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Automation systems and integration — Interoperability of capability units for manufacturing application solutions —

Part 3: Verification and validation of interoperability among capability units

Systèmes d'automatisation et intégration — Interopérabilité des unités d'aptitude pour la fabrication de solutions d'application —

Partie 3: Vérification et validation de l'interopérabilité au sein des unités d'aptitude

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 184, *Automation systems and integration*, Subcommittee SC 5, *Interoperability, integration, and architectures for enterprise systems and automation applications*.

A list of all parts in the ISO 16300 series can be found on the ISO website.

Introduction

ISO 16300 addresses requirements of users and suppliers of manufacturing software regarding the interoperability of software in the area of industrial automation.

User interoperability requirements include:

— integrating an automation application system by combining capabilities of a set of software components provided by various sources,

— substituting another software component in a software unit to provide an equivalent capability required by the automation application system,

— integrating the capability of a software unit from one resource system platform to another platform,

— validating and verifying the capability of a software unit to meet the automation application system requirements.

Supplier requirements include:

— representing the set of capabilities provided by a software component used in a software unit,

— verifying software component capability as a part of a required software unit capability,

— cataloguing a software unit in terms of its capability for interoperability in an automation application system to support wide distribution.

ISO 16300 also addresses software interoperability services which include:

— accessing the description of a software capability to enable interoperability assessment,

— enabling the search and location of candidate software units and components, preferably automatically, using search engines,

— representing the dependencies between software components for an automation application hosted on a particular system platform.

Software capability is first defined in terms of the potential function. It is then expressed and represented as facts about the software, how and what it can do. The ISO 16100 series was developed with the aim of providing a standardized method to describe capabilities of manufacturing software in terms of the MSU (manufacturing software unit) capability profile. In ISO 16100, the software component is included in the MSU. ISO 16100 also provides a way to exchange an MSU's capability as information by means of a capability profile. Software capability profiling is the basis for providing the above-mentioned software interoperability services. ISO 16100 is used and applied as the foundation for ISO 16300.

To establish ISO 16300, a number of steps were necessary. The initial step shows what interoperability services are enabled by using software capability profile. The following steps develop concrete methods and mechanisms to provide these interoperability services. The resulting output from ISO 16300 are several published parts.

ISO 16300-1 specifies a framework for describing an automation solution in terms of a set of capabilities provided by a set of MSUs. The framework also defines a set of capability elements and composition rules to represent the interoperability criteria in terms of the automation system capability requirements of an enterprise application.

ISO 16300-2 specifies the template definition to describe the capability of software unit of an automation solution that can be mapped to the functional requirements of target manufacturing application. It also specifies mapping rules for composing the contents of a software unit catalogue item in terms of the properties of the capability.

ISO 16300-3 specifies the framework for verifying interoperability of capability unit associated with application requirements and system solution.

ISO 16300-4 specifies the search methodology for acquiring candidate capability units which satisfies the manufacturing application requirements from the software unit catalogues and also describes the structure of the report as an outcome of the search, indicating the extent to which the candidates from the software unit catalogues correspond to the manufacturing application requirements.

Automation systems and integration — Interoperability of capability units for manufacturing application solutions —

Part 3: Verification and validation of interoperability among capability units

1 Scope

This document specifies a framework for verifying and validating the interoperability of manufacturing capability units (MCUs) having a set of capabilities that meet the functional requirements of a target manufacturing application solution.

The verification and validation framework describes the use of the interoperability criteria in ISO 16300-1 and the steps to be performed.

2 Normative references

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

ISO 16100-1, *Industrial automation systems and integration — Manufacturing software capability profiling for interoperability — Part 1: Framework*

ISO 16100-2, *Industrial automation systems and integration — Manufacturing software capability profiling for interoperability — Part 2: Profiling methodology*

ISO 16100-3, *Industrial automation systems and integration — Manufacturing software capability profiling for interoperability — Part 3: Interface services, protocols and capability templates*

ISO 16100-6, *Industrial automation systems and integration — Manufacturing software capability profiling for interoperability — Part 6: Interface services and protocols for matching profiles based on multiple capability class structures*

ISO/IEC 25000, *Systems and software engineering — Systems and software Quality Requirements and Evaluation (SQuaRE) — Guide to SQuaRE*

ISO/IEC 25010, *Systems and software engineering — Systems and software Quality Requirements and Evaluation (SQuaRE) — System and software quality models*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 16100-1, ISO 16100-3, ISO 16100-6 and the following apply.

