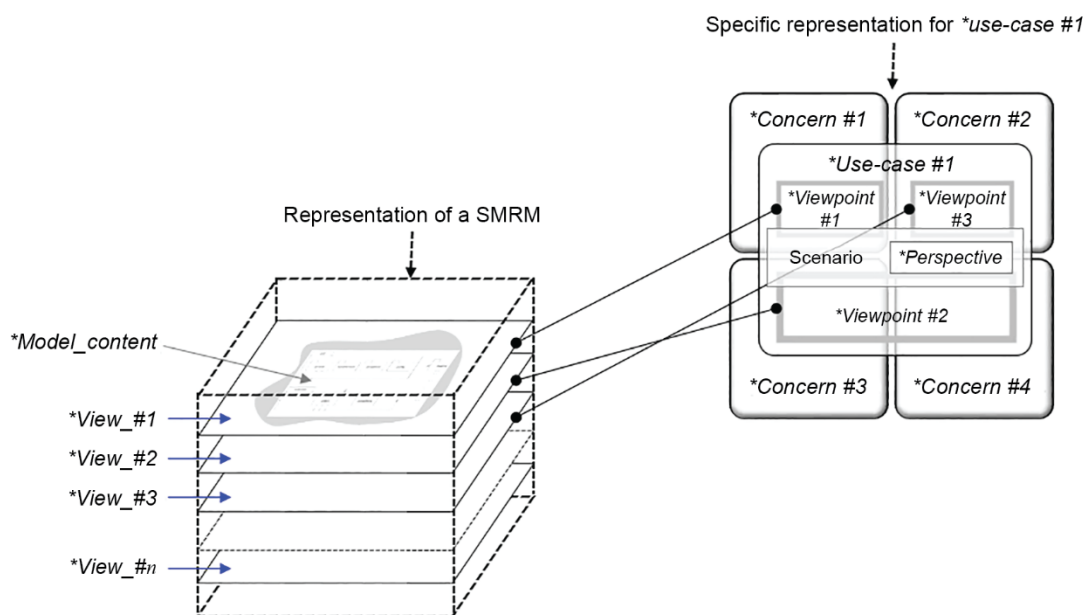


Figure 6 – Example of an implementation model for **use-case #1*

Through analysis, the following relationships among those **use-case* related concepts are:

- A **use_case* covers single or multiple **concern(s)*, and results in a single or multiple **viewpoint(s)* related to each concern.
- A **use_case* is characterized by a scenario articulating **concerns* corresponding to achievement of a specific goal from a particular **perspective*.
- A part of a **use_case* becomes the basis for a **viewpoint* specification that results in one or more **views* of **model content*.
- A characteristic such as location, cover area, and maturity, could be a parameter of each **viewpoint* that changes according to some conditions assigned by the **stakeholder* through the use of a parametric concern **use_case*.

Figure 7 shows the relationship between the related concepts of reference models and stakeholders. Those concepts are categorized into reference model or stakeholder.

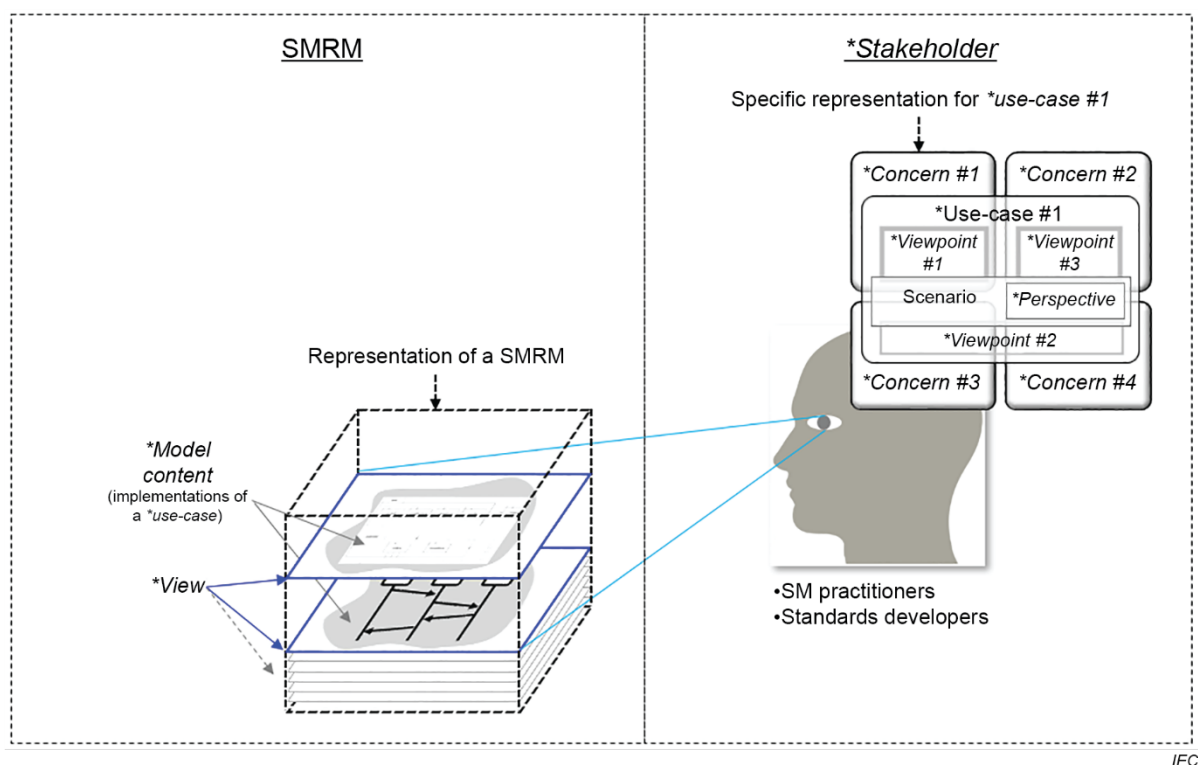


Figure 7 – Illustration about relation between a SMRM and a **stakeholder*

6.7.4 Examples of **model_content_purpose*

All the contributions include an ability to use information arising from the intersection of **aspect_collections* in a **facet* for the benefit of SM architects and designers. The relationship between the "production facility" and the "product" **aspect_collections* is one particular area of interest. There are many other areas that can be explored, once the relationships and the semantics of the information are established. As these relationships are identified, the ability of the "smart" system to respond will provide many more capabilities than are available in today's manufacturing systems.

