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Edition 1.0 2020-12

TECHNICAL REPORT

colour inside

Smart manufacturing standards map (SM2) – Part 1: Framework

ISO/IEC TR 63306-1:2020-12(en)

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Smart manufacturing standards map (SM2) –
Part 1: Framework

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CONTENTS

SMART MANUFACTURING STANDARDS MAP (SM2) –

Part 1: Framework

FOREWORD

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This document has been prepared by IEC systems committee SM: Smart Manufacturing, in collaboration with ISO technical committee 184: Automation systems and integration.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
SyCSM/42/DTR	SyCSM/46/RVDTR

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.

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.

In this document, the following print types are used.

– The font colour of the committee mandatory characteristics is red.
– The font colour of the committee conditional characteristics is purple.

A list of all parts in the ISO/IEC 63306 series, published under the general title *Smart Manufacturing Standards Map (SM2)*, can be found on the IEC and ISO websites.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

International and regional standards developing organizations (SDOs), as well as consortia and national initiatives, identified the need for clarifying the standards landscape of thousands of publications related to manufacturing in general and more specifically to smart manufacturing.

On this matter, the "Big Picture" project initiated by ISO/TC 184 "Automation systems and integration" in 2001 is notable. It resulted in the publication of ISO/TR 23087:2018 [1][1].

The other important contributions are:

– NISTIR 8107, Current Standards Landscape for Smart Manufacturing Systems [2], 2016;
– VDI/VDE and ZVEI, Reference Architecture Model Industrie 4.0 (RAMI4.0) [3], 2015;
– final report of ISO/TMB Strategic Advisory Group Industry 4.0/Smart manufacturing, 2016.

The Smart Manufacturing Standards Map (SM2) project was initiated by ISO and IEC in order to provide a credible, central, and neutral repository of information about standards related to smart manufacturing.

NOTE Standards is a generic term covering international and national standards, specifications, technical reports, technical specifications, white papers and other similar deliverables provided by standards developing organizations (SDO) or consortia.

The goals of this project are to provide a systematic and reliable classification method (vocabulary and catalogue), and in the future a central repository with visualization tools for sorting, classifying and comparing standards.

These tools are intended to support SDOs, their officers and experts in the following tasks:

– identify standards that apply to their own domain;
– examine the main features of selected standards;
– generate comparisons between the relative positioning of different standards in their domain or other domains.

These tools should also serve standards users in the following tasks:

– identify the relevant standards for their activity;
– evaluate their activity in terms of the standards and the standardization projects;
– build their product development roadmap in accordance with the standards landscape.

These tools and the information contained in the repository are updated frequently to reflect new standards and the need for new ways to characterize standards as technology advances.

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

SMART MANUFACTURING STANDARDS MAP (SM2) –

Part 1: Framework

1 Scope

This document describes the framework and the vocabulary that are used for the development of entries in the Smart Manufacturing Standards Map Catalogue. These enable the mapping and linking of standards and standard projects related to various aspects of smart manufacturing (product, production, supply chain, industrial services ...).

The framework applies to international standards, de facto standards and consortium specifications; publications or projects; thereafter named "standards".

The framework part (Clauses 4) briefly describes the principle of structuring the standards catalogue and its use for analysing the standards landscape.

The vocabulary part (Clauses 5 to 13) specifies the characteristics that are used for the classification of standards.

NOTE The vocabulary is not universal but is the best effort to name the concepts used in different domains.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

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

4 Principle of the Smart Manufacturing Standards Map (SM2)

4.1 Framework

The framework for the Smart Manufacturing Standards Map (SM2) enables the standardization stakeholders to identify, for each concerned standard, the characteristics related to its potential role and the impact of its use in the industry. These characteristics are defined in the SM2 Vocabulary.

Figure 1 shows the principle of this framework.

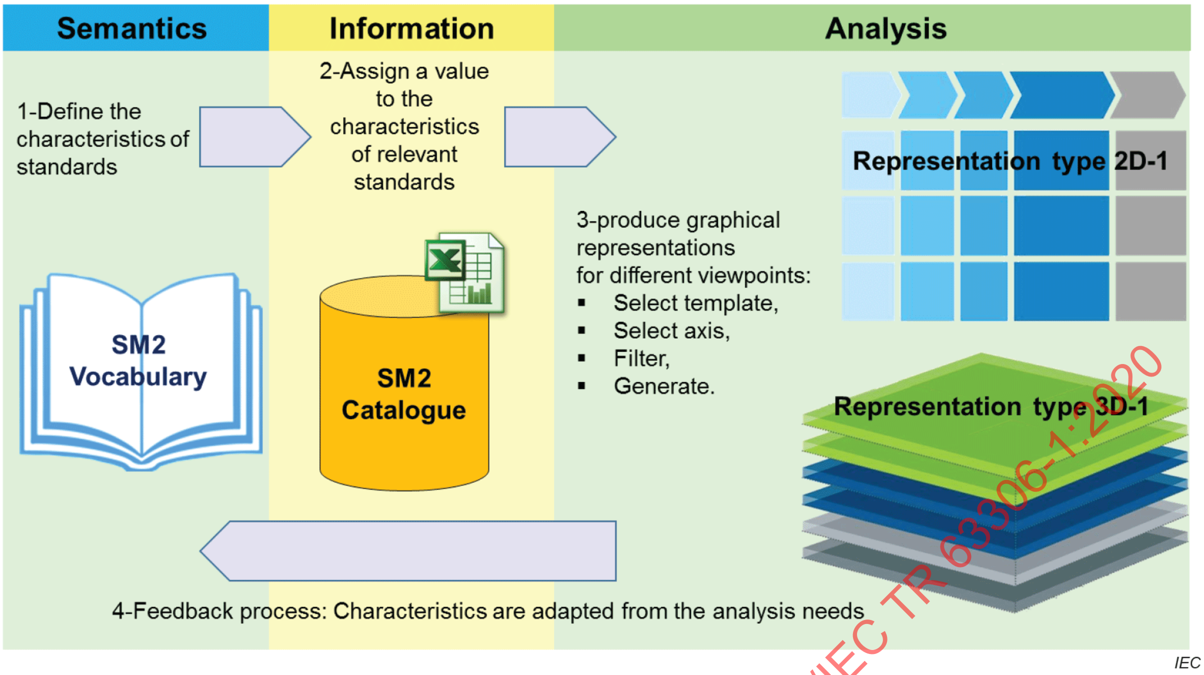


Figure 1 – Principle of the SM2 Framework

4.2 SM2 Catalogue

In the SM2 Catalogue, relevant standards and standardization projects are depicted in terms of the characteristics (properties of standards) organized in blocks and sub-blocks of characteristics as described in this document.

NOTE The reference model for the Smart Manufacturing Standards Map is based on ISO/TR 23087:2018 [1], which is intended to monitor the consistency of the published standards and the current or future standardization projects (see Annex E).

Each characteristic has a format, possible values and a qualifier.

The qualifier specifies which entity is expected to provide the value for the characteristic.

From the filtering of the SM2 Catalogue, different graphical representations can be built to facilitate understanding of the issues and decision making.

Figure 2 shows an example of a populated SM2 Catalogue.

Identification		Status	Publication	Publication	Publication
	Reference	Standard number	ISO/IEC 27000	IEC 61158-2	ISO 18629
	Title	Standard title	Information technology – Security techniques – Information security management systems – Overview and vocabulary	Industrial communication networks - Fieldbus specifications - Part 2: Physical layer specification and service definition	Industrial automation systems and integration – Process specification language – Part 1: Overview and basic principles, Part 11: PSL core, Part 12: Outer core, Part 13: Duration and ordering theories, Part 14: Resource theories, Part 41: Definitional extension: Activity extensions, Part 42: Definitional extension: Temporal and state extensions, Part 43: Definitional extension: Activity ordering and duration extensions
Hierarchy	Equipment hierarchy	Enterprise	1	-	1
		Facility	-	-	-
		Station	?	1	-
		Device	?	1	-
	Functional hierarchy	Connected world	1	-	-
		Business (L4)	-	-	-
		Operations management (L3)	-	-	-
		Control (L2)	-	1	-
		Sensors and actuators (L1)	-	1	-
		Process (L0)	-	1	-
		Product	-	1	-
Life cycle	Product type life cycle	Marketing	-	-	-
		Development	-	1	1
		Sales	-	-	-
		Obsolescence support	-	-	-
	Product instance life cycle	Manufacturing	-	1	-
		Transport & stock	-	-	-
		Use	-	1	-
		Disposal	-	-	-
	Production system life cycle	Concept	-	1	-
		Design	-	1	-
		Implementation	-	1	-
		Use	-	1	-
		Retirement	-	-	-
Interoperability	Interop. approach	Integration	-	-	1
		Federation	-	-	-
		Unification	1	-	1
	Interoperability concern	Business	1	-	-
		Process	-	-	1
		Service	-	-	-
		Data	-	-	-
	Interoperability layer	Business	1	-	-
		Function	-	-	1
		Information	-	-	1
		Communication	-	1	1
		Resources	1	1	-

IEC

Figure 2 – Example of populated SM2 Catalogue

4.3 Graphical representations

The standard mapping is necessarily linked with graphical representations that are essential for a human understanding.

Different graphical representations can be generated from the SM2 Catalogue. The type of graphical representation depends on the viewpoint that is selected for the investigation of stakeholder concerns.

For example, system integrators are typically involved in the production system life cycle and therefore need to consider the various product type life cycles. A representation as shown in Figure 3 can assist system integrators in the analysis of the relevant product catalogue data standards by showing in which phases of the life cycle(s) these standards can be used.

Figure 4 shows a possible structure for the mapping of relevant production system standards, along the axes "Interoperability layers", "Production system life cycle" and "Functional hierarchy".

The generation of graphical charts may be based on templates (like "Cube" or "2D Chart") and the configuration of chart parameters.

For example, in Figure 5, a 3D template was selected, and only standard numbers of international standards are displayed while in Figure 6 short titles are displayed.

In Figure 7 and Figure 8, a 2D template option display is selected; the search options selected are process instruments ec@talogue and ISO and IEC standards. In Figure 7, the display option standard number is selected, while in Figure 8 the standard short title option is selected.