Several examples were elaborated during the use case exercises:

1) Relationship between product and production equipment (ISO 22400 (all parts) [23])

This was referred to in one of the use case examples, the relationship between KPIs (ISO 22400 (all parts)) in the manufacturing execution system (production information) and the state of the equipment (overall equipment efficiency).

2) Relationship between different aspects of the production facility (ISO 20140 (all parts) [24])

This standard for energy efficiency notes the intersection of product information and the production facility. The amount of energy consumed to make a product can affect not only the product requirements (changing the type of packaging) but also affect the timing of the production management system, by setting up the production line to manufacture a heavy energy consumer to off-peak times for energy consumption.

3) Relationship between human activities and facility environmental settings

In many homes the intelligent thermostat reacts by changing its setpoint based upon interaction with other intelligent devices. Examples could be the sensing of human activity (motion) or changing light conditions, or possibly interacting with outside solar collectors.

As another example of **aspect intersections*, the successive additions of dimensions in the SSIF are considered.

The model content of a SSIF intersection of a 2D matrix is a **facet* of two (2) **aspect_collections* where the 2D intersection involves one **aspect* from each collection, e.g. Product.Material $\cap$ Production.Composition In (Production) – roughly the intersection of the information sets provided by the participating **aspects*. If the former set has material properties and the latter has methods for joining materials, then the intersection desired is the appropriate method for the given properties.

A 3D representation is a **facet* of three (3) **aspect_collections* where the 3D intersection involves one **aspect* from each collection, e.g. Product.Material $\cap$ Production.Composition In (Production) $\cap$ Business.Process, adding the process for applying the method to the material.

A 4D **facet* has four (4) **aspect_collections* where the 4D intersection involves one **aspect* from each collection, e.g. Product.Material $\cap$ Production.Composition In (Production) $\cap$ Business.Process $\cap$ Life cycle.Development, adding the life cycle phase at which the specification of material, method, and process occurs.

The NIST Smart Manufacturing Landscape and the Framework for the Smart Manufacturing Standards Map (SM2) have **model_content_purpose* that is the identification of specific International Standards with particular utility for one or more dimension of SM.

In summary, **model_content_purpose* can emerge from the interaction of **aspects* or be a label for that interaction. A SMRM will need multiple representations of the manufacturing domain space to identify the many kinds of **aspect* interaction expected in the future.

7 Mapping of the contributions for SMRMs to the SMRM meta-model

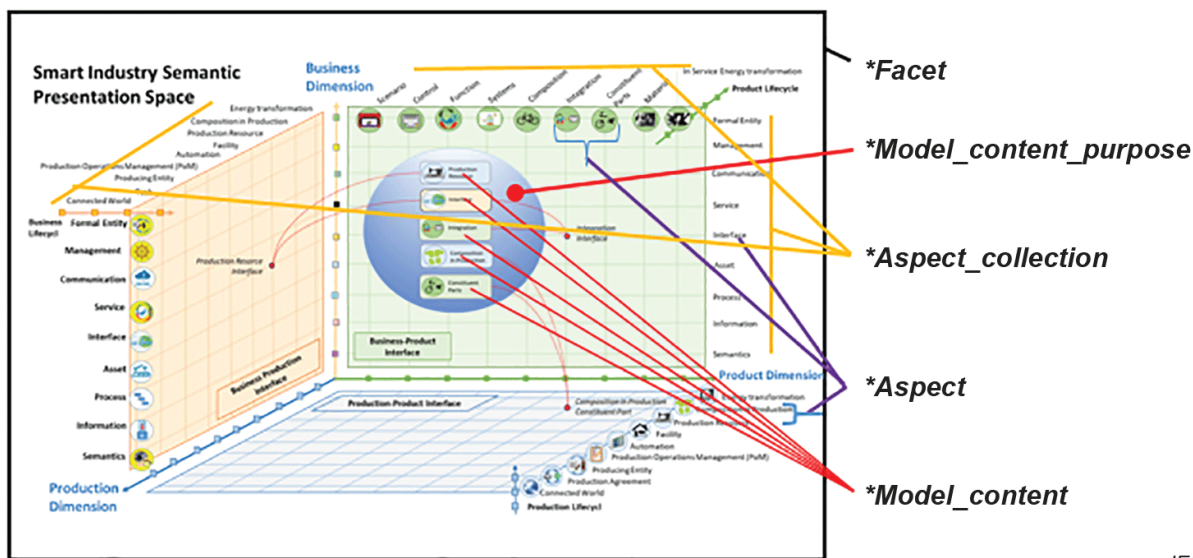
7.1 General

Clause 7 provides several example mappings of the meta-model concepts and relationships to the contributions for SMRMs. To verify the claim of coverage for the contributions for SMRMs, many are 'mapped' in Clause 7 to the meta-model concepts and discussed using meta-model terms in Clause 8.

7.2 Mapping for Scandinavian smart manufacturing model

7.2.1 Graphical depiction of SSIF mapping

Figure 8 shows the mapping for the Scandinavian smart manufacturing model.



IEC

NOTE 1 The **model_content_purpose* shown in this figure is the intersection of the **aspects* Business (Interface), Product (Integration, Constituent Parts), and Production (Production resource, Composition in Production).

NOTE 2 The mapping shown in this figure is to illustrate how the same meta-model configuration can be used to map a submitted model regardless of the submitted model's representation and configuration. It is not intended to represent the details of each model's mapping. Information on the submitted model can be obtained from each model's referenced documents.

NOTE 3 Not every **aspect* is identified.

NOTE 4 Reading of the text in targeted parts of the figure is not essential to understanding.

Figure 8 – Mapping for Scandinavian smart manufacturing model

The content of the **model_content_purpose* is the join of the content of the intersecting aspects, i.e. the **model_content* projected to compose the **view(s)* that comprise each of the intersecting **aspects*. As shown above: Business (Interface), Product (Integration), Production (Production resource, Composition in Production). This intersection is a conjunction of the **viewpoints* that govern the content of the **views* from which it is composed – a kind of super-viewpoint that results from the concerns of many stakeholders.