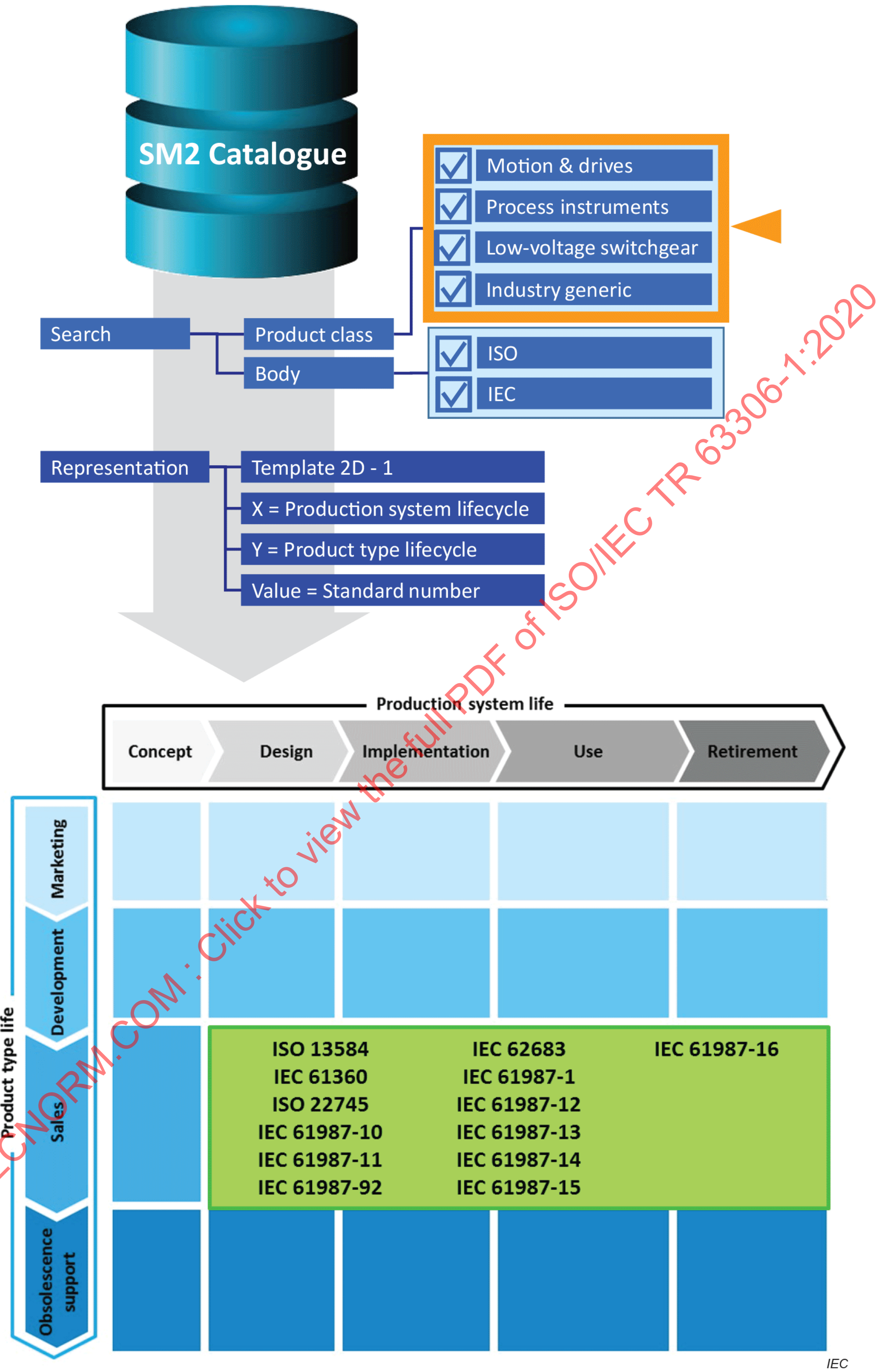


Figure 3 – Example mapping of product catalogue data standards

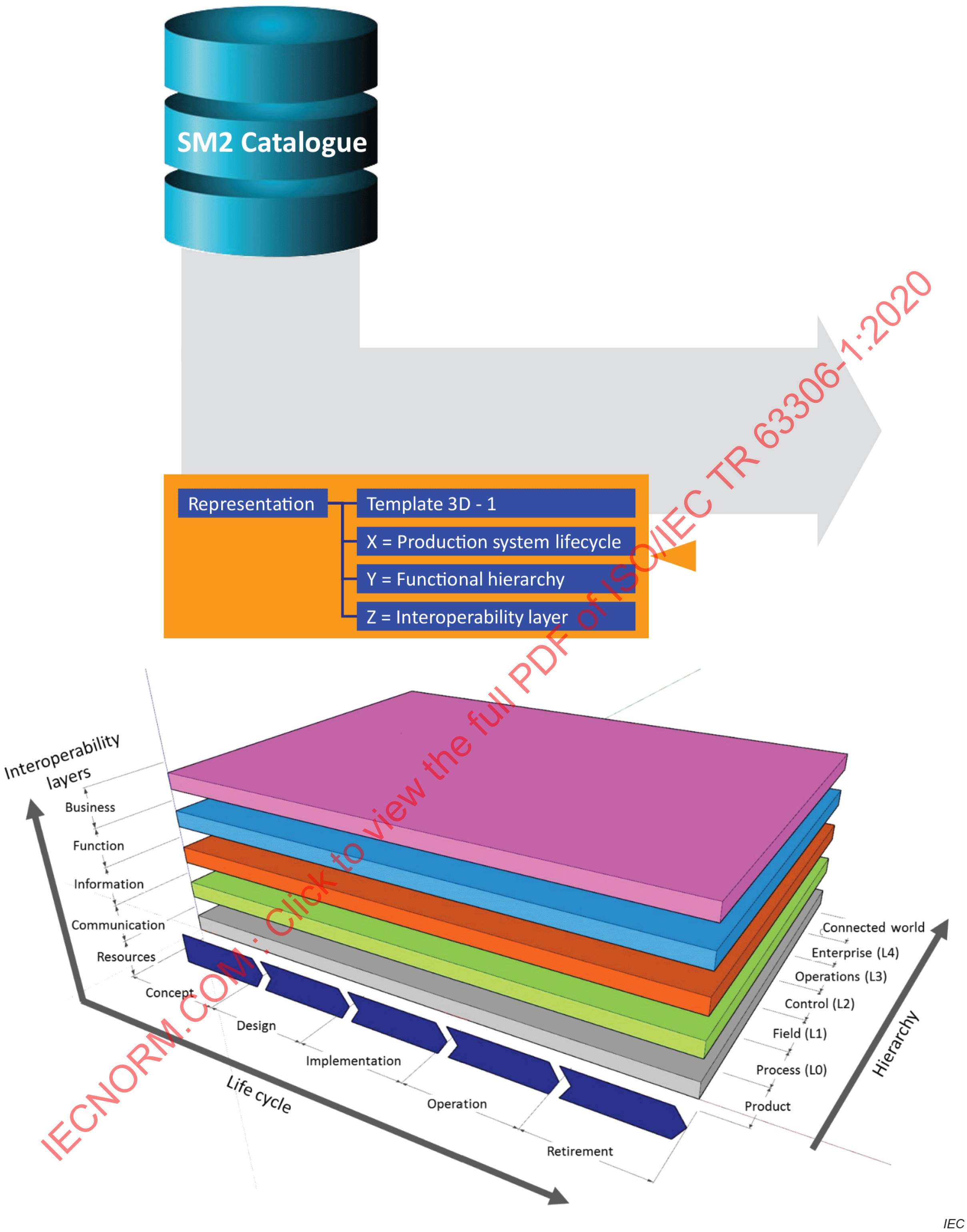


Figure 4 – Example mapping structure for production system standards

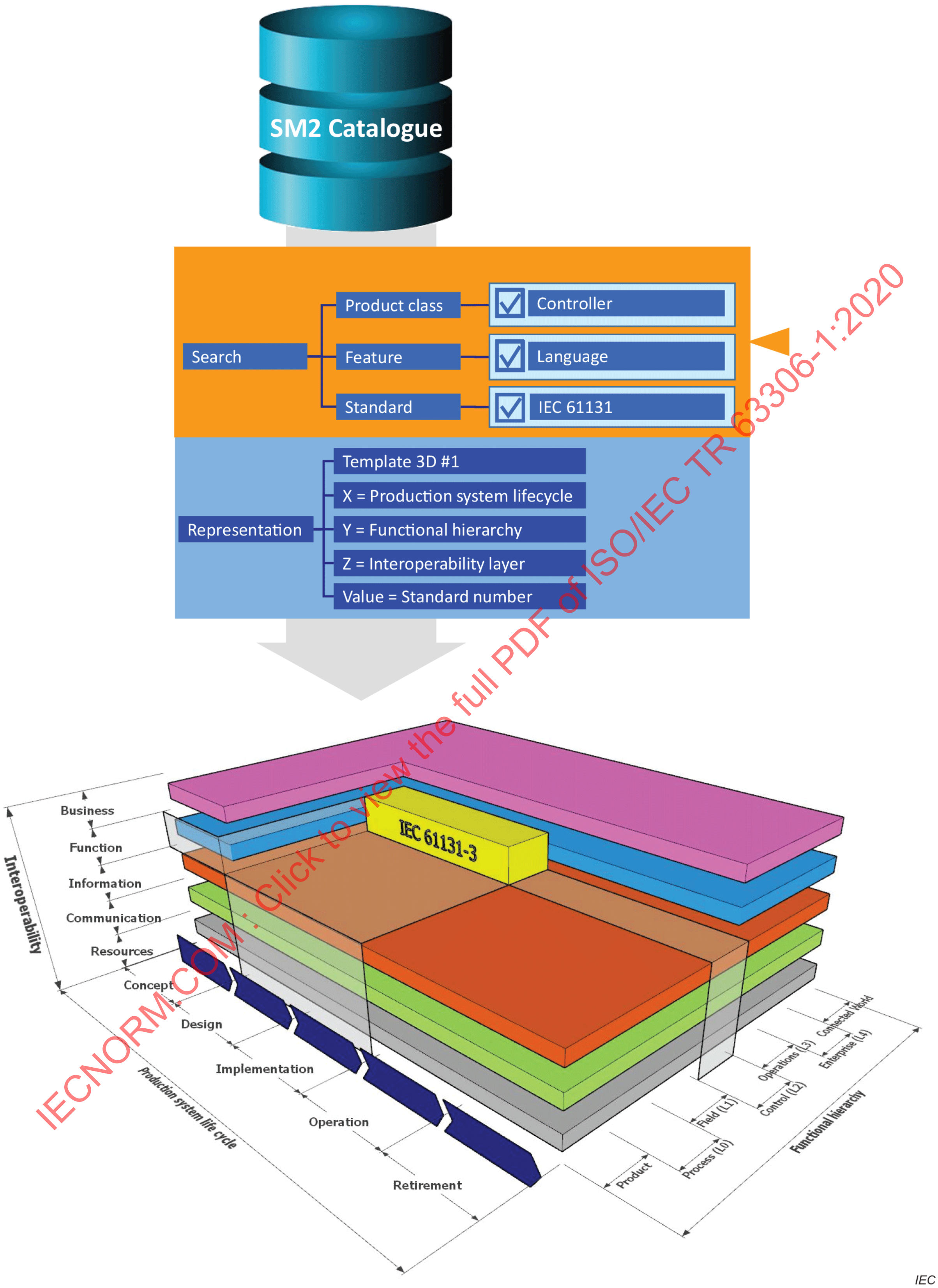


Figure 5 – Example chart "Production system cube" with standard numbers

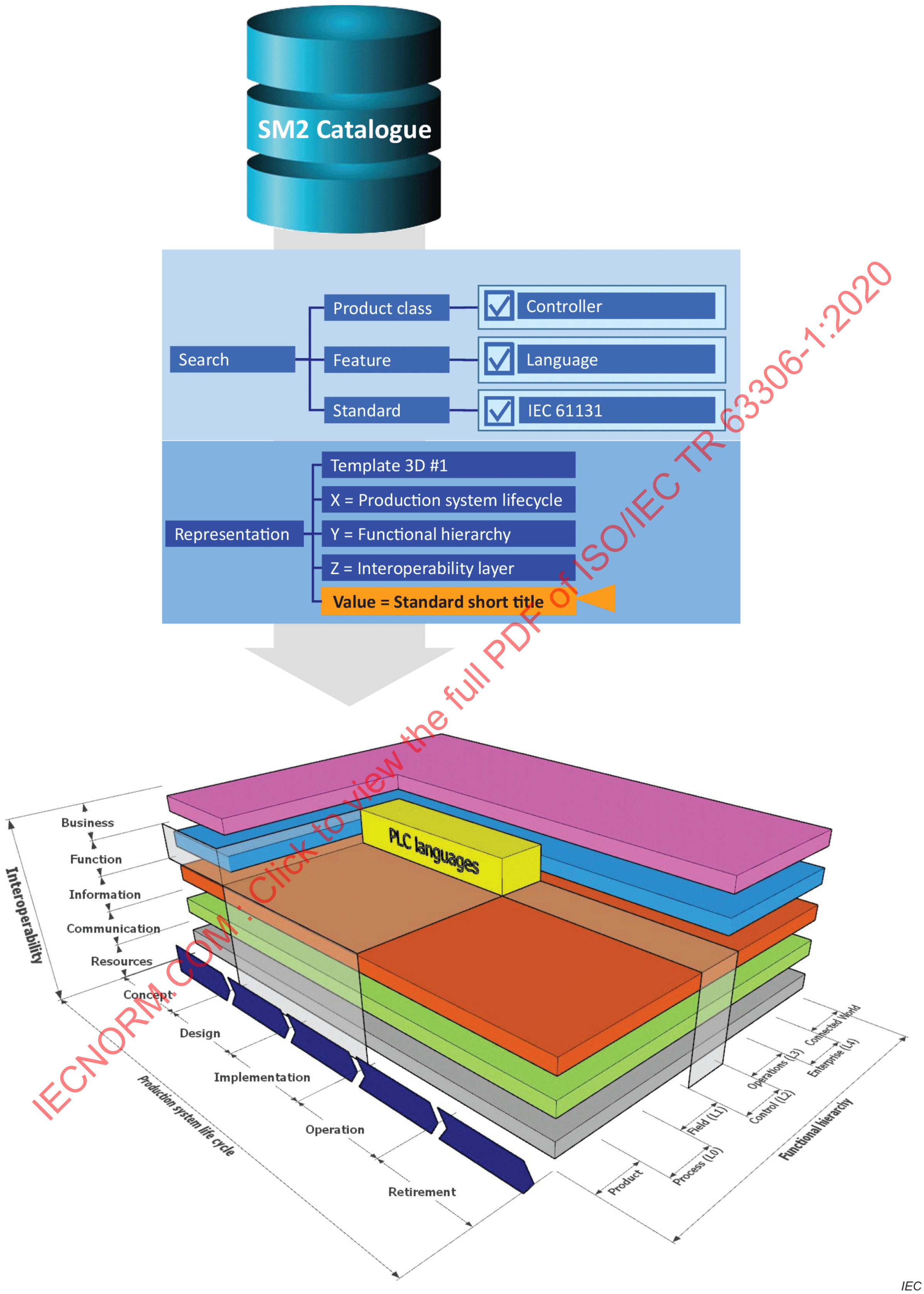


Figure 6 – Example chart "Production system cube" with short title

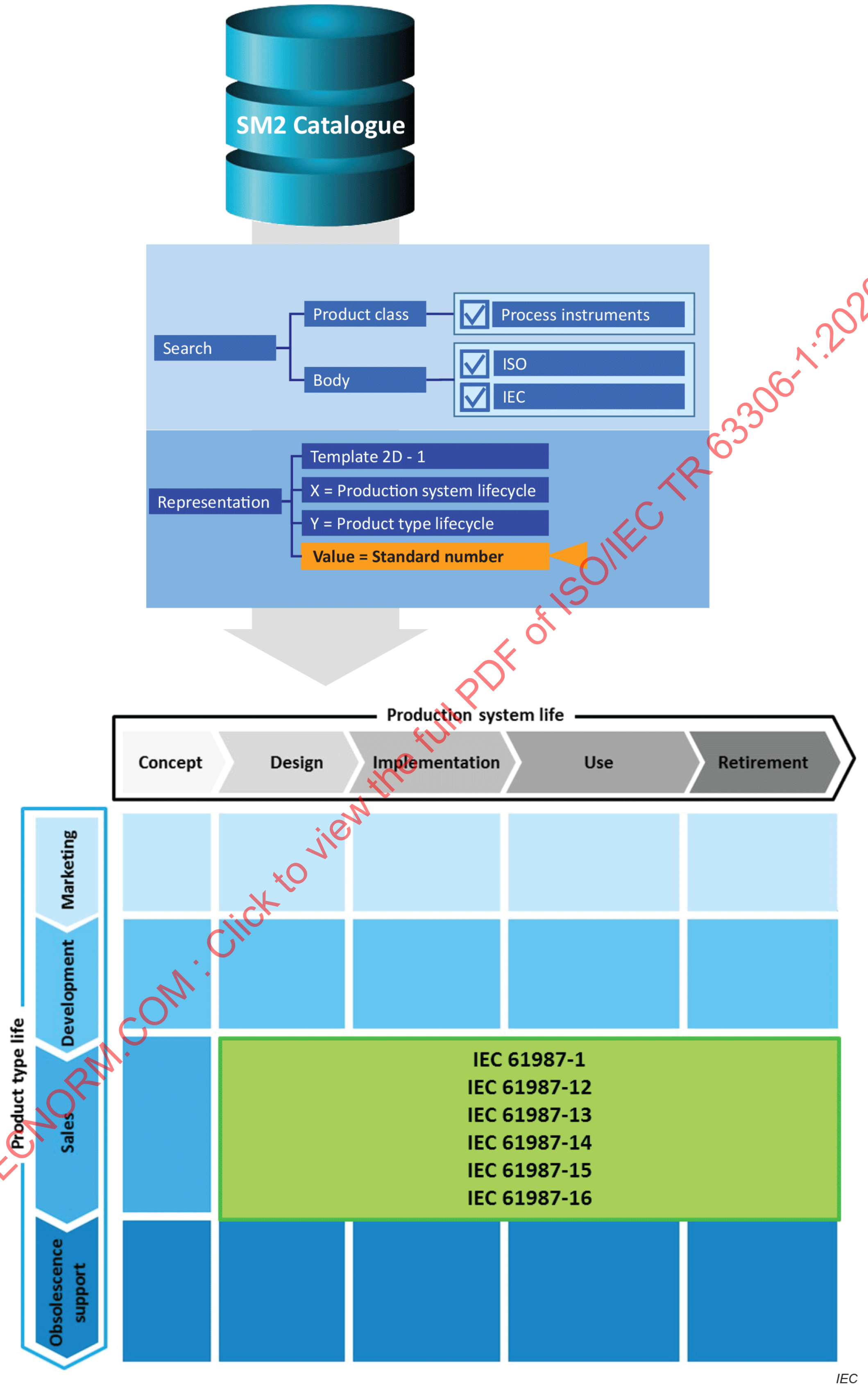


Figure 7 – Example 2D chart with standard numbers

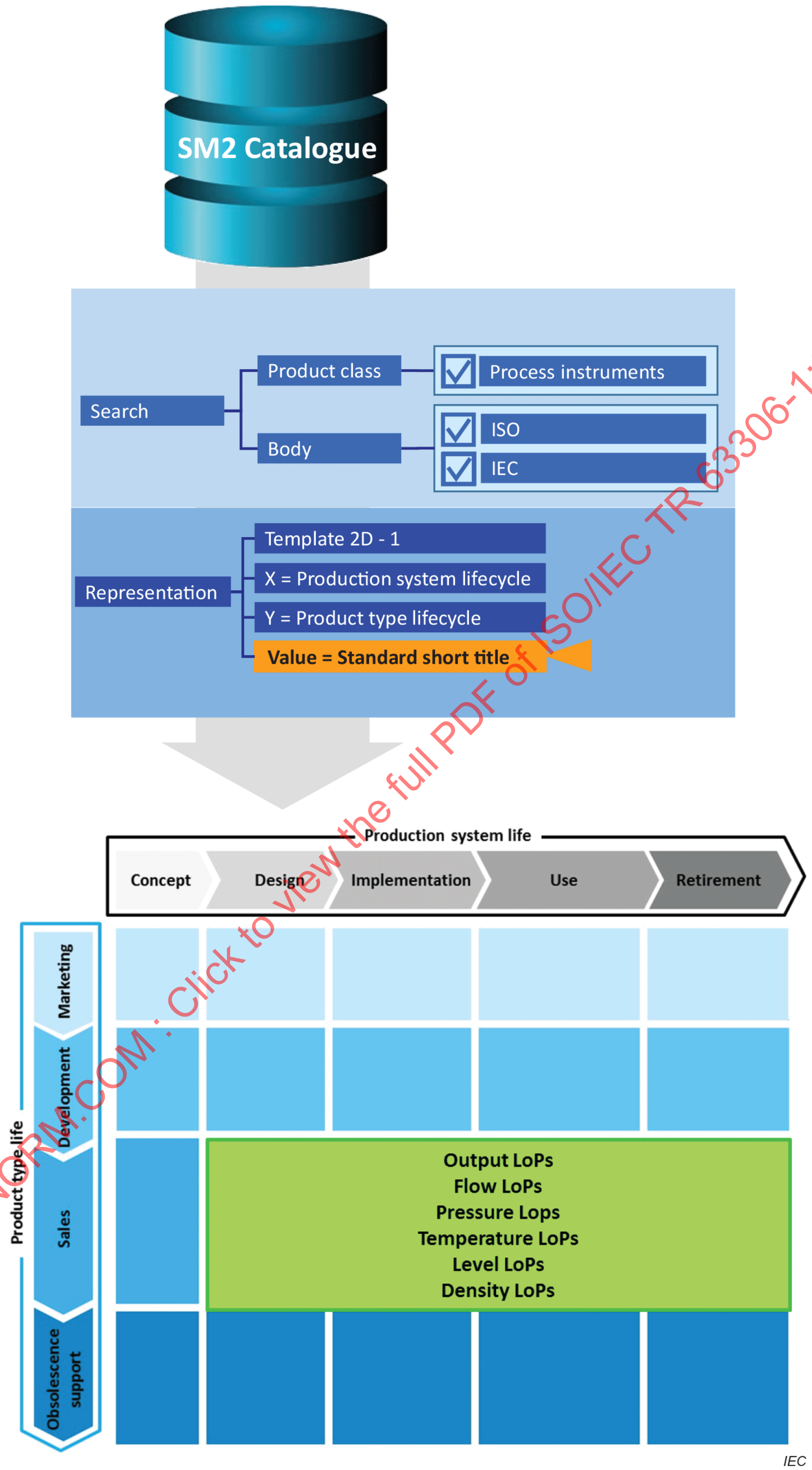


Figure 8 – Example 2D chart with short title

5 Overview of the SM2 Vocabulary

5.1 Summary of characteristics and blocks

The classification scheme uses the term "block" to indicate a top-level classifier and "sub-block" as a second level classifier for characteristics.

NOTE The term "block" is adopted from IEC 61360:2017 [4].

Table 1 to Table 8 depict this classification. This structure is used for the SM2 Catalogue. The following clauses (Clause 6 to Clause 13) specify the block, sub-block, characteristics and their attributes (data type, possible values and qualifier).

Table 1 – Block "Identification": sub-blocks and characteristics

Block	Sub-block	Characteristic
Identification	Reference	Status
		Standard number
	Publication	Edition
		Publication date
	Project	Project number
		Forecast publication date
	Owner	Organization
		Committee number
		Committee title
	ICS	International Classification for Standards
	Title	Standard title
		Standard short title

Table 2 – Block "Object": sub-blocks and characteristics

Block	Sub-block	Characteristic
Object	Type of standard	Basic standard
		Terminology standard
		Testing standard
		Product standard
		Process standard
		Service standard
		Interface standard
		Data standard
	Type of object	Product
		Production system
		Enterprise
		Personnel
	Manufacturing process type	Batch
		Discrete
		Continuous

Table 3 – Block "Hierarchy": sub-blocks and characteristics

Block	Sub-block	Characteristic
Hierarchy	Equipment hierarchy	Enterprise
		Facility
		Station
		Device
	Functional hierarchy	Connected world
		Business (L4)
		Operations management (L3)
		Control (L2)
		Sensors and actuators (L1)
		Process (L0)
		Product

Table 4 – Block "Life cycle": sub-blocks and characteristics

Block	Sub-block	Characteristic
Life cycle	Product type life cycle	Marketing
		Development
		Sales
		Obsolescence support
	Product instance life cycle	Manufacturing
		Transport and stock
		Use
		Retirement
	Production system life cycle	Concept
		Design
		Implementation
		Use
		Retirement

Table 5 – Block "Interoperability": sub-blocks and characteristics

Block	Sub-block	Characteristic
Interoperability	Interoperability approach	Integration
		Federation
		Unification
	Interoperability concern	Business
		Process
		Service
		Data
	Interoperability layer	Business
		Function
		Information
		Communication
		Resources

Table 6 – Block "System engineering process": sub-blocks and characteristics

Block	Sub-block	Characteristic
System engineering process	Agreement processes	Acquisition process
		Supply process
	Organizational project-enabling processes	Life cycle model management process
		Infrastructure management process
		Portfolio management process
		Project management process
		Human resource management process
		Quality management process
		Knowledge management process
	Technical management processes	Project planning process
		Project assessment and control process
		Decision management process
		Risk management process
		Configuration management process
		Information management process
		Measurement process
		Quality assurance process
	Technical processes	Business or mission analysis process
		Stakeholder needs and requirements definition process
		System requirements definition process
		Architecture definition process
		Design definition process
		System analysis process
		Implementation process
		Integration process
		Verification process
		Transition process

Block	Sub-block	Characteristic
		Validation process
		Operation process
		Maintenance process
		Disposal process

Table 7 – Block "Relevance to SM": sub-blocks and characteristics

Block	Sub-block	Characteristic
Relevance to SM		Relevance level
		Motivation

Table 8 – Block "Validation": sub-blocks and characteristics

Block	Sub-block	Characteristic
Validation		Responsible person
		Checked
		Check date
		Warning
		Comment

5.2 Values of the characteristics

The data type of a characteristic value can be:

- Boolean,
- string (sequence of alphanumeric characters expressing meaningful text),
- enumeration (selection of a value from a fixed list of options),
- date (yyyy-mm or yyyy-mm-dd).

In the catalogue, the Boolean type is displayed:

- "1" for value 1,
- "-" for value 0.

Any value can be additionally displayed:

- blank (empty) if the value of the characteristic was not evaluated by the owner,
- "?" if the owner could not evaluate the characteristic.

All the characteristics of the blocks Object, Hierarchy, Life cycle, Interoperability and System engineering process have a Boolean data type.

5.3 Qualifier

The qualifier specifies which entity is expected to provide the value for the characteristic.

The qualifier can be:

- committee mandatory characteristic: The characteristic value is provided by the project/publication owner technical committee (TC, SC, ...);

– committee conditional characteristic: The characteristic value is provided by the project/publication owner technical committee (TC, SC, ...) only for certain values of another characteristic;
– committee optional characteristic: The characteristic value is provided by the project/publication owner technical committee (TC, SC, ...);
– SDO characteristic: The characteristic value is provided by the project/publication owner SDO;
– administrative characteristic: The characteristic value is used for the management of the catalogue by the standards map organization.

NOTE The font colour of the committee mandatory characteristics is red. The font colour of the committee conditional characteristics is purple.

6 Block "Identification"

6.1 Composition

Table 9 describes the composition of the block "Identification".

Table 9 – Composition of the block "Identification"

Block	Sub-block	Characteristic	Characteristic data type, possible values and example	Qualifier
Identification	Reference	Status	Enumeration: publication, project, both	SDO characteristic
		Standard number	String EXAMPLE IEC 62264-1	
	Publication	Edition	String EXAMPLE 2.0	
		Publication date	Date (yyyy-mm) EXAMPLE 2015-05	
	Project	Project number	String EXAMPLE IEC 62264-1 Ed. 3.0	
		Forecast publication date	Date (yyyy-mm) EXAMPLE 2017-05	
	Owner	Organization	String EXAMPLE ISO	
		Committee number	String EXAMPLE ISO/TC 184/SC 4	
		Committee title	String EXAMPLE Industrial data	
	ICS	International Classification for Standards	String EXAMPLE 25.040.40-35.240.50	
	Title	Standard title	String EXAMPLE Enterprise-control system integration	
		Standard short title	String EXAMPLE 1 IEC CDD EXAMPLE 2 FDT	Committee optional characteristic

6.2 Qualifier

All characteristics of the block "Identification" except the "Standard short title" are SDO characteristics.

The characteristic "Standard short title" is committee optional.

6.3 Sub-block "Reference"

6.3.1 Characteristic "Status"

The characteristic "Status" indicates if the standard is a project, a publication or both.

Its data type is enumeration.

Table 10 describes the possible values of "Status".

Table 10 – Possible values of "Status"

Possible values	Explanation
Publication	The standard was published.
Project	The standard is being developed and has not been published yet.
Both	The standard has been published and is also under revision (new edition or amendment)

6.3.2 Characteristic "Standard number"

The characteristic "Standard number" is the generic identification of the standard.

Its data type is string.

It does not include the edition nor the date.

It may designate a standard, a part, several parts or all parts of a multi-part standard.

If several parts are referenced, the separator between parts is "-".

EXAMPLE 1 IEC 62424 designates a standard.

EXAMPLE 2 IEC/TR 60071-4 designates a part.

EXAMPLE 3 ISO/TS 18101-1 designates a part.

EXAMPLE 4 IEC 62264 designates all parts of a multi-part standard.

EXAMPLE 5 ISO 3864-1,2 designates two parts of a multi-part standard.

6.4 Sub-block "Publication"

6.4.1 Characteristic "Edition"

The data type of the characteristic "Edition" is string.

"edx" stands for for the edition x, "edx + am1" for the edition x and amendment 1, "edx + am1 + am2" for the edition x, amendment 1 and amendment 2.

EXAMPLE 1 ed2

EXAMPLE 2 ed2 + am1 + am2

For a multi-part standard, it might be irrelevant to indicate an edition because parts may have different edition numbers. In this case, the field is empty.

6.4.2 Characteristic "Publication date"

The data type of the characteristic "Publication date" is date (format yyyy-mm).

EXAMPLE 2015-05

For a multi-part standard, it might be irrelevant to indicate a date because parts may have different dates. In this case, the field is empty.

6.5 Sub-block "Project"

6.5.1 Characteristic "Project number"

The data type of the characteristic "Project number" is string.

The simple format is used: "edx", for a new edition, "amx" for an amendment.

Different formats for the project number are used by the different organizations, the format of SM2 is an alternative to adopting one of them.

In ISO, there are both a project number based on the standard number, the edition and the current draft document, and a five-digit project id.

EXAMPLE 1 For ISO/CD 22549-2 ed.1- id.75244, the expected value in the SM2 table is "ed1".

In IEC, the current (it changed) project number is based on the standard number, the edition and possibly the amendment number.

EXAMPLE 2 For IEC 62769-115-2 ED2, the expected value in the SM2 table is "ed2".

EXAMPLE 3 For IEC 63044-5-2/AMD1 ED1, the expected value in the SM2 table is "am1".

EXAMPLE 4 For IEC 60038/AMD1/FRAG1 ED7, the expected value in the SM2 table is "am1".

6.5.2 Characteristic "Forecast publication date"

The data type of the characteristic "Forecast publication date" is date (format yyyy-mm).

EXAMPLE 2017-05

6.6 Sub-block "Owner"

6.6.1 Characteristic "Organization"

The characteristic "Organization" designates the SDO.

Its data type is enumeration.

EXAMPLE ISO

6.6.2 Characteristic "Committee number"

The intent of this characterization is to identify the committee responsible for approving the publication of the document.

In ISO and IEC, the format is " ISO" or " IEC" " /" "TC" "space" <TC number> ("/" "SC" "space" <SC number>).

The same format is used for other organizations ("Organization" "/" "sub-body" "/" "sub-body" ...). Its data type is string.

EXAMPLE 1 ISO/TC 184/SC 4

EXAMPLE 2 IEC/TC 65/SC 65E

6.6.3 Characteristic "Committee title"

For sub-committees, the characteristic "Committee title" includes the committee title (complete path), both titles are separated by "/".

Its data type is string.

EXAMPLE 1 Automation systems and integration/Industrial data

EXAMPLE 2 Industrial-process measurement, control and automation/ Devices and integration in enterprise systems

6.7 Sub-block "ICS"

6.7.1 Characteristic "International Classification for Standards"

6.7.1.1 Description

The characteristic "International Classification for Standards" refers to the hierarchical classification as defined by ISO (see ICS:2015 [5]).

This classification consists of three levels:

– Level 1 covers 40 fields of activity;

– Level 2 is a subdivision into 392 groups;

– Level 3 further divides into 909 sub-groups.

The ICS codes reflect this classification. Several ICS codes may be assigned to one standard (in this case, "-" is used as separator).

6.7.1.2 Format

The data type is string.

The value combines the ICS codes and does not contain the ICS titles. The separator between ICS codes is "-".

Each ICS code is a three-level code, the separator between levels is ".":

– Level 1: two-digit code;

– Level 2: three-digit code;

– Level 3: two-digit code (this third level is optional).

The format of the characteristic "International Classification for Standards" is <ICS code 1> ("-" <ICS code 2>) ("-" <ICS code 3>) ("-" <ICS code 4>)

EXAMPLE 1 29.120.20

EXAMPLE 2 75.020-25.040.40

6.7.1.3 Possible values

The possible values of the characteristic "International Classification for Standards" are defined in ICS:2015 [5].

6.7.1.4 Comments

The following text is an extract from ICS:2015 [5].

"1 - Purpose of the ICS

1.1 The ICS (International Classification for Standards) is intended to serve as a structure for catalogues of international, regional and national standards and other normative documents, and as a basis for standing-order systems for international, regional and national standards. It may also be used for classifying standards and normative documents in databases, libraries, etc.

1.2 The ICS should facilitate the harmonization of information and ordering tools such as catalogues, selective lists, bibliographies, and databases on magnetic and optical media, thus promoting the world-wide dissemination of international, regional and national standards and other normative documents.

2 - Description of the ICS

2.1 For the purposes of this document, the general term "standard" is applied to all international, regional and national normative documents, such as standards, technical reports, standardized profiles, technical specifications, technical regulations, guides, codes of practice, technology trends assessments, etc. and the drafts of such documents.

2.2 The ICS is a hierarchical classification which consists of three levels.

2.3 Level 1 covers 40 fields of activity in standardization, e.g. road vehicle engineering, agriculture, metallurgy. Each field has a two-digit notation, e.g.

43 Road vehicle engineering

2.4 The fields are subdivided into 392 groups (level 2). The notation of a group consists of the field notation and a three-digit group number, separated by a point, e.g.

43.040 Road vehicle systems

2.5 144 of the 392 groups are further divided into 909 sub-groups (level 3). The notation of a sub-group consists of the group notation and a two-digit number, separated by a point, e.g.

43.040.20 Lighting, signalling and warning devices"

6.7.2 Other characteristics

The sub-block "ICS" has only one characteristic: "International Classification for Standards".

6.8 Sub-block "Title"

6.8.1 Characteristic "Standard title"

The characteristic "Standard title" is the exact standard title as recorded by the SDO.

The data type is string.

EXAMPLE Industrial automation systems and integration – Product data representation and exchange – Part 239: Application protocol: Product life cycle support

6.8.2 Characteristic "Standard short title"

The characteristic "Standard short title" is a text that can be displayed in a small table cell or in a figure.

The data type is string, the maximum length is 16 characters.

EXAMPLE 1 IEC CDD

EXAMPLE 2 STEP

7 Block "Object"

7.1 Composition

Table 11 describes the composition of the block "Object".

Table 11 – Composition of the block "Object"

Block	Sub-block	Characteristic	Characteristic data type, possible values and example	Qualifier
Object	Type of standard	Basic standard	Boolean	Committee optional characteristic
		Terminology standard	Boolean	
		Testing standard	Boolean	
		Product standard	Boolean	
		Process standard	Boolean	
		Service standard	Boolean	
		Interface standard	Boolean	
		Data standard	Boolean	
	Type of object	Product	Boolean	
		Production system	Boolean	
		Enterprise	Boolean	
		Personnel	Boolean	
	Manufacturing process type	Batch	Boolean	
		Discrete	Boolean	
		Continuous	Boolean	

7.2 Qualifier

The characteristics of the block "Object" are committee optional.

7.3 Sub-block "Type of standard"

7.3.1 Description

The sub-block "Type of standard" is defined by ISO/IEC Guide 2:2004 [6].

7.3.2 Characteristics

Table 12 describes the characteristics of "Type of standard".

The data type for these characteristics is Boolean.

A standard can be of different types, so the value 1 can be given to several characteristics.

Table 12 – Characteristics of "Type of standard"

Characteristics	Explanation
Basic standard	• Definition standard that has a wide-ranging coverage or contains general provisions for one particular field NOTE A basic standard may function as a standard for direct application or as a basis for other standards. [SOURCE: ISO/IEC Guide 2:2004 [6], 5.1]
Terminology standard	• Definition standard that is concerned with terms, usually accompanied by their definitions, and sometimes by explanatory notes, illustrations, examples, etc. [SOURCE: ISO/IEC Guide 2:2004 [6], 5.2]
Testing standard	• Definition standard that is concerned with test methods, sometimes supplemented with other provisions related to testing, such as sampling, use of statistical methods, sequence of tests [SOURCE: ISO/IEC Guide 2:2004 [6], 5.3]
Product standard	• Definition standard that specifies requirements to be fulfilled by a product or a group of products, to establish its fitness for purpose NOTE 1 A product standard may include in addition to the fitness for purpose requirements, directly or by reference, aspects such as terminology, sampling, testing, packaging and labelling and, sometimes, processing requirements. NOTE 2 A product standard can be either complete or not, according to whether it specifies all or only a part of the necessary requirements. In this respect, one may differentiate between standards such as dimensional, material, and technical delivery standards. [SOURCE: ISO/IEC Guide 2:2004 [6], 5.4]
Process standard	• Definition standard that specifies requirements to be fulfilled by a process, to establish its fitness for purpose [SOURCE: ISO/IEC Guide 2:2004 [6], 5.5]
Service standard	• Definition standard that specifies requirements to be fulfilled by a service, to establish its fitness for purpose NOTE Service standards may be prepared in fields such as laundering, hotel-keeping, transport, car-servicing, telecommunications, insurance, banking, trading. [SOURCE: ISO/IEC Guide 2:2004 [6], 5.6]
Interface standard	• Definition standard that specifies requirements concerned with the compatibility of products or systems at their points of interconnection [SOURCE: ISO/IEC Guide 2:2004 [6], 5.7]
Data standard	• Definition of standard on data to be provided standard that contains a list of characteristics for which values or other data are to be stated for specifying the product, process or service NOTE Some standards, typically, provide for data to be stated by suppliers, others by purchasers. [SOURCE: ISO/IEC Guide 2:2004 [6], 5.8]

7.4 Sub-block "Type of object"

7.4.1 Description

The sub-block "Type of object" defines the focus of the standard in the system approach.

7.4.2 Characteristics

Table 13 describes the characteristics of "Type of object".

The data type for these characteristics is Boolean.

A standard can be applicable to different types of object, so the value 1 can be given to several characteristics.