Of particular interest is the intersection within the model space that results from the intersections occurring on three surfaces, each surface being formed by two different **aspect_collections*, i.e. the Business Production Interface yielding Business Interface and Production Resource, the Business Product Interface yielding Business Interface and Product Integration, and the Production Product Interface yielding Composition in Production and Constituent Part.

7.2.2 SSIF **facet_composition_rule*

Each **aspect_collection* results from an analysis of the particular semantic dimensions of business, production, and product. Each dimension has a set of related core concepts with each concept associated with a set of concerns. These core concepts form the aspects of manufacturing collected into an **aspect_collection*, one collection for each semantic dimension. Each dimension also has a life cycle, represented as an orthogonal axis, with generic life cycle stages. The life cycle view for the Business-, Product- and Production- Dimensions is illustrated by three different 3D-views with one of the dimensions replaced by the Life cycle dimension.

7.2.3 Business dimension **aspect_collection*

The Business semantic dimension **aspect_collection* uses the following coherence rules to bind together the various **aspects*.

Table 1 shows the Business dimension **Aspect* and **Viewpoint* for the SSIF according to the reported **Perspective*. (**Viewpoints* are stated using the perspective of an Oxford dictionary definition rather than a presumably less generic domain stakeholder perspective.)

Table 1 – SSIF business dimension **Aspect* and **Viewpoint* according to **Perspective*

<i>*Aspect</i> (Concept)	<i>*Viewpoint</i> (Selected Definition for Swedish Smart Industry context)	<i>*Perspective</i> (Source)
(Formal) Actor	A (Formal) participant in an action or process	Oxford dictionary
Management	The responsibility for and control of a company or organization	Oxford dictionary
Communication	The imparting or exchanging of information by speaking, writing, or using some other medium	Oxford dictionary
Service	The action of helping or doing work for someone	Oxford dictionary
Interface	A point where two systems, subjects, organizations, etc. meet and interact	Oxford dictionary
Asset	An item of property owned by a person or company, regarded as having value and available to meet debts, commitments, or legacies	Oxford dictionary
Process	A series of actions or steps taken in order to achieve a particular end	Oxford dictionary
Information	Facts provided or learned about something or someone	Oxford dictionary
Semantics	The meaning of a word, phrase, or text	Oxford dictionary

7.2.4 Product dimension **aspect_collection*

The Product semantic dimension **aspect_collection* uses the following coherence rules to bind together the various **aspects*.

Table 2 shows the Product dimension **Aspect* and **Viewpoint* for the SSIF according to the reported **Perspective*. (**Viewpoints* are stated using the perspective of an Oxford dictionary definition rather than a presumably less generic domain stakeholder perspective.)

Table 2 – SSIF product dimension **Aspect* and **Viewpoint* according to **Perspective*

<i>*Aspect</i> (Concept)	<i>*Viewpoint</i> (Selected Definition for Swedish Smart Industry context)	<i>*Perspective</i> (Source)
Scenario	A postulated sequence or development of events	Oxford Dictionary
Control	Determine the behaviour or supervise its running	Oxford Dictionary
Function	Fulfil the purpose or task of (a specified thing)	Oxford Dictionary
System	A set of things working together as parts of a mechanism or an interconnecting network; a complex whole	Oxford Dictionary
Composition	The nature of something's ingredients or constituents; the way in which a whole or mixture is made up	Oxford Dictionary
Integration	Having different parts working together as a unit	Oxford Dictionary
Constituent (<i>Part</i>)	One of the parts that form something	Oxford Dictionary
Material	The matter from which a thing is or can be made	Oxford Dictionary
(<i>In Service Energy</i>) Transformation	A marked change in form, nature, or appearance (<i>of energy for Products during the In-Service Phase</i>)	Oxford Dictionary

7.2.5 Production dimension **aspect_collection*

The Production dimension **aspect_collection* uses the following coherence rules to bind together the various **aspects*.

Table 3 shows the production dimension **Aspect* and **Viewpoint* for the SSIF according to the reported **Perspective*. (**Viewpoints* are stated using the perspective of an Oxford dictionary definition rather than a presumably less generic domain stakeholder perspective.)

Table 3 – SSIF production dimension **Aspect* and **Viewpoint* according to **Perspective*

<i>*Aspect</i> (Concept)	<i>*Viewpoint</i> (Selected Definition for Swedish Smart Industry context)	<i>*Perspective</i> (Source)
Connected (World)	Brought together or into contact (Global digital) so that a real or notional link is established	Oxford dictionary
(Production) Agreement	A negotiated and typically legally binding arrangement (regarding production) between parties as to a course of action	Oxford dictionary
(Producing) Actor	A (Producing) participant in an action or process	Oxford dictionary
Production Operations Management	Planning, coordination and controlling of an organization's resources to facilitate the production process. POM is an extremely important management area. Issues such as the location of production facilities, labour and transportation costs, and production forecasting are extremely important considerations	Dictionary of Business Terms
Automation	The use or introduction of automatic equipment in a manufacturing or other process or facility	Oxford dictionary
Facility	A place, amenity, or piece of equipment provided for a particular purpose	Oxford dictionary
(Production) Resource	A stock or supply of money, materials, staff, and other assets that can be drawn on by a person or organization in order to function effectively (In production)	Oxford dictionary
Composition in (Production)	The nature of something's ingredients or constituents; the way in which a whole or mixture is made up (In production)	Oxford dictionary
(Production) Energy transformation	A marked change in form, nature, or appearance (of energy for the supply, production and distribution of product)	Oxford dictionary

7.2.6 Space Time dimension (Life cycle) **aspect_collection*

The Space Time dimension **aspect_collection* uses the following coherence rules to bind together the various **aspects*.

Table 4 shows the Space Time dimension **Aspect* and **Viewpoint* for the SSIF according to the reported **Perspective*. (**Viewpoints* are stated using the perspective of an Oxford dictionary definition rather than a presumably less generic domain stakeholder perspective.)