Table 13 – Characteristics of "Type of object"

Characteristics	Explanation
Product	• Definition desired output or by-product of the processes of an enterprise Note 1 to entry: A product can be an intermediate product, end product, or finished goods from a business perspective. [SOURCE: IEC 62264-1:2013 [7], 3.1.27] • Comment In this notion of product, service is not included. The product is the result of a process and object of trade. • Examples of standard IEC 62683-1, *Low-voltage switchgear and controlgear – Product data and properties for information exchange – Part 1: Catalogue data* IEC 61987-1, *Industrial-process measurement and control – Data structures and elements in process equipment catalogues – Part 1: Measuring equipment with analogue and digital output*

Characteristics	Explanation
Production system	• Definition of production system system intended for production of goods Note 1 to entry: The concept of production system includes spare parts. Note 2 to entry: The concept of production system does not encompass the whole manufacturing facility. It excludes in particular the supporting infrastructure (such as building, power distribution, lighting, ventilation). It also excludes financial assets, human resources, raw process materials, energy, work pieces in process, end products. Note 3 to entry: Production systems may support different types of production processes (continuous, batch, or discrete). [SOURCE: IEC TS 62832-1:2016 [8], 3.1.20] • Definition of system something of interest as a whole or as comprised of parts NOTE Therefore a system may be referred to as an entity. A component of a system may itself be a system, in which case it may be called a subsystem. [SOURCE: ISO/IEC 10746-2:2009 [9], 6.5] and [ISO 15745-1:2003 [10]] • Comment The term also covers the production assets that are resources for the manufacturing system. • Examples of item Enterprise, factory, machine. • Example of standard IEC 61915-2, *Low-voltage switchgear and controlgear – Device profiles for networked industrial devices – Part 2: Root device profiles for starters and similar equipment*
Enterprise	• Definition human undertaking or venture that has explicit and clearly defined mission, goals, and objectives to offer products or services, or to achieve a desired project outcome or business outcome Note 1 to entry: When in operation, an enterprise functions as a system that realizes the mission through life cycle activities within a life history. Note 2 to entry: In this document, "enterprise" refers to concrete (e.g. company, project or extended supply chain enterprise) or abstract (e.g. virtual enterprise) entities. Note 3 to entry: One or more organizational unit participates in an enterprise. For an enterprise involving more than one such unit, each brings various resources forward for use, participating to the extent that it benefits from their involvement, which most often occurs to address some challenge that it is unable to address on its own. [SOURCE: ISO 15704:2019 [11], 3.4]
Personnel	• Definition all persons engaged in a given organization, including employer(s), employees or self-employed persons [SOURCE: ISO 9707:2008 [12], 2.25]

7.5 Sub-block "Manufacturing process type"

7.5.1 Description

A process is a sequence of chemical, physical or biological activities for the conversion, transport or storage of material or energy. Industrial manufacturing processes can generally be classified as continuous, discrete parts manufacturing or batch. How a process is classified depends on whether the output from the process appears in a continuous flow (continuous), in finite quantities of parts (discrete parts manufacturing), or in finite quantities of material (batches).

[SOURCE: IEC 61512-1:1997 [13], 4.1]

The sub-block "Manufacturing process type" describes which of these three types the standard applies to.

7.5.2 Characteristics

Table 14 describes the characteristics of "Manufacturing process type".

The data type for these characteristics is Boolean.

A standard can be applicable to different types of process, so the value 1 can be given to several characteristics.

Table 14 – Characteristics of "Manufacturing process type"

Characteristics	Explanation
Discrete	Discrete parts manufacturing processes In a discrete parts manufacturing process, products are classified into production lots that are based on common raw materials, production requirements and production histories. In a discrete parts manufacturing process, a specified quantity of product moves as a unit (group of parts) between workstations, and each part maintains its unique identity. [SOURCE: IEC 61512-1:1997 [13], 4.1.2]
Batch	Batch process process that leads to the production of finite quantities of material by subjecting quantities of input materials to an ordered set of processing activities over a finite period of time using one or more pieces of equipment [SOURCE: IEC 61512-1:1997 [13], 3.7] Batch processes The batch processes addressed in this standard lead to the production of finite quantities of material (batches) by subjecting quantities of input materials to a defined order of processing actions using one or more pieces of equipment. The product produced by a batch process is called a batch. Batch processes are discontinuous processes. Batch processes are neither discrete nor continuous; however, they have characteristics of both. [SOURCE: IEC 61512-1:1997 [13], 4.1.3]
Continuous	Continuous processes In a continuous process, materials are passed in a continuous flow through processing equipment. Once established in a steady operating state, the nature of the process is not dependent on the length of time of operation. Start-ups, transitions and shutdowns do not usually contribute to achieving the desired processing. [SOURCE: IEC 61512-1:1997 [13], 4.1.1]

8 Block "Hierarchy"

8.1 Composition

Table 15 describes the composition of the block "Hierarchy".

Table 15 – Composition of the block "Hierarchy"

Block	Sub-block	Characteristic	Characteristic data type, possible values and example	Qualifier
Hierarchy	Equipment hierarchy	Enterprise	Boolean	Committee optional characteristic
		Facility	Boolean	
		Station	Boolean	
		Device	Boolean	
	Functional hierarchy	Connected world	Boolean	Committee mandatory characteristic
		Business (L4)	Boolean	
		Operations management (L3)	Boolean	
		Control (L2)	Boolean	
		Sensors and actuators (L1)	Boolean	
		Process (L0)	Boolean	
		Product	Boolean	
		Motivation	String	

8.2 Qualifier

The characteristics of the sub-block "Equipment hierarchy" are committee optional.

The characteristics of the sub-block "Functional hierarchy" are committee mandatory.

8.3 Sub-block "Equipment hierarchy"

8.3.1 Description

The sub-block "Equipment hierarchy" defines which level in the role-based equipment hierarchy of the enterprise the standard deals with.

It is based on IEC 62264-1:2013 [7] (ISA 95) and IEC 61512-1:1997 [13] (ISA 88).

NOTE Annex C provides the mapping of the "Equipment hierarchy" to several existing hierarchy designations.

The mapping of the "Equipment hierarchy" on the legacy levels is documented in Clause C.7.

A standard can be applicable to different levels of the hierarchy, so the value 1 can be given to several characteristics.

8.3.2 Characteristics

Table 16 describes the characteristics of "Equipment hierarchy".

The data type for these characteristics is Boolean.

Table 16 – Characteristics of "Equipment hierarchy"

Characteristics	Explanation
Enterprise	• <u>Definition</u> one or more organizations sharing a definite mission, goals and objectives which provides an output such as a product or service [SOURCE: IEC 62264-1:2013 [1], 3.1.10]

Characteristics	Explanation
Facility	• Definition The facility hierarchy level concatenates the site and area hierarchy levels defined in the role-based equipment hierarchy of IEC 62264-1:2013 [1]. **site** identified physical, geographical, and/or logical component grouping of a manufacturing enterprise [SOURCE: IEC 62264-1:2013 [1], 3.1.39] **area** physical, geographical or logical grouping of resources determined by the site [SOURCE: IEC 62264-1:2013 [1], 3.1.2]
Station	• Definition The station hierarchy level concatenates the work center and work unit hierarchy levels defined in the role-based equipment hierarchy of IEC 62264-1:2013 [1]. **work center** equipment element under an area in a role-based equipment hierarchy that performs production, storage, material movement, or any other Level 3 or Level 4 scheduled activity [SOURCE: IEC 62264-1:2013 [1], 3.1.44] This generic term is more often used in batch production as "process cell", in continuous production as "production unit", in discrete production as "production line" and in storage or movement as "storage zone". **work unit** equipment element under a work center in a role-based equipment hierarchy that performs production, storage, material movement [SOURCE: IEC 62264-1:2013 [1], 3.1.45, modified] This generic term is more often used in batch and continuous production as "unit", in discrete production as "work cell" and in storage or movement as "storage unit".
Device	• Definition The device hierarchy level concatenates the equipment module and control module hierarchy levels defined in the role-based equipment hierarchy of IEC 61512-1:1997 [13]. **equipment module** A functional group of equipment that can carry out a finite number of specific minor processing activities. NOTES 1 An equipment module is typically centered around a piece of process equipment (a weigh tank, a process heater, a scrubber, etc.). This term applies to both the physical equipment and the equipment entity. 2 Examples of minor process activities are dosing and weighing. [SOURCE: IEC 61512-1:1997 [13], 3.16] **control module** The lowest level grouping of equipment in the physical model that can carry out basic control. NOTE This term applies to both the physical equipment and the equipment entity. [SOURCE: IEC 61512-1:1997 [13], 3.10]

8.4 Sub-block "Functional hierarchy"

8.4.1 Description

The sub-block "Functional hierarchy" defines which level in the functional hierarchy of the enterprise the standard deals with.

It is based on the functional hierarchy defined in IEC 62264-1:2013 [1] (ISA 95) with an upper level as defined in SGAM [14] and IEC PAS 63088:2017 [15] (RAMI 4.0) and a lower level as defined in IEC PAS 63088:2017 [15] (RAMI 4.0).

NOTE Annex C provides the description of the several existing hierarchies and the mapping of the "Functional hierarchy" to them.

8.4.2 Characteristics

Table 17 describes the characteristics of "Functional hierarchy".

The data type for these characteristics is Boolean.

A standard can be applicable to different levels of the hierarchy, so the value 1 can be given to several characteristics.

Table 17 – Characteristics of "Functional hierarchy"

Characteristics	Explanation
Connected world	It reflects the horizontal market operations in value added networks. EXAMPLE Network of factories
Business (L4)	Business planning, operation and logistics Level 4 functions involved in the business-related activities needed to manage a manufacturing organization [SOURCE: IEC 62264-1:2013 [1], 3.1.16] Establishing and executing the basic plant schedule for production, material use, delivery, shipping, determining inventory levels, operational management, etc. [SOURCE: IEC 62264-1:2013 [1], Figure 3]
Operations management (L3)	Operations management manufacturing operations management MOM activities within Level 3 of a manufacturing facility that coordinate the personnel, equipment and material in manufacturing [SOURCE: IEC 62264-1:2013 [1], 3.1.22] Level 3 functions involved in managing the work flows to produce the desired end-products [SOURCE: IEC 62264-1:2013 [1], 3.1.17] Work flow / recipe control to produce the desired end products. Maintaining records and optimizing the production process, dispatching production, detailed production scheduling, reliability assurance, etc. [SOURCE: IEC 62264-1:2013 [1], Figure 3]
Control (L2)	Level 2 functions involved in monitoring and controlling of the physical process [SOURCE: IEC 62264-1:2013 [1], 3.1.17] Monitoring, supervisory control and automated control of the production process [SOURCE: IEC 62264-1:2013 [1], Figure 3]
Sensors and actuators (L1)	Level 1 functions involved in sensing and manipulating the physical process [SOURCE: IEC 62264-1:2013 [1], 3.1.18]
Process (L0)	Level 0 actual physical process [SOURCE: IEC 62264-1:2013 [1], 3.1.19]
Product	The hierarchy level "Product" denotes the cooperating or collaborating product to be manufactured as an integral part of a smart manufacturing value-added process.

9 Block "Life cycle"

9.1 Composition

Table 18 describes the composition of the block "Life cycle".

Table 18 – Composition of the block "Life cycle"

Block	Sub-block	Characteristic	Characteristic data type, possible values and example	Qualifier
Life cycle	Product type life cycle	Marketing	Boolean	Committee conditional characteristic (the value of "Type of object" is "Product")
		Development	Boolean	
		Sales	Boolean	
		Obsolescence support	Boolean	
	Product instance life cycle	Manufacturing	Boolean	
		Transport and stock	Boolean	
		Use	Boolean	
		Retirement	Boolean	
	Production system life cycle	Concept	Boolean	Committee conditional characteristic (the value of "Type of object" is "Production system")
		Design	Boolean	
		Implementation	Boolean	
		Use	Boolean	
		Retirement	Boolean	

9.2 Qualifier

The characteristics of the block "Life cycle" are committee conditional.

The characteristics of the sub-blocks "Product type life cycle" and "Product instance life cycle" are provided if the value of the characteristic "Type of object" is "Product".

The characteristics of the sub-block "Production system life cycle" are provided if the value of the characteristic "Type of object" is "Production system".

9.3 Sub-block "Product type life cycle"

9.3.1 Description

The product type life cycle (see Figure 9) is the set of phases of a product type from the start of the marketing phase to the end of the product abandonment.

The product type life cycle begins with the marketing phase where market analysis is conducted and marketing requirements are published.

The marketing phase is followed by the development phase, in which the product is developed as a product type. The development includes design, simulation and test activities, production and sales ramp-up, and trials (piloting) in the targeted system environments. When the specified technical and commercial criteria have been met, the product is released for sale (see milestone 1). Following the conclusion of successful testing, production ramp-up and service preparation, the delivery release is achieved (milestone 2). This enables manufacturing of the product, which means, in the context of the introduced terminology, the instantiation of the product type starts.

The sales phase follows the development phase. The operational business with the product type finishes with the end of sales (see milestone 3). Typically, the end of production (see milestone 4) is after the end of the sales phase and depends on technical and economic conditions. An announcement of end of sales (milestone 3) should be communicated to enable users to cover their demands before end of production.

Standard service for the product begins with delivery release (see milestone 2) and ends with product abandonment (see milestone 6). The obsolescence support phase begins with the end of sales (see milestone 3) and finishes with product abandonment. The end of service (see milestone 5) occurs in the obsolescence support phase prior to product abandonment. This means that all product-related deliveries and standard services provided by the producer end with the product abandonment. An announcement of product abandonment (milestone 6) should be communicated to enable users to cover their service demands before end of product life cycle. After milestone 6, the product (type) is obsolete.

The sum of these phases for a product type is called the product life cycle. The term "cycle" is meant to express that there is a recurring sequence in the context of the product evolution. These innovation cycles result in new product versions of the product.

NOTE This description is derived from IEC 62890:2020 [16].

See also Annex B.

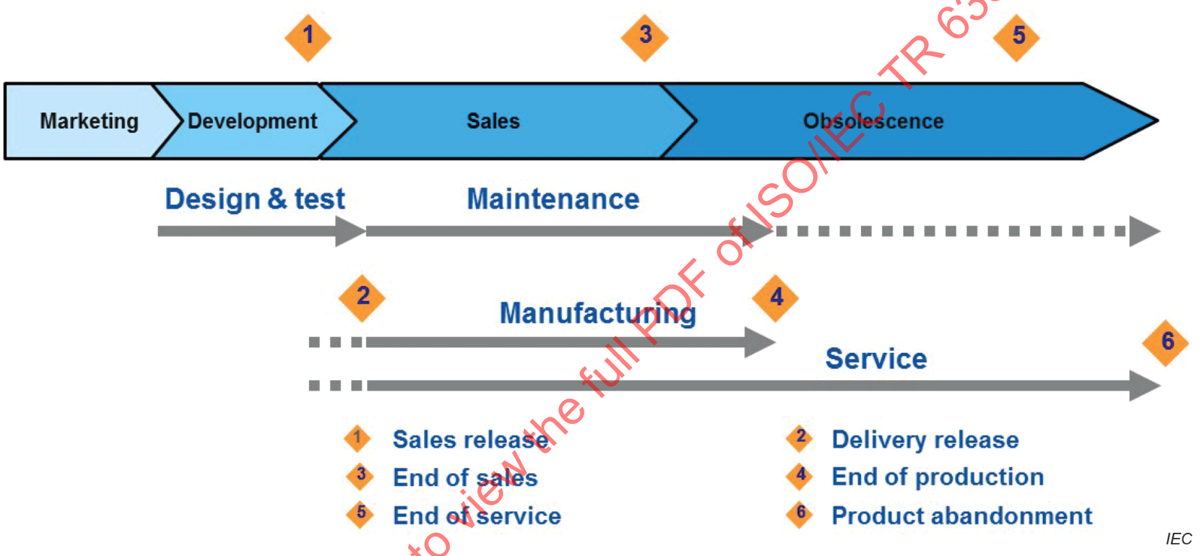


Figure 9 – Product type life cycle

9.3.2 Characteristics

Table 19 describes the characteristics of "Product type life cycle".

The data type for these characteristics is Boolean.

A standard can be applicable to different phases of the life cycle, so the value 1 can be given to several characteristics.

A standard can be applicable to different life cycles, so the value 1 can be given to characteristics in different sub-blocks of the "Life cycle" block.

Table 19 – Characteristics of "Product type life cycle"

Characteristics	Explanation
Marketing	Market analysis and marketing requirements
Development	Design, simulation and test activities, production and sales ramp-up, and trials
Sales	The product can be purchased by customers.
Obsolescence support	The product cannot be purchased by customers but the manufacturer still provides services.

9.4 Sub-block "Product instance life cycle"

9.4.1 Description

Product instance life cycle is the consecutive and interlinked phases of a product, from raw material acquisition or generation from natural resources to final disposal.

NOTE This is the definition of life cycle in ISO 14040:2006 [17], 3.1, but "stages of a product system" has been replaced with "phases of a product".

The product instance is concrete, manufactured and shipped to the customer. It is described by a product type that is documented in catalogues.

See also Annex B.

9.4.2 Characteristics

Table 20 describes the characteristics of "Product instance life cycle".

The data type for these characteristics is Boolean.

A standard can be applicable to different phases of the life cycle, so the value 1 can be given to several characteristics.

A standard can be applicable to different life cycles, so the value 1 can be given to characteristics in different sub-blocks of the "Life cycle" block.

Table 20 – Characteristics of "Product instance life cycle"

Characteristics	Explanation
Manufacturing	The product instance is manufactured.
Transport and stock	The product instance is shipped and stored.
Use	The product instance is used, it might have some outage periods and be repaired or upgraded. The product instance becomes an asset part of a production system and may play different roles during its time of use.
Retirement	The product is decommissioned, disposed of, recycled.

9.5 Sub-block "Production system life cycle"

9.5.1 Description

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

NOTE This is the definition of life cycle in ISO 19439:2006 [18], 3.42.

See also Annex B.

The phases of a production system life cycle are defined in ISO 15704:2019 [11] for example as shown in Figure 10 [SOURCE: ISO 15704:2019 [11], Figure B.2].

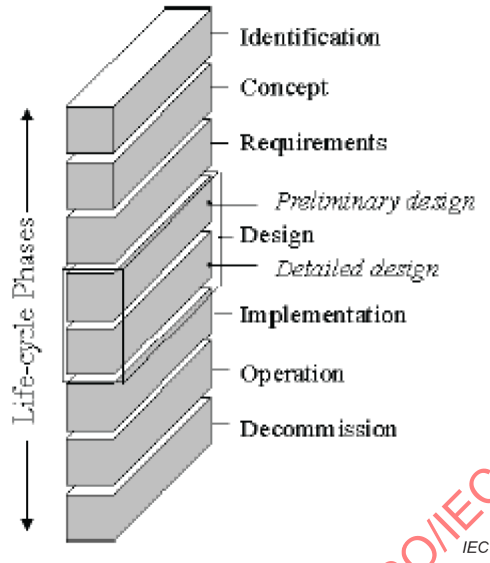


Figure 10 – GERA life cycle phases

9.5.2 Characteristics

Table 21 describes the characteristics of "Production system life cycle".

The data type for these characteristics is Boolean.

A standard can be applicable to different phases of the life cycle, so the value 1 can be given to several characteristics.

A standard can be applicable to different life cycles, so the value 1 can be given to characteristics in different sub-blocks of the "Life cycle" block.

Table 21 – Characteristics of "Production system life cycle"

Characteristics	Explanation
Concept	Identification, concept and requirements.
Design	Preliminary design and detailed design.
Implementation	Procurement, construction, commissioning.
Use	Operation, maintenance and refurbishment.
Retirement	Decommissioning, recycling and disposal.

10 Block "Interoperability"

10.1 General

Smart manufacturing involves the networking and integration of different companies through value networks.

Interoperability enables the exchange of entities (information objects or physical objects) and sharing among the heterogeneous systems within these value networks.

– Cross-domain interoperability is becoming increasingly important as business operations become more global and organizations from different domains are inter-connected. A common meta-model used as baseline for industry specific models enables cross-domain interoperability.
– Cross-asset interoperability will allow seamless integration of any asset, i.e. seamless device-to-cloud integration.

10.2 Composition

Table 22 describes the composition of the block "Interoperability".

Table 22 – Composition of the block "Interoperability"

Block	Sub-block	Characteristic	Characteristic data type, possible values and example	Qualifier
Interoperability	Interoperability approach	Integration		Committee mandatory characteristic
		Federation	Boolean	
		Unification	Boolean	
	Interoperability concern	Business	Boolean	
		Process	Boolean	
		Service	Boolean	
		Data	Boolean	
	Interoperability layer	Business	Boolean	
		Function	Boolean	
		Information	Boolean	
		Communication	Boolean	
		Resources	Boolean	

10.3 Qualifier

The characteristics of the block "Interoperability" are committee mandatory.

10.4 Sub-block "Interoperability approach"

10.4.1 Description

The sub-block "Interoperability approach" describes the way interoperability problems are solved and barriers are overcome [SOURCE: ISO 11354-1:2011 [19]].

10.4.2 Characteristics

Table 23 describes the characteristics of "Interoperability approach".

The data type for these characteristics is Boolean.

A standard can generally apply to one approach; nevertheless, the value 1 can be given to several characteristics.

Table 23 – Characteristics of "Interoperability approach"

Characteristics	Explanation
Integration	A common form is used to represent the exchanged entities. • Example "Integration" or "Unification" for ISO 10303 (all parts) [20]. STEP defines a full integrated approach, but some of its parts are used as constructs in systems and other standards, then they participate to the unification approach. • Additional explanations "In the integrated approach a common form shall be used to represent the exchanged entities. This common form shall be sufficiently expressive to capture those details that affect interoperability of the items to be exchanged, rather than the process or system as a whole. The common form is not necessarily an International Standard but needs to be agreed by participating enterprises in order to elaborate these entities and build systems accordingly." [SOURCE ISO 11354-1:2011 [19], 5.4.2]
Federation	Standardized interfaces are defined to ensure the communication and interoperability between applications developed independently. • Example "Federation" for IEC 62264-1:2013 [1], which addresses explicitly the federation approach with the definition of a standardized interface. "Federation" for ISO 15745-1:2003 [10] and ISO 16100:2009 [21]. • Additional explanations "In the federated approach, there is no sufficiently capable common form or meta-model to guide the interaction between enterprises that need to interoperate. The lack of capability is often related to different terminologies or methodologies that need to be resolved by business entity interaction. While there can be a common understanding between the business entities, in the federated approach, no business entity imposes their own models, languages and methods of work." [SOURCE ISO 11354-1: 2011 [19], 5.4.4]
Unification	A common meta-model, which is applicable for the participating entities and used as a common reference to map existing models' syntax and semantics is identified and detailed. • Example "Unification" for ISO 15704:2019 [11], which addresses the unification approach with the definition of a reference architecture and the building up of constructs (e.g. partial models). "Integration" or "Unification" for ISO 10303 (all parts) [20]. ISO 10303 (all parts) [20] (STEP) defines a full integrated approach, but some of its parts are used as constructs in systems and other standards, then they participate to the unification approach. • Additional explanations "In the unified approach, a common meta-model, which is applicable for the participating entities and used as a common reference to map existing models' syntax and semantics, shall be identified and detailed. This meta-model provides at least a reference vocabulary, but could be a complete ontology. Such a meta-model is not an executable entity. Instead, it shall provide a means for semantic equivalence to enable mapping between entities. Using this meta-model, a translation between the constituent entities is then possible. However, that translation might involve the loss of some information because the participating entities can have different extensions or instantiations of the same meta-model." [SOURCE ISO 11354-1:2011 [19], 5.4.3]

Additional information is given in

– ISO 11354-1:2011 [19],
– ISO 14258:1998 [22], 3.8.2, and
– ISO 15704:2019 [11].

10.5 Sub-block "Interoperability concern"

10.5.1 Description

The sub-block "Interoperability concern" describes the aspect of interaction or interoperation that is of interest to an enterprise stakeholder.

ISO 11354-1:2011 [19], 5.2.1 states that

"The interoperability concern viewpoint shall describe the kinds of concerns that are relevant for enterprise interoperability.

…

Data are used by services. Services are employed by processes to realize the business of the enterprise. From another perspective, the goal of an enterprise is to run its business. The business is realized through processes. Processes employ services that in turn need data to perform activities."

10.5.2 Characteristics

Table 24 describes the characteristics of "Interoperability concern".

The data type for these characteristics is Boolean.

A standard can apply to several concerns, so the value 1 can be given to several characteristics.

Table 24 – Characteristics of "Interoperability concern"

Characteristics	Explanation
Business	Business interoperation occurs when a particular business is understood and shared without ambiguity among interacting partners. [SOURCE ISO 11354-1:2011 [19], 5.2.5] It can be interpreted as context.
Process	Process interoperation occurs when either – a particular process is capable of receiving and using needed information and other entities provided by an external process, or conversely, – an external process is capable of receiving and using needed information and other entities from a process within the enterprise. [SOURCE ISO 11354-1:2011 [19], 5.2.4]
Service	Service interoperation occurs when either – a particular service is capable of receiving and using needed information provided by an external service, or conversely, – an external service is capable of receiving and using needed information from a service within the enterprise. [SOURCE ISO 11354-1:2011 [19], 5.2.3] It can be interpreted as conveyance.
Data	Data interoperation occurs when either – a particular entity is capable of receiving and using needed data items provided by an external source, or conversely, – an external source is capable of receiving and using needed data items from an entity within the enterprise. [SOURCE ISO 11354-1:2011 [19], 5.2.2] It can be interpreted as content.

10.6 Sub-block "Interoperability layer"

10.6.1 Description

The sub-block "Interoperability layer" is related to the concept of interoperability barrier from ISO 11354-1:2011 [19] as described in SGAM [14] (See the summary in Annex D).

10.6.2 Characteristics

Table 25 describes the characteristics of "Interoperability layer".

The data type for these characteristics is Boolean.

A standard can generally apply to one layer but also to several, so the value 1 can be given to several characteristics.

Table 25 – Characteristics of "Interoperability layer"

Characteristics	Explanation
Business	The business layer represents the business view on the information exchange related to smart manufacturing. It can be used to map regulatory and economic (market) structures and policies, business models, business portfolios (products and services) of market parties involved. Also, business capabilities and business processes can be represented in this layer. In this way it supports business executives in decision making related to (new) business models and specific business projects (business case) as well as regulators in defining new market models.
Function	The function layer describes functions and services including their relationships from an architectural viewpoint. The functions are represented independent from actors and physical implementations in applications, systems and components. The functions are derived by extracting the use case functionality which is independent from actors.
Information	The information layer describes the information that is being used and exchanged between functions, services and components. It contains information objects and the underlying canonical data models. These information objects and canonical data models represent the common semantics for functions and services in order to allow an interoperable information exchange via communication means.
Communication	The emphasis of the communication layer is to describe protocols and mechanisms for the interoperable exchange of information between components in the context of the underlying use case, function or service and related information objects or data models.
Resources	The emphasis of the resources layer is the physical distribution of all participating components in the smart manufacturing context. This includes system actors, applications, equipment (typically located at process and field level), control devices, network infrastructure (wired and wireless communication connections, routers, switches, servers) and any kind of computers.

11 Block "System engineering process"

11.1 General

ISO/IEC/IEEE 24748-1:2018 [23] gives a general overview of the system engineering process definitions, as background for treatment of life cycle processes. It shows the relationships of life cycle concepts to the hardware, human, services, process, procedure, facility and naturally occurring entity aspects of projects. It describes how its concepts relate to detailed process standards, for example, in the areas of measurement, project management and risk management.

The life cycle processes can be used by any organization when acquiring and using, as well as when creating and supplying, a system. Each process has a specific purpose, a set of expected outcomes and a set of activities. The life cycle processes are based on principles of ownership (a process is associated with a responsibility) and modularity. That is, all the parts of a process are strongly related (strongly cohesive), and the number of interfaces among the processes is kept to a minimum (loosely coupled).

These processes can be applied at any level in the hierarchy of a system structure. Selected sets of these processes can be applied throughout the life cycle for managing and performing the stages of a system life cycle. This is accomplished through the involvement of all stakeholders, with the goal of achieving customer satisfaction.

ISO/IEC/IEEE 15288:2015 [24] establishes a common framework of process descriptions for describing the life cycle of systems created by humans. It defines a set of processes and associated terminology from an engineering viewpoint. These descriptions are used in the explanations of the tables in Clause 11.

NOTE These processes are also described in ISO/IEC/IEEE 12207:2017 [25].

These processes are not intended to preclude or discourage the use of additional processes that organizations find useful.

The "Project management process" from ISO 21500:2012 [26] has been added in the characteristic "Organizational project-enabling processes". ISO 21500:2012 [26] provides guidance for project management and can be used by any type of organization, including public, private or community organizations, and for any type of project, irrespective of complexity, size or duration.

11.2 Composition

Table 26 describes the composition of the block "System engineering process".

Table 26 – Composition of the block "System engineering process"

Block	Sub-block	Characteristic	Characteristic data type, possible values and example	Qualifier
System engineering process	Agreement processes	Acquisition process	Boolean	Committee optional characteristic
		Supply process	Boolean	
	Organizational project-enabling processes	Life cycle model management process	Boolean	
		Infrastructure management process	Boolean	
		Portfolio management process	Boolean	
		Project management process	Boolean	
		Human resource management process	Boolean	
		Quality management process	Boolean	
		Knowledge management process	Boolean	
	Technical management processes	Project planning process	Boolean	
		Project assessment and control process	Boolean	
		Decision management process	Boolean	
		Risk management process	Boolean	
		Configuration management process	Boolean	

		Information management process	Boolean	
		Measurement process	Boolean	
		Quality assurance process	Boolean	
	Technical processes	Business or mission analysis process	Boolean	
		Stakeholder needs and requirements definition process	Boolean	
		System requirements definition process	Boolean	
		Architecture definition process	Boolean	
		Design definition process	Boolean	
		System analysis process	Boolean	
		Implementation process	Boolean	
		Integration process	Boolean	
		Verification process	Boolean	
		Transition process	Boolean	
		Validation process	Boolean	
		Operation process	Boolean	
		Maintenance process	Boolean	
		Disposal process	Boolean	

11.3 Qualifier

The characteristics of the block "System engineering process" are committee optional.

11.4 Sub-block "Agreement processes"

11.4.1 Description

Organizations are producers and users of systems. One organization (acting as an acquirer) can task another (acting as a supplier) for products or services. This is achieved using agreements.

11.4.2 Characteristics

Table 27 describes the characteristics of "Agreement processes".

The data type for these characteristics is Boolean.

A standard can generally apply to one process; nevertheless, the value 1 can be given to several characteristics.

Table 27 – Characteristics of "Agreement processes"

Characteristics	Explanation
Acquisition process	The purpose of the acquisition process is to obtain a product or service in accordance with the acquirer's requirements.
Supply process	The purpose of the supply process is to provide an acquirer with a product or service that meets agreed requirements.

11.5 Sub-block "Organizational project-enabling processes"

11.5.1 Description

The organizational project-enabling processes are concerned with providing the resources needed to enable the project to meet the needs and expectations of the organization's interested parties. The organizational project-enabling processes are typically concerned at a strategic level with the management and improvement of the organization's business or undertaking, with the provision and deployment of resources and assets, and with its management of risks in competitive or uncertain situations.

11.5.2 Characteristics

Table 28 describes the characteristics of "Organizational project-enabling processes".

The data type for these characteristics is Boolean.

A standard can generally apply to one process; nevertheless, the value 1 can be given to several characteristics.

Table 28 – Characteristics of "Organizational project-enabling processes"

Characteristics	Explanation
Life cycle model management process	The purpose of the life cycle model management process is to define, maintain, and assure availability of policies, life cycle processes, life cycle models, and procedures for use by the organization with respect to the scope of this document.
Infrastructure management process	The purpose of the infrastructure management process is to provide the infrastructure and services to projects to support organization and project objectives throughout the life cycle.
Portfolio management process	The purpose of the portfolio management process is to initiate and sustain necessary, sufficient and suitable projects in order to meet the strategic objectives of the organization.
Project management process	The purpose of the project management process is to identify project objectives, initiate project planning, define project detail, implement project activities and provision of deliverables, control process for monitoring, measuring, and performance against project plan to achieve objectives, and to close the project and report lessons learned.
Human resource management process	The purpose of the human resource management process is to provide the organization with necessary human resources and to maintain their competencies, consistent with business needs.
Quality management process	The purpose of the quality management process is to assure that products, services and implementations of the quality management process meet organizational and project quality objectives and achieve customer satisfaction.
Knowledge management process	The purpose of the knowledge management process is to create the capability and assets that enable the organization to exploit opportunities to re-apply existing knowledge.

11.6 Sub-block "Technical management processes"

11.6.1 Description

The technical management processes are concerned with managing the resources and assets allocated by organization management and with applying them to fulfil the agreements into which the organization or organizations enter.

11.6.2 Characteristics

Table 29 describes the characteristics of "Technical management processes".

The data type for these characteristics is Boolean.

A standard can generally apply to one process; nevertheless, the value 1 can be given to several characteristics.

Table 29 – Characteristics of "Technical management processes"

Characteristics	Explanation
Project planning process	The purpose of the project planning process is to produce and coordinate effective and workable plans.
Project assessment and control process	The purpose of the project assessment and Control process is to assess if the plans are aligned and feasible; determine the status of the project, technical and process performance; and direct execution to help ensure that the performance is in accordance with plans and schedules, within projected budgets, to satisfy technical objectives.
Decision management process	The purpose of the decision management process is to provide a structured, analytical framework for objectively identifying, characterizing and evaluating a set of alternatives for a decision at any point in the life cycle and select the most beneficial course of action.
Risk management process	The purpose of the risk management process is to identify, analyse, treat and monitor the risks continually.
Configuration management process	The purpose of configuration management (CM) is to manage and control system elements and configurations over the life cycle. CM also manages consistency between a product and its associated configuration definition.
Information management process	The purpose of the information management process is to generate, obtain, confirm, transform, retain, retrieve, disseminate and dispose of information, to designated stakeholders.
Measurement process	The purpose of the measurement process is to collect, analyse, and report objective data and information to support effective management and demonstrate the quality of the products, services, and processes.
Quality assurance process	The purpose of the quality assurance process is to help ensure the effective application of the organization quality management process to the project.

11.7 Sub-block "Technical processes"

11.7.1 Description

The technical processes are concerned with technical actions throughout the life cycle. Technical processes transform the needs of stakeholders into a product and service. By applying that product or operating that service, technical processes provide sustainable performance, when and where needed, in order to meet the stakeholder requirements and achieve customer satisfaction. The technical processes are applied in order to create and use a system, whether it is in the form of a model or is a finished product. The technical processes apply at any level in a hierarchy of system structure and at any phase in the life cycle.