Table 4 – SSIF Space Time dimension **Aspect* and **Viewpoint* according to the **Perspective*

<i>*Aspect</i> (Concept)	<i>*Viewpoint</i> (Selected definition for Swedish smart industry context)	<i>*Perspective</i> (Source)
Space	The dimensions of height, depth, and width within which all things exist and move	Oxford dictionary
Time	The indefinite continued progress of existence and events in the past, present, and future regarded as a whole	Oxford dictionary
Energy	The property of matter and radiation which is manifest as a capacity to perform work (such as causing motion or the interaction of molecules)	Oxford dictionary

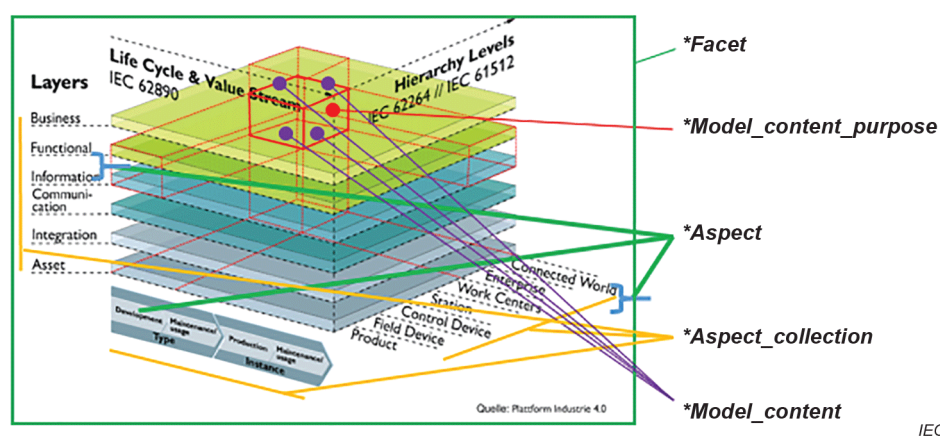
*Aspect (Concept)	*Viewpoint (Selected definition for Swedish smart industry context)	*Perspective (Source)
Interaction	A particular way in which matter, fields, and atomic and subatomic particles affect one another, e.g. through gravitation or electromagnetism	Oxford dictionary
Matter	Physical substance in general, as distinct from mind and spirit; (in physics) which occupies space and possesses rest mass, especially as distinct from energy. 'the structure and properties of matter'	Oxford dictionary
Topology	The way in which constituent parts are interrelated or arranged	Oxford dictionary
Node	A point in a network or diagram at which lines or pathways intersect or branch	Oxford dictionary
Life Cycle	A series of stages through which something (such as an individual, culture, or manufactured product) passes during its lifetime	Merriam Webster (not in Oxford dictionary)
Life Cycle Phase	A subdivision (of the life cycle) to phases with defined levels of maturity	Oxford dictionary

For further details on the SSIF model, refer to Clause B.11.

7.3 Mapping for RAMI 4.0

7.3.1 Graphical depiction of RAMI 4.0 mapping

Figure 9 shows the mapping for the RAMI 4.0.



NOTE 1 The **model_content_purpose* as shown in this figure is the intersection of the **aspects* Layers (Functional, Information), Hierarchy Levels (Connected World, Enterprise), and Life Cycle & Value Stream (Development).

NOTE 2 The mapping shown in this figure is to illustrate how the same meta-model configuration can be used to map a submitted model regardless of the submitted model's representation and configuration. It is not intended to represent the details of each models mapping. Information on the submitted model can be obtained from each model's referenced documents.

NOTE 3 Not every **aspect* is identified.

SOURCE: Reference [25], used with the permission of the authors.

Figure 9 – Mapping for RAMI 4.0

The content of the **model_content_purpose* is the join of the content of the intersecting **aspects*, i.e. the **model_content* projected to compose the **view(s)* that comprise each of the intersecting **aspects* as shown above: Layers (Functional, Information), Hierarchy Levels (Connected World, Enterprise), and Life Cycle & Value Stream (Development).

Having many further possibilities, the overall goal of the RAMI 4.0 architecture is to provide a model with minimum complexity and universality. Therefore, the following three **aspect_collections* were chosen as axes along three aspects which were found most generally applicable:

- assets (items a stakeholder has interests in), featuring:
 - products as the fundamental goal of manufacturing;
 - manufacturing equipment such as machines and materials as well as non-physical artefacts to be used during and/or generated during manufacturing;
- life cycles of Assets (products and manufacturing equipment) to be dealt with in a comprehensive and consistent manner;
- processes and Services of Assets on different levels of systems of systems integration belonging to different phases of Asset life cycles.

The discontinuity in the life cycle axis that occurs when transitioning from the "type" coordinate set to the "instance" coordinate set is observed. The effect is a bifurcation of the **facet* into two **facets*, one associated with entity types and one associated with entity instances with the implication that life cycle is bound to an entity development process. The use of the term "type" rather than "class" implies an attention to the internal specification of the entity rather than its external characterization.

These bifurcations are intentionally used by the RAMI 4.0 model in order to describe the relevant particularities of the real world by defining a homogenous and comprehensive space of only three **aspect_collections*. The bifurcations are not chosen randomly but are reflecting important and universal (timeless) relations between **model_contents*. These bifurcations are described in Table 5.

Table 5 – RAMI 4.0 **aspect_collections* and bifurcations

<i>*aspect_coll ection</i>	Bifurcation	Universal (timeless) relations
life cycle	type/instance	Without loss of generality, the creation, development, realization and usage of assets follows this principle. Even on a one-of-a-kind basis, requirements, concepts, planning, design are done on a type level (an internal, virtual conception). Subsequently, instances are derived from a type, often by a 1:n relationship.
layer	asset & integration/ other layers	The model needs to respect the duality and synchronization between physical world and the digital representation (see 4.3.2). In order to do so, all digital representation is always associated with respect to an entity in the physical world, thus, asset. This is a fundamental decision of the RAMI 4.0 model (see below). Therefore, the asset layer relates to the physical world, the communication/information/functional/business layers relate to the digital representation. Integration serves as a means of adaption/translation between these layers.
hierarchy	product/field device .. enterprise/ connected world	The relation between work items (products, goods manufactured) and manufacturing resources (automation components, machines, equipment, factories) are found universal, as well. Both are assets in the perception of the model and both are subject to the same digital representation means. Thus, they are to be found within the same <i>*aspect_collection</i>. The same goes true for products, which are created by one value chain partner but being used by other value chain partners. A means of connection is required. In order to maintain the possibility of value chains, new partnerships and the requirements of comprehensive digitalization (see 4.2), the connected world is part of this <i>*aspect_collection</i>, as well. Requirements, information, experiences from outside of an organization is associated to assets and is therefore available to be related to, and taken advantage from, other model contents, such as products, processes and manufacturing equipment. This facilitates constant optimization in SM, e.g. part of big data and artificial intelligence scenarios (see 4.3.4).