11.7.2 Characteristics

Table 30 describes the characteristics of "Technical processes".

The data type for these characteristics is Boolean.

A standard can generally apply of one process; nevertheless, the value 1 can be given to several characteristics.

Table 30 – Characteristics of "Technical processes"

Characteristics	Explanation
Business or mission analysis process	The purpose of the business or mission analysis process is to define the business or mission problem or opportunity, characterize the solution space, and determine potential solution class(es) that could address a problem or take advantage of an opportunity.
Stakeholder needs and requirements definition process	The purpose of the stakeholder needs and requirements definition process is to define the stakeholder requirements for a system that can provide the capabilities needed by users and other stakeholders in a defined environment.
System requirements definition process	The purpose of the system requirements definition process is to transform the stakeholder, user-oriented view of desired capabilities into a technical view of a solution that meets the operational needs of the user.
Architecture definition process	The purpose of the architecture definition process is to generate system architecture alternatives, to select one or more alternative(s) that frame stakeholder concerns and meet system requirements, and to express this in a set of consistent views.
Design definition process	The purpose of the design definition process is to provide sufficient detailed data and information about the system and its elements to enable the implementation consistent with architectural entities as defined in models and views of the system architecture.
System analysis process	The purpose of the system analysis process is to provide a rigorous basis of data and information for technical understanding to aid decision-making across the life cycle.
Implementation process	The purpose of the implementation process is to realize a specified system element.
Integration process	The purpose of the integration process is to synthesize a set of system elements into a realized system (product or service) that satisfies system requirements, architecture, and design.
Verification process	The purpose of the verification process is to provide objective evidence that a system or system element fulfils its specified requirements and characteristics.
Transition process	The purpose of the transition process is to establish a capability for a system to provide services specified by stakeholder requirements in the operational environment.
Validation process	The purpose of the validation process is to provide objective evidence that the system, when in use, fulfils its business or mission objectives and stakeholder requirements, achieving its intended use in its intended operational environment.
Operation process	The purpose of the operation process is to use the system to deliver its services.
Maintenance process	The purpose of the maintenance process is to sustain the capability of the system to provide a service.
Disposal process	The purpose of the disposal process is to end the existence of a system element or system for a specified intended use, appropriately handle replaced or retired elements, and to properly attend to identified critical disposal needs (e.g., in accordance with an agreement, in accordance with organizational policy, or for environmental, legal, safety, security aspects).

12 Block "Relevance to SM"

12.1 Composition

Table 31 describes the composition of the block "Relevance to SM".

Table 31 – Composition of the block "Relevance to SM"

Block	Sub-block	Characteristic	Characteristic data type, possible values and example	Qualifier
Relevance to SM		Relevance level	Enumeration: None, Low, Medium, High	Committee mandatory characteristic
		Motivation	String	

12.2 Qualifier

The characteristics of the block "Relevance to SM" are committee mandatory.

12.3 Characteristic "Relevance level"

The "Relevance level" characteristic evaluates the relevance of the standard to smart manufacturing.

Annex A provides some definitions on the current understanding of the term "smart manufacturing" that may help for valuing this characteristic.

Its data type is enumeration.

Table 32 describes the possible values of the characteristic "Relevance level".

Table 32 – Possible values of "Relevance level"

Possible values	Explanation
None	The standard has no relevance to smart manufacturing concepts.
Low	The standard has low relevance to smart manufacturing concepts. It adds no new capabilities beyond those of existing manufacturing processes but does provide foundational capabilities for manufacturing in general.
Medium	The standard has medium relevance to smart manufacturing concepts. It adds new capabilities but those capabilities provide only incremental improvement in manufacturing processes.
High	The standard has high relevance to smart manufacturing concepts. It adds capabilities essential to smart manufacturing.

12.4 Characteristic "Motivation"

The "Motivation" characteristic is a textual justification of the value of the characteristic "Relevance level". It identifies the context for which the motivation applies.

Its data type is string.

13 Block "Validation"

13.1 Composition

Table 33 describes the composition of the block "Validation".

Table 33 – Composition of the block "Validation"

<table>
<tr><th>Block</th><th>Sub-block</th><th>Characteristic</th><th>Characteristic data type, possible values and example</th><th>Qualifier</th></tr>
<tr><td rowspan="5">Validation</td><td rowspan="5"></td><td>Responsible person</td><td>String</td><td rowspan="5">Administrative characteristic</td></tr>
<tr><td>Checked</td><td>Boolean</td></tr>
<tr><td>Check date</td><td>Date (yyyy-mm-dd)</td></tr>
<tr><td>Warning</td><td>Boolean</td></tr>
<tr><td>Comment</td><td>String</td></tr>
</table>

13.2 Qualifier

The characteristics of the block "Validation" are administrative.

13.3 Characteristics specification

The block "Validation" is intended for the management of the SM2 Catalogue. It enables identification of who is in charge of editing an entry. It is composed of the following characteristics:

– "Responsible person" (name and possibly company or SDO);
– "Checked" (indicates whether it is an assignment or if the editing is already done);
– "Check date" (indicates when the editing or the assignment was done);
– "Warning" (indicates that someone detected a possible issue);
– "Comment" (explains the issue).

Administrative characteristics: The characteristic value of the block "Validation" is used for the management of the catalogue by the standards map organization.

Annex A
(informative)

Compilation of definitions of smart manufacturing

A.1 Objective

Annex A is a compilation of definitions and descriptions about smart manufacturing that are currently available from committees in ISO and IEC.

It aims at supporting the TC/SC officers who are invited to provide characterization data on the standards owned by their committee.

NOTE 1 The references to [IEC/TC 65/JWG 21 joint with ISO/TC 184; Smart Manufacturing Reference Model (SMRM)] are picked from different revisions of that document still currently under development.

NOTE 2 The global economy is undergoing a profound transformation that impacts the whole of society. This is the "New Economy" described in [27]: an economy of experiences where companies can take advantage of breakthrough opportunities and reinvent the way they are doing business.

A.2 Definition

[SOURCE: IEC/SyCSM; SyCSM/6/DL]

IEC SyC SM (Systems Committee Smart Manufacturing of IEC) and ISO/SMCC (Smart Manufacturing Coordination Committee of ISO) endorsed the following definition of Smart Manufacturing.

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 Performance aspects include agility, efficiency, safety, security, sustainability or any other performance indicators identified by the enterprise.

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

A.3 Complements to the definition

[SOURCE: IEC/TC 65/JWG 21 joint with ISO/TC 184; Smart Manufacturing Reference Model (SMRM)]

In JWG 21, the above definition was discussed from the viewpoint of JWG 21, and the following interpretation was proposed:

"Manufacturing approach that improves its performance and technological aspects with the integrated use of intelligent decision making, processes, operations and resources enabled by emerging information technology in cyber, human and physical spheres to create and deliver sustainable products and services systems, which also collaborates with other domains within and among multiple enterprises' value chains.

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

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

A simplified mechanism for smart manufacturing was drafted with an eye towards clarifying the scope of JWG 21. The interpretation is the following:

"Smart manufacturing is extending manufacturing. It is characterized by independent actors sharing standardized information. The actors can pro-actively and re-actively act upon the information. The actors collaborate dynamically in network structures. This collaboration occurs among and within life cycles, on both strategic and operational levels, providing added value for organizations. The scope is to develop a reference architecture for smart manufacturing.

NOTE Examples of actors are companies, products, assets, processes and parts."

As another characterization of the mechanism for smart manufacturing, a new interpretation was drafted as:

"Set of methodologies and technologies for making goods and providing services with manufacturing systems that are designed with learning capability and operated based on product/service requirements so that it can respond in real time to meet changing demands and conditions in the factory, in the supply network and in customer needs, and can improve itself continuously.

This is obtained by the intensive use of digital technology (including IoT) to integrate products, production systems and business activities through their life cycles and value chains, and increasing decentralized decision making."

A.4 Vision

[SOURCE: ISO SAG Industry4.0/SM, Final report to TMB, Clause 2. The vision of Smart Manufacturing, September 2016]

Smart manufacturing leads to the emergence of agile, real-time optimized, self-organizing value chains, which are highly adaptive to fast changing socio-technical environments. This dynamic requires an appropriate standardized interface and harmonized business processes. This vision of smart manufacturing is characterized by:

- Enhanced product flexibility:

  It will be possible to incorporate individual customer and product specific features into the design, configuration, ordering, planning, production, operation and recycling phases. One-off items (lot size 1 in mass production) and very small quantities of products, services and processes will become possible, also supported by new production methods, such as 3D printing, Artificial Intelligence and mobile robots.

- New partnerships:

  A new level of socio-technical interaction will take place between all the actors and resources involved in design, manufacturing and operation, with networks of manufacturing resources that are autonomous and capable of controlling themselves in response to different situations. Smart factories will be embedded into inter-company value networks for both the manufacturing process and the manufactured product, achieving seamless convergence of the digital and physical worlds.

- New intrinsic built-in product properties:

  The smart products in smart manufacturing are uniquely identifiable in their respective contexts and may, in these contexts, be located at all times. Finished goods know the parameters within which they can function optimally and are able to recognize signs of wear and tear. Some of them may also communicate with other entities. Explicit agreements on clear policies on what to communicate to whom, and when, are needed.

- Flexible work organization:

  Workers are capable of controlling, regulating and configuring smart manufacturing resource networks and manufacturing steps with greater compatibility between their work and their personal needs.

- Fast, functionally safe, available communication networks:

  Robust, secure communication infrastructure assures safety, privacy, self-configuration and ease of use.

- Scalable, distributed manufacturing:

  Capability for lot size 1 and the possibility of very small quantities enables the demand for fast delivery of individual goods, and makes attractive manufacturing closer to industrial markets.

- Environmental sustainability:

  Less energy and materials use through improved and precise management, logistics and manufacturing, aiming for manufacturing and maintenance that produce no waste or pollution while resilient to constantly changing situations.

- Servitization:

  Manufacturing capacity results from supplier-based integration of physical products and value adding services often provided in real-time.

A.5 Difference from the manufacturing to date

[SOURCE: IEC/TC 65/JWG 21 joint with ISO/TC 184, Smart Manufacturing Reference Model (SMRM)]

The main changes of smart manufacturing from the conventional manufacturing can be listed as:

- New value creation:
  - Service orientation in the way manufacturing occurs and products are utilized.
- Automation innovation:
  - Product embedded in a system as a part of the automation solution – Smart work-in-process can have built in tracking and diagnostics capabilities that are utilized by the manufacturing operation and during the product use phases;
  - Elimination of offline engineering in favour of online configuration by technologically advanced devices capable of computational work and autonomous decision-making at the point of value creation.
- Higher interoperability:
  - Interoperability facilitated by system(s) characterized by their standardized capabilities;
  - Vertical interoperability (integration, federation, …) – New aspects include passive objects/assets, products communicating with equipment, internet and cloud technologies;
  - Horizontal interoperability (integration, federation, …) (Logistics, Conceptualization, Design, Procurement, Construction, Commission Production, Development, …);

NOTE It may be better to combine the two bullets above. The intention is that products and systems "communicate". This is more than just interoperability – it is the interaction up/down in the manufacturing operations, and the real-time interaction in the supply chain.

  - Interaction and cooperation across and between all life cycles – from internal value chains to value network partners;
  - Technical solution for legal issues e.g., negotiations between two machines, data privacy, etc.
- Comprehensive digitalization:

  - Thorough digitalization of manufacturing processes based on comprehensive Information Communication Technology (ICT) infra-structure;
  - Coexistence of real things and their Digital Twin.
- Information and knowledge intensive:
  - Data, Information and Knowledge exchange inside and outside of manufacturing entities and between operating technology and information technology become ubiquitous;
  - New communication – Each object/asset can communicate with surrounding object/asset in scope;
  - New business models arising from data – Data analytics is one aspect. Data that is portable (not constrained within a particular thing) enables more flexible applications, such as digital twinning and simulation.
- Computation intensive:
  - Impact of high speed real time processes and effect on integration of cyber-physical systems (CPS).
- Human centric:
  - Self-improvement adaptive decision support systems interacting with humans – Some decision support systems rely upon human-the-loop for final decision;
  - Refined roles of employees in manufacturing enterprises, contributing to high value work.

The changes lead to:

- Individualization (up to lot size 1 in mass production) of products, services and processes;
- Networking of systems, which results in highly complicated structures and CPS;
- Value creation through new business models and subsequent services;
- Evolution of safety, security, organization, processes and work design;
- Impact on human productivity and innovation cycles.

A.6 New technologies for smart manufacturing

[SOURCE: IEC/TC 65/JWG 21 joint with ISO/TC 184; Smart Manufacturing Reference Model (SMRM)]

New technologies like 3D printing and artificial intelligence have created a paradigm shift in manufacturing and revealed a new world of making. New technologies for smart manufacturing could be categorized into fundamental concepts, factory related technologies, enabling technologies, communications, marketing and applications. These technologies include:

- Fundamental Concepts
  - Digital twin: Digital twin refers to a digital replica of physical assets (physical twin), processes and systems that can be used for various purposes [*Minds + Machines: Meet A Digital Twin*. YouTube. GE Digital. Retrieved 26 July 2017]. The digital representation provides both the elements and the dynamics of how an Internet of Things device operates and lives throughout its life cycle.
  - Digital thread: Digital thread is a communication framework that connects traditionally separated elements in manufacturing processes and provides an integrated view of an asset throughout the manufacturing life cycle.
  - Cyber-physical system: A cyber-physical system (CPS) is a mechanism that is controlled or monitored by computer-based algorithms, tightly integrated with the Internet and its users. In cyber-physical systems, physical and software components are deeply intertwined, each operating on different spatial and temporal scales, exhibiting multiple and distinct behavioural modalities, and interacting with each other in a myriad of ways that change with context.

- Factory related
  - Digital factory: A digital factory uses digital technology to model, communicate and to operate the manufacturing process. This arrangement of technology allows managers to configure, model, simulate, assess and evaluate items, procedures and system before the factory is constructed. The digital factory gives answers for configuration, design, screen and control of a production system.
  - MEMS: Microelectromechanical systems (MEMS, also written as micro-electro-mechanical, MicroElectroMechanical or microelectronic and microelectromechanical systems and the related micromechatronics) is the technology of microscopic devices, particularly those with moving parts. It merges at the nano-scale into nanoelectromechanical systems (NEMS) and nanotechnology. They usually consist of a central unit that processes data (the microprocessor) and several components that interact with the surroundings such as microsensors.
  - Human-machine interaction: a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them.
  - Advanced Robotics: advanced robots, also known as smart machines, operate autonomously and can communicate directly with manufacturing systems. By evaluating sensory input and distinguishing between different product configurations, these machines are able to solve problems and make decisions independent of people. These robots are able to complete work beyond what they were initially programmed to do and have artificial intelligence that allows them to learn from experience [*On the Journey to a Smart Manufacturing Revolution*. www.industryweek.com. Retrieved 2016-02-17]. These machines have the flexibility to be reconfigured and re-purposed. This gives them the ability to respond rapidly to design changes and innovation, which is a competitive advantage over more traditional manufacturing processes [NIST, US Department of Commerce, *Robotic Systems for Smart Manufacturing*. www.nist.gov. Retrieved 2016-03-04]. An area of concern surrounding advanced robotics is the safety and well-being of the human workers who interact with robotic systems. Traditionally, measures have been taken to segregate robots from the human workforce, but advances in robotic cognitive ability have opened up opportunities, such as cobots, for robots to work collaboratively with people.
  - Additive manufacturing: is any of various processes in which material is joined or solidified under computer control to create a three-dimensional object, with material being added together (such as liquid molecules or powder grains being fused together).
  - Mass customization: Mass customization is the use of flexible computer-aided manufacturing systems to produce custom output. Such systems combine the low unit costs of mass production processes with the flexibility of individual customization.
  - Predictive maintenance: Predictive maintenance has the following meanings: the care and servicing by personnel for the purpose of maintaining equipment in satisfactory operating condition by providing for systematic inspection, detection, and correction of incipient failures either before they occur or before they develop into major defects; the work carried out on equipment in order to avoid its breakdown or malfunction. It is a regular and routine action taken on equipment in order to prevent its breakdown. Maintenance, including tests, measurements, adjustments, parts replacement, and cleaning, performed specifically to prevent faults from occurring.
- Enabling technologies:
  - Edge computing: Edge computing is a method of optimizing cloud computing systems by taking the control of computing applications, data, and services away from some central nodes (the "core") to the other logical extreme (the "edge") of the Internet which makes contact with the physical world.
  - Artificial intelligence: The traditional problems (or goals) of AI research include reasoning, knowledge representation, planning, learning, natural language processing, perception and the ability to move and manipulate objects. General intelligence is among the field's long-term goals. Approaches include statistical methods, computational intelligence, and traditional symbolic AI. Many tools are used in AI, including versions of search and mathematical optimization, artificial neural networks,

and methods based on statistics, probability and economics. Latest research interests of AI include deep learning, reinforcement learning, etc.