7.3.2 RAMI 4.0 – *facet_composition_rule

The key principle of the model is the asset orientation: the model utilizes an extended understanding of the asset, as the subject of digital representation within the model.

Assets are defined, in coherence with international standards, as "physical or logical object owned by or under the custodial duties of an organization, having either a perceived or actual value to the organization" [e.g. IEC TS 62443-1-1:2009 [8], 3.2.6].

Assets can be material, such as: "physical objects, equipment (machine, cabinet, contactor, computer, actuator, cables, connectors, sensors, etc.), raw material, parts components and pieces, supplies, consumables or products" being manufactured, but also immaterial, such as "software, licence, copyright, idea, plan, process definition, standards, patents, general procedure, recipe, equipment type definition, product/family type definition, production plans, project plans business procedures" and more (see "Trilateral structure of the Administration Shell" [26]).

The asset orientation together with the extended understanding of what an asset is, are contributing to the following effects/benefits:

- **Scalability:** By its definition, the description of assets by digital means allows for a large amount of digital representation (see 4.3.2) and is therefore a key enabler of comprehensive digitalization. It provides integrated views on all kinds of assets throughout their complete life cycle.
- **Connectivity:** Traditionally separated elements in manufacturing processes are represented by the same concepts and technical means (see below). This makes connectivity simple.
- **Composition:** Without loss of generality, products are composed out of parts and materials and equipment are composed out of components and sub-assemblies. Composition influences almost every process and methodology within the domain of SM. Composed assets are a special case of assets, possessing special values not directly made up by the sum of their components. Asset orientation goes along well with composability; composability provides economies of scales for implementation efforts.
- **Trustworthiness:** In practice, clear trustworthiness is a key enabler. In the RAMI 4.0 model, responsibilities, functionalities, services and intellectual properties are bound to well identified assets, which can be received by well-established business relations. Trustworthiness can therefore be guaranteed, especially in "inter-company value networks" (see 4.2).
- **Stakeholders and use-cases:** By having an asset-orientation principle, many different stakeholders and use-cases are already defined and validated by the practical presence of already existing assets. Use-cases and requirements can be easily identified.
- **Servitization:** Today the delivery of assets is the essence of supply chains and added value networks. Therefore, the asset as an ideal entity unites new services, allowing existing vendors to provide new added values networks and for new vendors to become part of existing added value networks.
- **Retro-fit, re-use and upgrade scenarios:** By having already existing assets and providers of these assets, these providers can easily extend their after-sales portfolio to such services.

7.3.3 Service oriented architecture as a universal technical approach

Because asset is a common concept for every associated aspect in the model, asset services can be defined. This harmonized concept realizes a universal technical approach for all different assets (entities) in the production domain, leveraging scalability and connectivity (see 7.3.2).

One such harmonized concept is the Asset Administration Shell (AAS). The AAS is a registry of asset services and constitutes, in conjunction with its related asset, a cyber-physical component:

- the asset orientation delivers a natural and easy-to-understand view towards concrete systems;
- the asset orientation constitutes a concept to map the recursion within technical systems to a generic model perpetuating the same rules on each extent of their static de-composition;
- AAS is an easy to learn concept of system partitioning, system de-composition and assignment of services;
- AAS enables integration of products of multiple stakeholders under a homogeneous unifying concept.

By allowing for different deployment scenarios and data formats, the AAS concept can be adopted for both intelligent and non-intelligent assets. This allows all kinds of different assets to be represented by a single concept.

In particular, products, processes and manufacturing resources can be represented by the same digital framework and methodologies, providing large economies of scale. All assets share the same technology for providing properties and services, independent of their traditional different origin (e.g. products vs. equipment). Management, methodologies and connectivity are independent of actual deployment and technical realization. In this sense, the Administration Shell makes available all kinds of asset services associated with an asset and provided by a value chain partner. Interoperability of value-chain partners is therefore possible. As a result, advancements of SM can be brought to many different industries and company sizes, providing economies of scale and making comprehensive algorithmic support and automatic assistance reasonable, allowing for speed-ups in engineering and operation/maintenance.

7.3.4 Layers **aspect_collection_coherence_rule*

The **aspect_collection* "RAMI 4.0 Layers" associates the structural properties and asset services of an asset or combination of assets for a certain coordinate set (see 7.3.1) with the **aspects* from **aspect_collections* life cycle and hierarchy. The asset (physical twin, see 4.3.2) resides in the lowest layer (**aspect*), while the upper 4 layers are representing the asset at this certain coordinate set in the digital representation world by (possibly standardized) properties and services. The intermediate integration layer represents the transition from the physical world to the (partially standardized) information world, containing proprietary means for adaptation, translation, interfacing. The layers are described further in Table 6.

For different coordinate sets (combination of the **aspects* from **aspect_collections* life cycle and hierarchy), the model will hold and make available different properties and asset services, reflecting e.g. the different needs for engineering and operation of assets. This happens also for the bifurcations mentioned above in 7.3.1, such as transitioning from type to instance. As all associations are always done with regards to an asset (and a worldwide unique asset identification), full information traceability is established (see 4.2, comprehensive digitalization).

Layers do not always have to have content for a specific combination of coordinate set and asset. Connections between the layers are bridged by being associated to the same asset. Interactions can take place between layers or within a layer. Hence, these layers, together with hierarchy and life cycle **aspects*, are providing a classification of different asset services, allowing for efficient and consequent discussion and definition of these matters.

Table 6 describes the **Aspect* and **Viewpoint* for the RAMI 4.0 Layers.

Table 6 – **Aspect* and **Viewpoint* for RAMI 4.0 Layers

<i>*Aspect</i>	<i>*Viewpoint</i>
Asset	The asset layer represents the asset itself ("physical twin"). As a consequence of the 3-dimensional nature of the model, the asset is also associated with a certain life cycle state and hierarchy level, as the asset is undergoing an evolution of different life cycle phases. Each hierarchy level typically features various kinds of assets.

*Aspect	*Viewpoint
Integration	Assets ("physical twins") need to be associated with the information ("digital") world. This bridging element is represented by the Integration aspect. It could possibly contain services for linking 2D-codes of the asset to Administration Shell or a proprietary active communication between asset and Administration Shell. Providing standardized services and procedures to this aspect will be the key factor for efficient management of SM, digital representations and services.
Communication	This aspect contains all provisions for an Industrie 4.0 compliant communication between different Administration Shells and also towards other systems. Covering and formalizing communication connections is of high importance, as many proprietary communications hinder approaches such as plug&play or quick reconfiguration of production equipment.
Information	This aspect contains all formalized and even standardized information and knowledge associated with the asset. The use of semantic identification and properties (IEC 61360 [27], ISO 13584 [28]) is fostered.
Functional	Assets ("physical twins") but also Administration Shells ("digital twin") will provide much more differentiated functionality in the future. This functionality needs to be described and securely invoked.
Business	SM needs a lot of orchestration. In the future, much more decisions are expected to be taken on a decentralized basis. This aspect gives room to these demands.

7.3.5 Hierarchy Levels **aspect_collection_coherence_rule*

The Hierarchy Levels **aspect_collection* is based on the reference architecture model for a factory along the lines of IEC 62264-1 [29] and IEC 61512-1 [30], the standards for integrating enterprise IT and control systems.

To ensure a consistent consideration across as many sectors as possible from factory automation to the process industry, the terms "enterprise", "work centers", "station" and "control device" have been taken as being most representative from the above-mentioned standards. Figure B.3 in Annex B shows the selection of these aspects under the consideration of different industry segments. The model therefore fits discrete, hybrid, continuous manufacturing and intralogistics. Additions were made for the particularities of SM: Connected world, (intelligent) field devices and produced products.

Table 7 describes the **Aspect* and **Viewpoint* for the RAMI 4.0 Hierarchy Levels.

Table 7 – **Aspect* and **Viewpoint* for RAMI 4.0 Hierarchy Levels

*Aspect	*Viewpoint
Connected World	Connection to other factories and partners in the added value chain; connection to other verticals (use of produced products, customers).
Enterprise, Work Centers, Station, Control Device	Corresponds to the definition of "Enterprise", "Work center", "Equipment module", "Control module" of IEC 62264-1:2013, 3.1.44 [29] (see in IEC 62264-1:2013, 5.3 Role-based equipment hierarchy).
Product	Produced products are assets and need to be reflected by an <i>*aspect_collection</i> . For SM, product features and features of the production equipment are closely correlated (e.g. for highly customized products and enhanced product flexibility, see 4.2) and therefore, both elements need to be connected and maintained together.

7.3.6 Life cycle **aspect_collection_coherence_rule*

The **aspect_collection* "RAMI 4.0 Life cycle" is used to describe an asset at a particular state during its lifetime, from initial requirements, design and development, over marketing and supply, to its production, value-added use and its maintenance right up to its disposal.

With this **aspect_collection*, the asset is characterized by its state at a particular time at a particular location via the intersection with the layers **aspect_collection*. The model offers great potential for improvement throughout the life cycle of products, machines, lines and overall factories.

IEC 62890 [31] is a good guideline for consideration of the life cycle. The fundamental distinction between type and instance is of central importance in those considerations and answers many qualitative and quantitative differentiations, which are applied to products, production equipment and IT systems.

Table 8 describes the **Aspect* and **Viewpoint* for the RAMI 4.0 Life cycle. It extends the description of the RAMI 4.0 aspects by a motivation of their importance in future models.

Table 8 – **Aspect* and **Viewpoint* for the RAMI 4.0 Life cycle

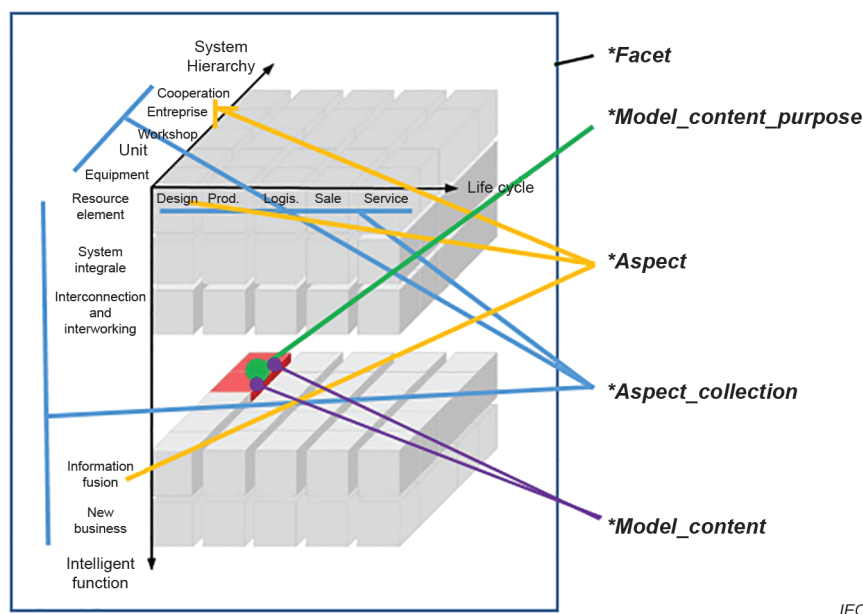
<i>*Aspect</i>		<i>*Viewpoint</i>
Type	Development	Valid from the ideation/conceptualization to first prototypes/test. The 'type' of an asset is defined, and distinguishing properties and functionalities are defined and implemented. All (internal) design artefacts are created, such as CAD data, schematics, embedded software, and are associated with the asset type. All this information, both for products but also production equipment, is very important for SM, as many later decisions rely on these definitions and need to be tracked seamlessly.
	Maintenance/ Usage	Ramping up production capacity. The 'external' information associated to the asset is created, such as technical data sheets, marketing information. The selling process starts. In future scenarios for digital economy, marketplaces and automatic business processes will be a vital part of the SM domain and need to be integrated.
Instance	Production	Asset instances are created/produced, based on the asset type information. Specific information about production, logistics, qualification and test are associated with the asset instances. The digital representation of assets ("digital twin") needs to capture instance specific data, to be more specific and useful for many application cases. Digital (secure) identity management will become important in the future.
	Maintenance/ Usage	Usage phase by the purchaser of the asset instances. Usage data is associated with the asset instance and could be shared with other value chain partners, such as the manufacturer of the asset instance. Also included: maintenance, re-design, optimization and de-commissioning of the asset instance. The full life cycle history is associated with the asset and could be archived/shared for documentation. Such data will be the key-enabler of smart behaviour of entities in SM.