- Big data: Big data is data sets that are so big and complex that traditional data-processing application software are inadequate to deal with them. Big data challenges include capturing data, data storage, data analysis, search, sharing, transfer, visualization, querying, updating, information privacy and data source.
- Cloud computing: Cloud computing is an information technology (IT) paradigm that enables ubiquitous access to shared pools of configurable system resources and higher-level services that can be rapidly provisioned with minimal management effort, often over the Internet.
- AR/VR: Augmented Reality (AR) is an interactive experience of a real-world environment whose elements are "augmented" by computer-generated perceptual information, sometimes across multiple sensory modalities, including visual, auditory, haptic, somatosensory, and olfactory. Virtual reality (VR) is an interactive computer-generated experience taking place within a simulated environment, that incorporates mainly auditory and visual, but also other types of sensory feedback like haptic. This immersive environment can be similar to the real world or it can be fantastical, creating an experience that is not possible in ordinary physical reality.

- Communication
  - 5G: 5G is the term used to describe the next-generation of mobile networks beyond the 4G LTE mobile networks of today. 5G brings three new aspects to the table: greater speed (to move more data), lower latency (to be more responsive), and the ability to connect a lot more devices at once (for sensors and smart devices).
  - TSN: Time-Sensitive Networking (TSN) is a set of standards under development by the Time-Sensitive Networking task group of the IEEE 802.1 working group. The three basic components of TSN are: (1) time synchronization – all devices that are participating in real-time communication need to have a common understanding of time; (2) scheduling and traffic shaping – all devices that are participating in real-time communication adhere to the same rules in processing and forwarding communication packets; (3) selection of communication paths, path reservations and fault-tolerance – all devices that are participating in real-time communication adhere to the same rules in selecting communication paths and in reserving bandwidth and time slots, possibly utilizing more than one simultaneous path to achieve fault-tolerance.
  - NB-IoT: Narrowband IoT (NB-IoT) is a Low Power Wide Area Network (LPWAN) radio technology standard developed by 3GPP to enable a wide range of cellular devices and services. NB-IoT focuses specifically on indoor coverage, low cost, long battery life, and high connection density.
- Marketing
  - Business intelligence: Business intelligence (BI) comprises the strategies and technologies used by enterprises for the data analysis of business information. In [*Minds + Machines: Meet A Digital Twin*. YouTube. GE Digital. Retrieved 26 July 2017] BI technologies provide historical, current and predictive views of business operations. Common functions of business intelligence technologies include reporting, online analytical processing, analytics, data mining, process mining, complex event processing, business performance management, benchmarking, text mining, predictive analytics and prescriptive analytics.

Annex B
(informative)

Life cycles

B.1 General

Annex B gives additional information on the concept described in the main body text and presents legacy life cycles.

B.2 Product life cycle

The product is the result of the manufacturing process. It can become a component of a manufacturing system or be consumed.

The differentiation between product types and product instances is fundamental.

Each product instance is an instantiation of a product type. The product type is an abstract concept generally defined in a catalogue where it is linked to different standardized attributes.

A product type can refer to:

– a part of a product as well as a final product: for instance, a spare part of a product has a product type, whereas the final product has also its specific product type. A link needs to be established to indicate the relation between both products.
– a product type can also refer to the standardized grouping of one or more product types. For instance, a manufactured part may be available on the market on different packaging depending on the quantity.

The product instance is concrete, manufactured and shipped to the customer. It can be a final product or a part of the final product, as well as a grouping of final products. A link can be established to indicate the relation between both instances.

Identification of product type and product instance is crucial.

The product type life cycle can be described with different granularities. Figure B.1 shows a decomposition into four or five phases:

– marketing, which can be split into market analysis and marketing requirements;
– development;
– sales;
– obsolescence support, which can be abbreviated to obsolescence.

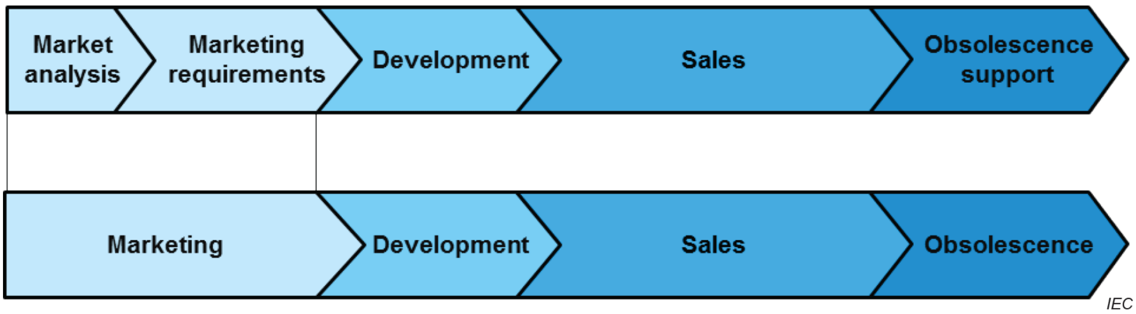


Figure B.1 – Product type life cycle

Generally a product type evolves over time, as shown in Figure B.2.

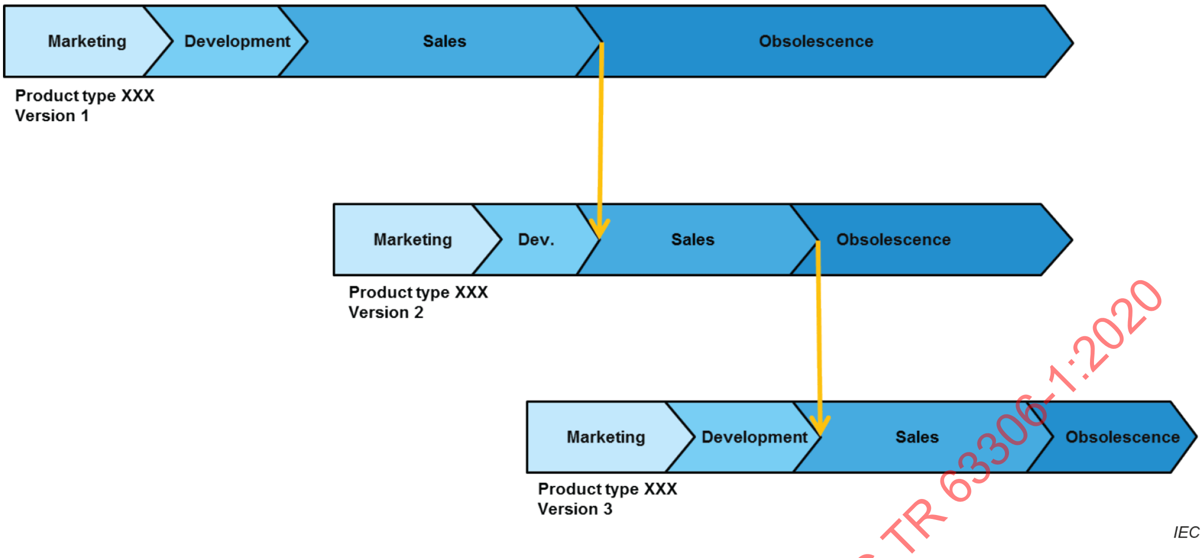


Figure B.2 – Versions of a product type

Different versions of a product type may be marketed by a manufacturer over the same period of time possibly in different region of the world because of logistics constraints.

After a certain period of time the product type is replaced by a new range corresponding to a new generation benefiting from new technologies or a better mastery of the manufacturer development team or meeting new regulatory requirements for economic or societal purposes.

The product type has a life cycle because the feedback of previous version(s) is the basis of the improvement of the following one (see Figure B.3).

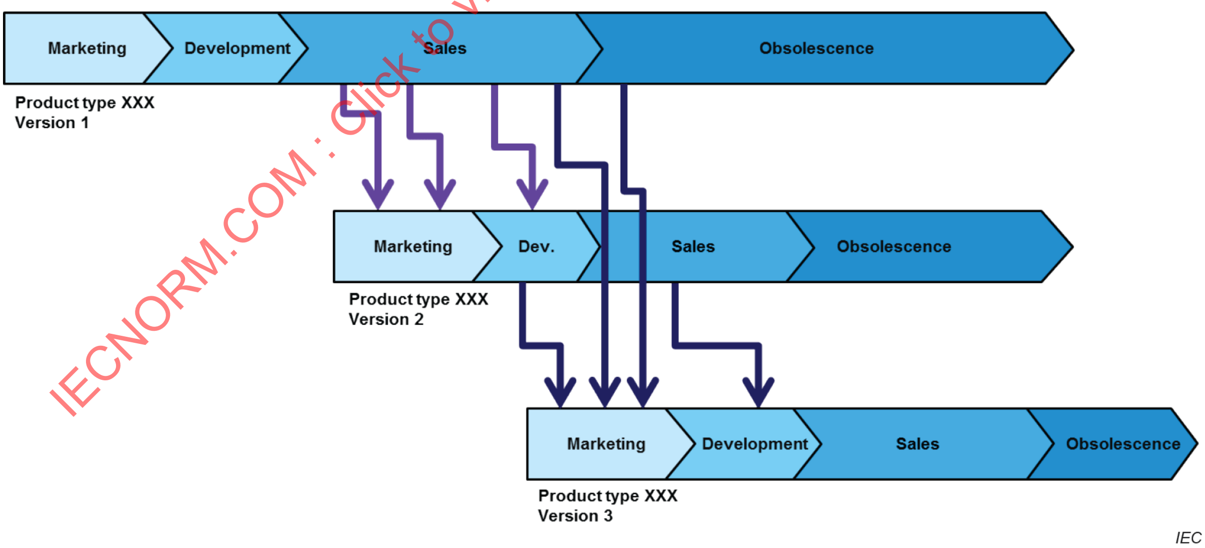


Figure B.3 – Product type improvement

The product instance has a life time, not cycle, because it goes from birth to death. The product instance life cycle can be described with different granularities. Figure B.4 show a decomposition into four phases:

– manufacturing;

– transport and stock;

– use;
– disposal.

Figure B.4 – Product instance life time

The life time of a product instance and the life cycle of its product type are linked by the manufacturing phase (see Figure B.5). Generally, the life time of a product instance exceeds the end of its product type life cycle. In some cases, the customer gets the insurance that the manufacturer will guarantee the product maintenance for a contractual period of time (nuclear industry for example).

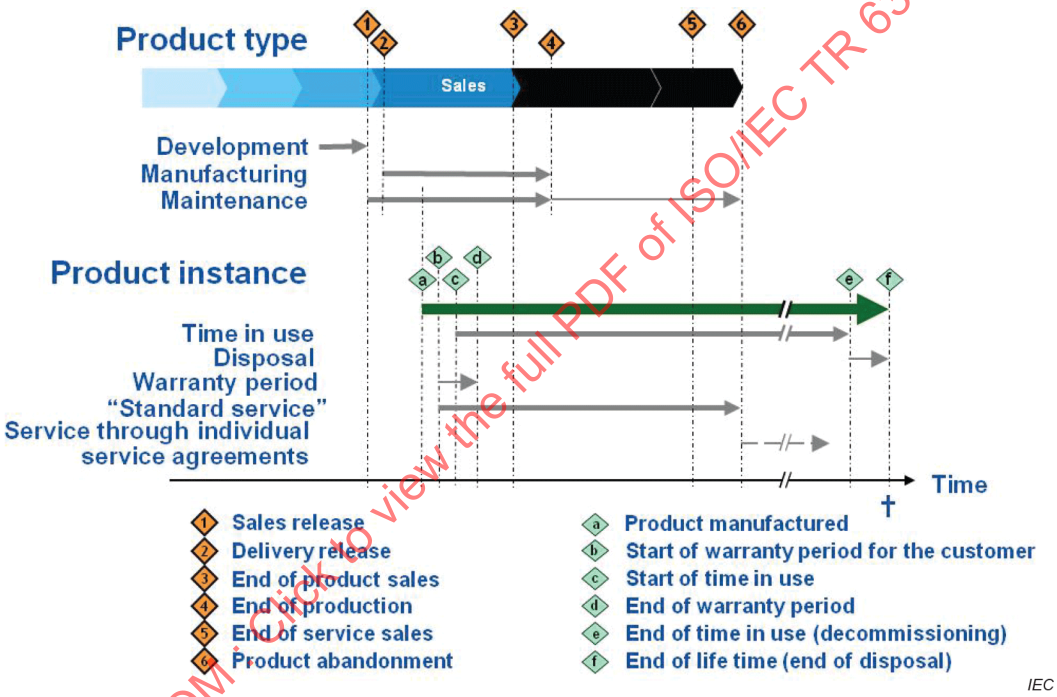


Figure B.5 – Product instance and product type

B.3 Production system life cycle

The production system is composed of production assets. These production assets are products from the component manufacturer point of view.

The production system life cycle can be described with different granularities. Figure B.6 shows a decomposition into ten phases:

– identification;
– concept;
– requirements;
– design;
– procurement;
– construction;

– commissioning;
– operation and maintenance in parallel with refurbishment;
– decommissioning;
– disposal.

Figure B.6 – Production system life cycle

The enterprise that owns the production system has business relations with different external actors: the device manufacturers and distributors, the machine manufacturers, the system integrator (see Figure B.7).

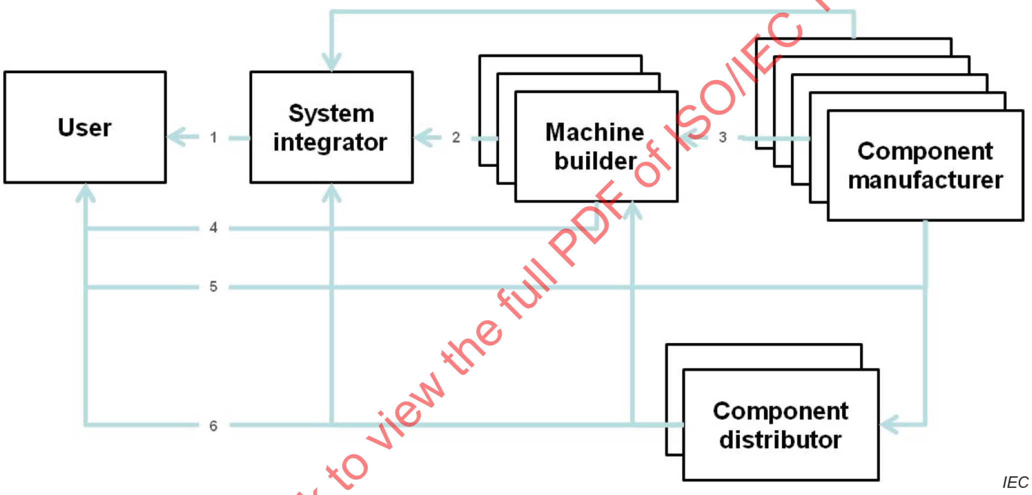


Figure B.7 – The user and the external actors

One of the issues that the user faces is the incompatible format of information provided by these actors, especially between the system integrator and the user (see Figure B.8), which makes it difficult to perform an efficient asset management.

A second issue is the lack of interoperability of the digital system representation provided by the system integrator and the tools used by the user's maintenance team.

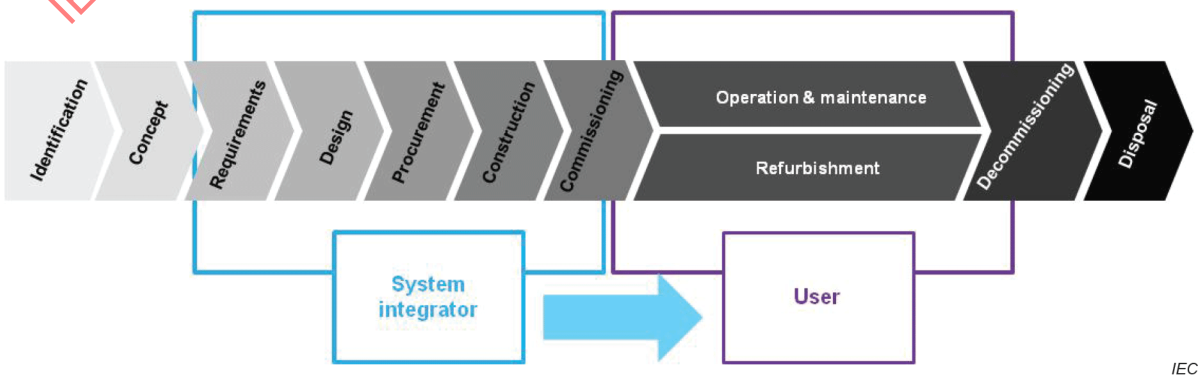


Figure B.8 – From the design to maintenance

The product type life cycles are getting shorter because the component manufacturer needs to be competitive. The manufacturing system owner wants to extend the life time of its manufacturing system. This may lead to problems when a component needs to be replaced and no instance of its product type is available on the market anymore (see Figure B.9).