For further details, refer to Clause B.1.

7.4 Mapping for IMSA

7.4.1 Graphical depiction of IMSA mapping

Figure 10 shows the mapping for the IMSA.



NOTE 1 The **model_content_purpose* as shown in this figure is the intersection of the **aspects* System Hierarchy (Cooperation, Enterprise), Intelligent Function (Information Fusion), Life cycle (Design).

NOTE 2 The mapping shown in this figure is to illustrate how the same meta-model configuration can be used to map a submitted model regardless of submitted model's representation and configuration. It is not intended to represent the details of each model's mapping. Information on the submitted model can be obtained from each model's referenced documents.

NOTE 3 Not every **aspect* is identified.

Figure 10 – Mapping for IMSA

The content of the **model_content_purpose* is the joining of the content of the intersecting **aspects*, i.e. the **model_content* projected to compose the **view(s)*, that comprise each of the intersecting **aspects* as shown above: System Hierarchy (Cooperation, Enterprise), Intelligent Function (Information Fusion), and Life Cycle (Design).

7.4.2 System Hierarchy **aspect_collection_coherence_rule*

The System Hierarchy means the hierarchy division of the organization structure related to the enterprise production activities, including the equipment hierarchy, unit hierarchy, workshop hierarchy, enterprise hierarchy and cooperation hierarchy. These hierarchical aspects identify the distribution of authority and responsibility for production activities.

Table 9 describes the **Aspect* and **Viewpoint* for the IMSA System Hierarchy.

Table 9 – **Aspect* and **Viewpoint* for the IMSA System Hierarchy

<i>*Aspect</i>	<i>*Viewpoint</i>
Cooperation	Cooperation hierarchy is a hierarchy used to achieve interconnection and sharing process of internal and external information by the enterprise.
Enterprise	Enterprise hierarchy is a hierarchy used to achieve enterprise management.
Workshop	Workshop hierarchy is a hierarchy used to achieve production and management in the factory or workshop.
Unit	Unit hierarchy is a hierarchy used to achieve information process in the factory and to monitor and control physical processes.
Equipment	Equipment hierarchy means the hierarchy in which the enterprise utilizes the sensor, instrument and monitor display, machine and device to realize the actual physical process and perceive and control the physical process.

7.4.3 Life Cycle **aspect_collection_coherence_rule*

Life cycle means a series of mutually connected value creation activities of the phases from the product prototype research and development to product recycling and remanufacturing, including design, production, logistics, sales and service. Iterative optimization can be conducted for the life cycle activities with the characteristics such as sustainable development. Life cycle phase components of different industries are different.

Table 10 describes the **Aspect* and **Viewpoint* for the IMSA Life Cycle.

Table 10 – **Aspect* and **Viewpoint* for IMSA Life Cycle

<i>*Aspects</i>	<i>*Viewpoints</i>
Design	Design refers to the process in which the construction, simulation, verification, optimization and other research and development activities are conducted on the demands according to all the constraint conditions of and the technology selected by the enterprise.
Production	Production refers to the process in which the order-required product is created given the personnel, equipment, materials and other resources.
Logistics	Logistics refers to the process of moving goods and materials from the supply place to their destinations. This includes moving activities before and after production, which means both receiving of raw materials/parts for production as well as delivery of products from production line to customers.
Sales	Sales refers to the post production business transaction activities through which products or commodities are transferred from enterprises to customers.
Service	Service refers to the process and its corresponding result of a series of activities generated in the shared process between the provider and the clients, including recycling.

7.4.4 Intelligent Function **aspect_collection_coherence_rule*

Intelligence characteristics refer to the categories of a new generation of information communication technology to make manufacturing activities with one or more functions, such as self-sensing, self-learning, self-decision, self-execution, and self-adaptation. These categories include the five intelligent requirements **aspects* of resources elements, interconnection and interworking, information fusion and sharing, system integration and new business pattern.

NOTE **Aspect* sequence is a changing target.

Table 11 describes the **aspects* possible values and explanations for the IMSA Intelligent Functions.

Table 11 – **Aspects* possible values and explanation for the IMSA Intelligent Functions

Possible values (<i>*Aspects</i>)	Explanation (<i>*Viewpoints</i>)
New business pattern	New business pattern refers to a setting used to perform value chain integration between enterprises to form new industry configurations for value chains of mass customization, network-based cooperative manufacturing, and remote operation and maintenance, possibly including an industrial cloud.
System integration	System integration refers to the process of enabling interoperability of intelligent equipment with the intelligent production unit, intelligent production line, digital workshop, intelligent factory, and even intelligent manufacturing system by the enterprise, realizing the integration from small to large scale.
Interconnection and Networking	Interconnection refers to the connection between equipment, equipment and control system, between enterprises through the wired, wireless and other communication technology, and even physical world and cyber world, using wired or wireless communication technologies.

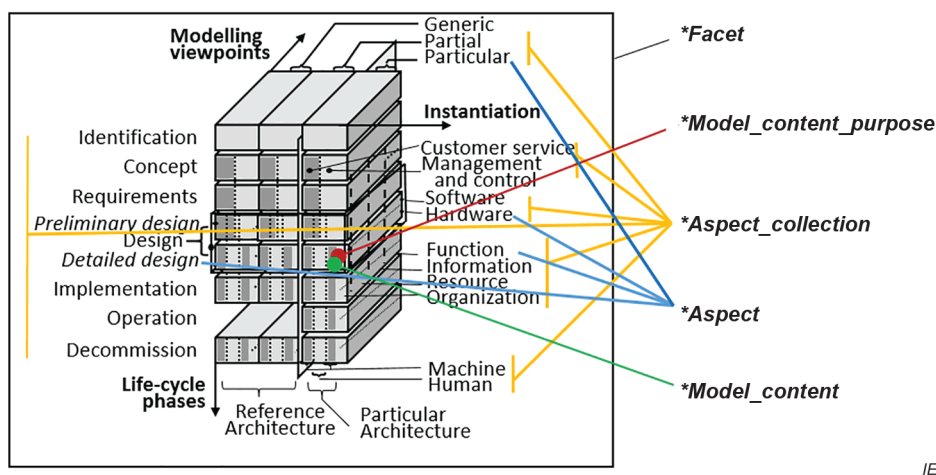
Possible values (<i>*Aspects</i>)	Explanation (<i>*Viewpoints</i>)
Information collection and utilization – Information fusion	Information fusion and sharing refers to collaborative information sharing with cloud computing, big data and other new generation of information and communication technologies based on the interconnection and interworking in the premise of ensuring the information security.
Resource elements	Resource elements refer to the tangible and intangible assets such as raw materials, equipment, workshop, factory, design and construction drawings, product technique documents, employees and energy, which are used to achieve the digital processes during productions.

For further details, refer to Clause B.2.

7.5 Mapping for ISO 15704:2019, Annex B – GERAM

7.5.1 Graphical depiction of ISO 15704:2019, Annex B – GERAM

Figure 11 shows the mapping for ISO 15704:2019, Annex B – GERAM.



IEC

NOTE 1 The **model_content_purpose* is shown in this figure: Life cycle phase (Detailed design), Instantiation (Particular), Viewpoint (Function), Manifestation (Hardware). Notice the overlay or partitioning of the sub-dimension for Manifestation on the Modelling Viewpoints surface of the 3D representation. In total, this representation shows six different **aspect_collections* on one 3D structure.

NOTE 2 This figure illustrates how the same meta-model configuration can be used to map a submitted model regardless of submitted model's representation and configuration. It is not intended to represent the details of each models mapping. Information on the submitted model can be obtained from each model's referenced documents.

NOTE 3 Not every **aspect* is identified.

Figure 11 – Mapping for ISO 15704:2019 – GERAM Annex

The content of the **model_content_purpose* is the join of the content of the intersecting **aspects*, i.e. the **model_content* projected to compose the view(s) that comprise each of the intersecting **aspects* as shown above: Life cycle phase (Detailed design), Instantiation (Particular), Viewpoint (Function), Manifestation (Hardware).

7.5.2 GERAM **facet_composition_rules*

GERAM provides an analysis and modelling framework that relies upon the life cycle concept and identifies the following three dimensions, i.e. **aspect_collections*, for defining the scope and content of enterprise modelling:

- Life cycle Dimension – providing for the controlled modelling process of enterprise entities according to life cycle activities;

- Genericity Dimension – providing for the controlled particularization (instantiation) process from generic and partial to particular;
- Viewpoint Dimension – providing for the controlled visualization of specific views of the enterprise-entity.

The reference part of the modelling framework consists of the generic and the partial extent of genericity only. These two columns structure the definitions of concepts, basic and macro constructs (i.e. the modelling languages), and the model prototypes for description of an area of concern. The particular extent of genericity represents the results of the modelling process, which is the model or description of the enterprise entity at the state of the modelling process corresponding to the particular set of life cycle activities.

NOTE The genericity dimension of GERAM has similarities with the Life cycle and Value Stream dimension of RAMI 4.0.

7.5.3 Life cycle phases **aspect_collection_coherence_rule*

Life cycle activities encompass all activities from identification to decommissioning at end of life of the enterprise or entity. GERAM defines seven life cycle activity collections. Table 12 shows the **aspects* and **viewpoints* for GERAM life cycle

Table 12 – **Aspects* and **viewpoints* for GERAM life cycle

<i>*Aspect</i>	<i>*Viewpoint</i>
Domain identification	Model phase that identifies the enterprise domain to be modelled with respect to its business objectives, the enterprise domain inputs and outputs and their respective origins and destinations
Concept definition	Model phase that defines the business concepts of an enterprise domain to be employed in realizing its business objectives and its operation, including the necessary enterprise domain inputs and outputs
Requirements definition	Model phase that defines the operations needed to achieve enterprise objectives and the conditions necessary to enable those operations, both being without reference to implementation options or implementation decisions
Design Specification	Model phase that specifies the business processes, together with capabilities and rules, which are to be performed to achieve the requirements (sometimes subdivided further into two sub-collections of activities based on the subdivision into preliminary and detailed design activities)
Implementation	Model phase that describes the final set of processes, resources and rules implemented to achieve the desired operational performance for execution of the business processes and enterprise activities specified in the design specification phase
Operation	Model phase that encompasses the operational use of the domain model
Decommission	Model phase that defines the final state of a decommissioned operational system, all its components for a particular enterprise domain and the processes employed to conduct the decommissioning, so enabling re-use or disposition of those components

Throughout the life cycle, the appropriate modelling languages support the two-way dependency relationship between models of adjacent life cycle phases. That is, the derivation of models from one state of elaboration to a more elaborated state or the abstraction of elaborated models to one or more models in a less elaborated state can occur without having to create different models for the different sets of life cycle activities. This support capability aids in achieving coherence of models throughout the life cycle.

7.5.4 Modelling viewpoints **aspect_collection_coherence_rule*

The **aspects* of the modelling viewpoint **aspect_collection* arise from years of experience as essential for the purpose of articulating a holistic integrated enterprise reference architecture specification, i.e. they constitute the coordinates of a holistic perspective dimension of the enterprise reference architecture.