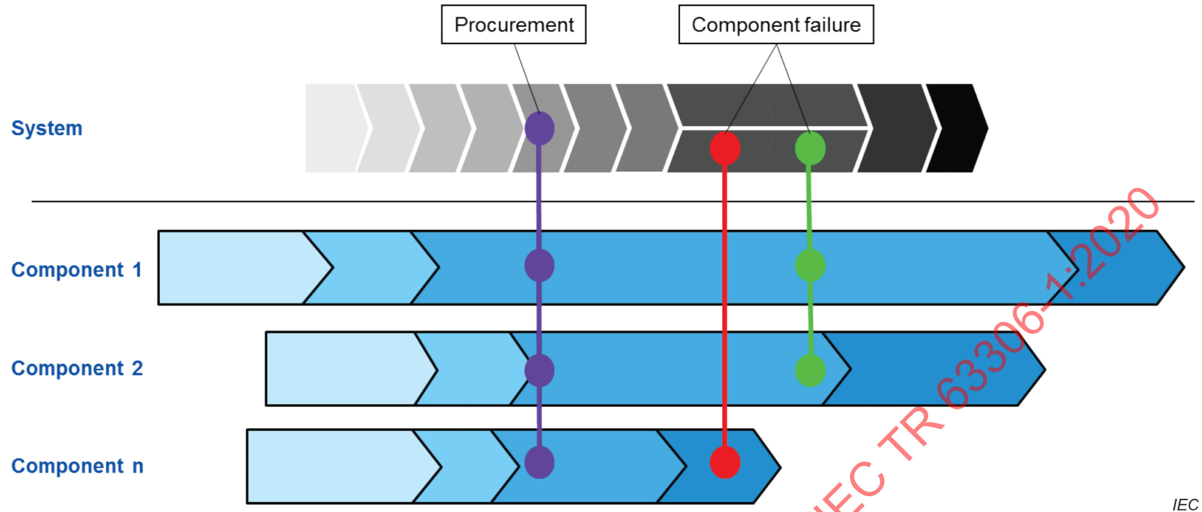


Figure B.9 – Spare component discontinued

B.4 Supply chain life cycle

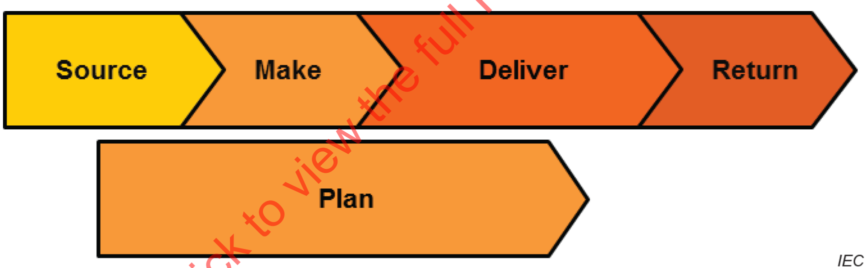


Figure B.10 – Supply chain life cycle

The product supply chain life cycle (see Figure B.10) encompasses all product flows and product information relating to these flows at all levels of the product life cycle management. Several supply chains need to be taken into account:

– Supply chain of the production system.
– Upstream supply chain: product flows that are consumed by the manufacturing process.
– Manufacturing supply chain: flows of resources (primary goods, spare parts, machine, robots, human) within the manufacturing area (or during the manufacturing process).
– Downstream supply-chain: manufactured goods supply chain, from the plant to the consumer (B2B or B2C), through different intermediaries.
– The whole supply chain: all of the previous supply chains.

The digitization of industrial activities implies that physical products, from their conception and design stage onward, are digitally represented, identified and actionable (The digital product needs the connection with the physical product and vice-versa). These representations and identifications apply to product types and instances during the product life cycle and are crucial for supply chain optimization. Instances are more commonly used from the operation stage onward.

Identification of product types is a key for all stakeholders across the supply chain to access or share generic information (for instance through catalogues and data pools) pertaining to the specifications of a product: in the supply chain context, this information will be used to find similar or compatible products to replace a missing one, identifying spare parts, ordering a specific product, managing stocks and inventories, optimizing deliveries according to the product specifications (size, weight, etc.), identifying counterfeited products, managing product removal on the market, etc. Robots also need generic information on products in order to handle them correctly (size, weight, solidity, etc.). Final consumers may want to have access to these data when trying to sell them on second-hand markets.

Identification of product instances is crucial to access and share information between stakeholders across the supply chain to ensure product traceability, motivated by security or optimization purposes: allowing targeted product recalls, personalized production, maintenance optimization, product authentication, stock and delivery mutualization and optimization. The product traceability chain is ensured via the publication and sharing of information on events (what, where, when, why) and is called events traceability. "Warning" indicates that someone detected a possible mistake.

B.5 Characteristic "RAMI4.0 Life cycle"

B.5.1 Description

The characteristic "RAMI4.0 Life cycle" is used to describe an asset at a particular point in time during its lifetime, from its production and value-added use right up to its disposal. [SOURCE: IEC PAS 63088:2017 [15]]

With this characteristic, the asset is characterized by its state at a particular time at a particular location. Industry 4.0 offers great potential for improvement throughout the life cycle of products, machines, factories, etc.

IEC 62890:2020 [16] is a reference for consideration of the life cycle. The fundamental distinction between type and instance is of central importance in those considerations.

B.5.2 Possible values

Table B.1 describes the possible values of the characteristic "RAMI4.0 Life cycle".

Table B.1 – Possible values of "RAMI4.0 Life cycle"

Possible values	Explanation
type_development type_maintenance/usage	Type: A type is always created with the initial idea, i.e., as a product comes into being in the development phase. This covers the placing of design orders, development and testing up to the first sample and prototype production. The type of the product, machine, etc. is thus created in this phase. On conclusion of all tests and validation, the type is released for series production.
instance_production instance_maintenance/usage	Instance: Products are manufactured industrially on the basis of the general type. Each manufactured product then represents an instance of that type, and, for example, has a unique serial number. The instances are sold and delivered to customers. For the customer, the products are initially once again only types. They become instances when they are installed in a particular system. The change from type to instance may be repeated several times. Improvements reported back to the manufacturer of a product from the sales phase can lead to an amendment of the type documents. The newly created type can then be used to manufacture new instances. Similarly, to each individual instance, then, the type is also subject to use and updating.

B.6 Characteristic "IMSA Life cycle"

B.6.1 Description

Life cycle means a series of mutually connected value creation activities of the stages 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, and the life cycle components of different industries are different.

B.6.2 Possible values

Table B.2 describes the possible values of the characteristic "IMSA Life cycle".

Table B.2 – Possible values of "IMSA Life cycle"

Possible values	Explanation
Design	Design refers to the process in which the construction, simulation, verification, optimization and other research and development activities are conducted on the demands in accordance with 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 human, equipment, materials and other resources.
Logistics	Logistics refers to the process from the goods supplied to their destinations.
Sales	Sales refers to the business activity in which the products or commodities are transferred from the enterprise to the clients.
Service	Service refers to the process and its corresponding result of a series of activities generated in the mutual process between the provider and the clients, including recycling.

Annex C
(informative)

Hierarchies

C.1 General

Annex C presents legacy hierarchies.

C.2 Characteristic "Equipment hierarchy" of IEC 62264-1 and IEC 61512-1

C.2.1 Description

The characteristic "Equipment hierarchy" defines which level in the role-based equipment hierarchy of the enterprise (as defined in IEC 62264-1:2013 [1] (ISA 95)) the standard deals with.

It is supplemented by lower levels defined in IEC 61512-1:1997 [13] (ISA 88).

C.2.2 Possible values

Table C.1 describes the possible values of "Equipment hierarchy".

Table C.1 – Possible values of "Equipment hierarchy"

Possible values	Explanation
Enterprise	• Definition one or more organizations sharing a definite mission, goals and objectives which provides an output such as a product or service [SOURCE: IEC 62264-1:2013 [1], 3.1.10]
Site	• Definition identified physical, geographical, and/or logical component grouping of a manufacturing [SOURCE: IEC 62264-1:2013 [1], 3.1.39]
Area	• Definition physical, geographical or logical grouping of resources determined by the site [SOURCE: IEC 62264-1:2013 [1], 3.1.2]
Work center	• Definition equipment element under an area hierarchy that performs production, storage, material movement [SOURCE: IEC 62264-1:2013 [1], 3.1.44, modified] This generic term is more often used in batch production as "process cell", in continuous production as "production unit", in discrete production as "production line" and in storage or movement as "storage zone".
Work unit	• Definition equipment element under a work center in a role-based equipment hierarchy that performs production, storage, material movement [SOURCE: IEC 62264-1:2013 [1], 3.1.45, modified] This generic term is more often used in batch and continuous production as "unit", in discrete production as "work cell" and in storage or movement as "storage unit".
Equipment module	• Definition

Possible values	Explanation
	A functional group of equipment that can carry out a finite number of specific minor processing activities. NOTES 1 An equipment module is typically centered around a piece of process equipment (a weigh tank, a process heater, a scrubber, etc.). This term applies to both the physical equipment and the equipment entity. 2 Examples of minor process activities are dosing and weighing. [SOURCE: IEC 61512-1:1997 [13], 3.16]
Control module	• Definition The lowest level grouping of equipment in the physical model that can carry out basic control. NOTE This term applies to both the physical equipment and the equipment entity. [SOURCE: IEC 61512-1:1997 [13], 3.10]

C.3 Characteristic "Functional hierarchy" of IEC 62264-1

C.3.1 Description

The characteristic "Functional hierarchy" defines which level in the functional hierarchy of the enterprise (as defined in IEC 62264-1:2013 [1] (ISA 95)) the standard deals with.

C.3.2 Possible values

Table C.2 describes the possible values of "Functional hierarchy".

Table C.2 – Possible values of "Functional hierarchy"

Possible values	Explanation
Business (L4)	Business planning, operation and logistics Level 4 functions involved in the business-related activities needed to manage a manufacturing organization [SOURCE: IEC 62264-1:2013 [1], 3.1.16] Establishing and executing the basic plant schedule for production, material use, delivery, shipping, determining inventory levels, operational management, etc. [SOURCE: IEC 62264-1:2013 [1], Figure 3]
Operations management (L3)	Operations management manufacturing operations management MOM activities within Level 3 of a manufacturing facility that coordinate the personnel, equipment and material in manufacturing [SOURCE: IEC 62264-1:2013 [1], 3.1.22] Level 3 functions involved in managing the work flows to produce the desired end-products [SOURCE: IEC 62264-1:2013 [1], 3.1.17] Work flow / recipe control to produce the desired end products. Maintaining records and optimizing the production process, dispatching production, detailed production scheduling, reliability assurance, etc. [SOURCE: IEC 62264-1:2013 [1], Figure 3]
Control (L2)	Level 2 functions involved in monitoring and controlling of the physical process [SOURCE: IEC 62264-1:2013 [1], 3.1.17]

Possible values	Explanation
	Monitoring, supervisory control and automated control of the production process [SOURCE: IEC 62264-1:2013 [1], Figure 3]
Sensors and actuators (L1)	Level 1 functions involved in sensing and manipulating the physical process [SOURCE: IEC 62264-1:2013 [1], 3.1.18]
Process (L0)	Level 0 actual physical process [SOURCE: IEC 62264-1:2013 [1], 3.1.19]

C.4 Characteristic "SGAM Zones"

C.4.1 Description

The zones represent the hierarchical levels of manufacturing management. These zones reflect a hierarchical model which considers the concept of aggregation and functional separation in manufacturing management. The basic idea of this hierarchical model is laid down in the Purdue Reference Model for computer-integrated manufacturing which was adopted by IEC 62264-1 for enterprise-control system integration.

The concept of aggregation considers multiple aspects in power system management:

- Data aggregation: data from the field zone is usually aggregated or concentrated in the station zone in order to reduce the amount of data to be communicated and processed in the operation zone.
- Spatial aggregation: from distinct location to wider area.

In addition to aggregation, the partitioning in zones follows the concept of functional separation. Different functions are assigned to specific zones. The reason for this assignment is typically the specific nature of functions, but also considering user philosophies. Real-time functions are typically in the field and station zones (sensing, metering, protection, etc.).

C.4.2 Possible values

Table C.3 describes the possible values of "SGAM Zones".

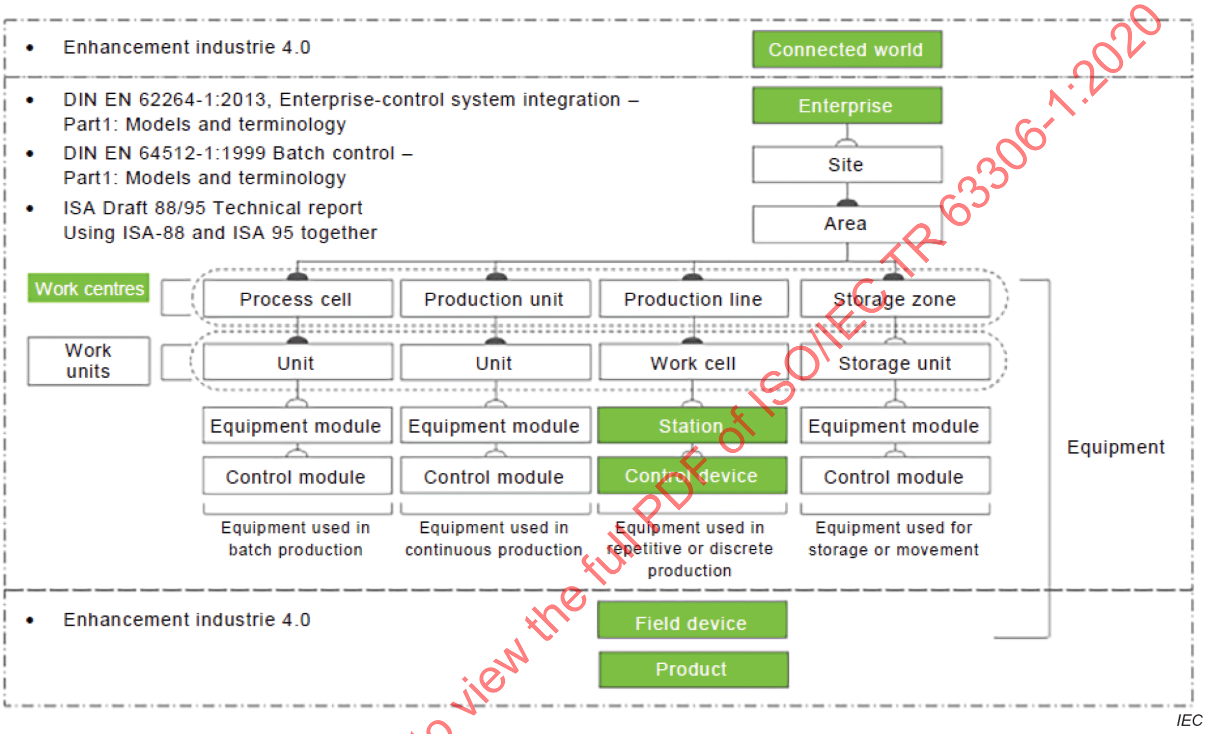
Table C.3 – Possible values of "SGAM Zones"

Possible values	Explanation
Market	Reflecting the horizontal market operations in value added networks.
Enterprise	Includes commercial and organizational processes, services and infrastructures for enterprises, e.g., asset management, logistics, work force management, staff training, customer relation management, billing and procurement, etc.
Operation	The SGAM definition of "operation" is specific to the electrical energy supply and power systems management.
Station	Representing the areal aggregation level for field level, e.g., control, data concentration, functional aggregation, local SCADA systems, plant supervision etc.
Field	Equipment to protect, control and monitor the process.
Process	The physical, chemical or spatial transformations of energy, raw material and pieces to final products and the physical equipment directly involved.

C.5 Characteristic "RAMI4.0 Hierarchy levels"

C.5.1 Description

The characteristic "RAMI4.0 Hierarchy levels" is based on the reference architecture model for a factory along the lines of IEC 62264-1:2013 [1] and IEC 61512-1:1997 [13], 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 centres", "station" and "control device" have been taken from the above-mentioned standards (see Figure C.1).



[SOURCE: IEC PAS 63088:2017 [15]]

Figure C.1 – RAMI4.0 Hierarchy

C.5.2 Possible values

Table C.4 describes the possible values of "RAMI4.0 Hierarchy levels".

Table C.4 – Possible values of "RAMI4.0 Hierarchy level"

Possible values	Explanation
Connected world	"Connected world" describes the relationship between an asset or combination of assets (such as an installation or company) and another asset or combination of assets (another installation or company), in other words, for example, a network of factories.
Enterprise	Corresponds to the definition of "enterprise" of IEC 62264-1:2013 [1], 3.1.10 (see Table C.1)
Work centers	Corresponds to the definition of "work center" of IEC 62264-1:2013 [1], 3.1.44 (see Table C.1)
Station	Corresponds to the definition of "equipment module" of IEC 61512-1:1997 [13], 3.16 (see Table C.1)
Control device	Corresponds to the definition of "control module" of IEC 61512-1:1997 [13], 3.10 (see Table C.1)