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

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

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

3.1
capability class structure
hierarchy of capability classes

[SOURCE: ISO 16100-6:2011, 3.2, modified — The Note was deleted.]

3.2
capability profiling
selection of a set of offered services defined by a particular interface within a software interoperability framework

[SOURCE: ISO 16100-1:2009, 3.5]

3.3
interoperability validation
procedure which examines the implemented interoperability mechanisms to determine the extent to which they are compliant with a set of quality characteristics (reliability, security, performance, time response, etc.)

Note 1 to entry: These quality characteristics are considered as pertinent for the expected behaviour of the current manufacturing application processes.

3.4
interoperability verification
procedure of checking that the designed interoperability of manufacturing processes match the corresponding implemented interoperability mechanisms

3.5
manufacturing application requirements document
MARD
document specifying necessary processes to be designed and implemented in order to meet the targeted manufacturing goal, and also specifying various resources to be available to accomplish processes execution

3.6
manufacturing capability unit
MCU
manufacturing unit of a type (i.e. mechanical, electrical, electronic, hardware, and/or software, etc.) intended to support the execution of a particular manufacturing task.

Note 1 to entry: Manufacturing capability unit is a resource capability unit or a process capability unit.

3.7
manufacturing process capability unit
MPCU
process capability unit of a type (i.e. mechanical, electrical, electronic, hardware, and/or software) corresponding to the execution of a particular manufacturing process

3.8
manufacturing resource capability unit
MRCU
manufacturing capability unit (3.6) of resource (i.e. human, energetic, mechanical, electrical, electronic, hardware, and/or software, etc.) supporting the execution of manufacturing application (process, activity or task)

3.9
manufacturing capability profile
concise representation of a *manufacturing capability unit* (3.6) to meet a requirement of a manufacturing application

[SOURCE: ISO 16100-1:2009, 3.21]

3.10
manufacturing software
type of software resource within an automation system that provides value to a manufacturing application (e.g. CAD/PDM) by enabling the flow of control and information among the automation system components involved in the manufacturing processes, between these components and other enterprise resources, and between enterprises in a supply chain or demand chain

[SOURCE: ISO 16100-1:2009, 3.16, modified — The Note was deleted and "(e.g. CAD/PDM)" was added to the definition.]

3.11
manufacturing software unit
MSU
class of software resource, consisting of one or more *manufacturing software* (3.10) components, performing a definite function or role within a manufacturing activity while supporting a common information exchange mechanism with other units

Note 1 to entry: A software unit can be modelled using UML as a software object.

[SOURCE: ISO 16100-1:2009, 3.18, modified — The acronym MSU was added to the term.]

3.12
matcher
mechanism set to compare an offered *manufacturing capability profile* (3.9) with a required manufacturing capability profile

[SOURCE: ISO 16100-3:2005, 3.1.6, modified — The verb "set" was added after "mechanism" and the adjective "manufacturing" was added before "capability profile" twice.]

3.13
matching level
<profile> qualitative measure of how closely a capability profile of a *manufacturing software unit* (3.11) meets the software functional requirements of a manufacturing activity

[SOURCE: ISO 16100-3:2005, 3.1.7]

3.14
MSU interoperability
capability of a *manufacturing software unit* (3.11) to support a particular usage of an interface specification in exchanging a set of application information (services) with another manufacturing software unit

[SOURCE: ISO 16100-3:2005, 3.1.8, modified — The word "(services)" was added to the definition.]

4 Symbols and abbreviated terms

MARD manufacturing application requirements document

MCU manufacturing capability unit

MPCU manufacturing process capability unit

MRCU manufacturing resource capability unit

MSU manufacturing software unit

OPM object process model

UML unified modelling language

5 Interoperability of MSUs

5.1 Interoperability background

A manufacturing application is developed to realize a product which meets its predetermined specifications as a result of the application execution. The invoked specifications elaborated according to the expectations of the product customers or users, include required characteristics to be assured by the targeted product without exceeding the fixed limits of manufacturing costs and delays.

The development of a manufacturing application generally starts with elaborating a subsequent requirements specification which is described in MARD. This document includes the architectural, functional, and qualitative specifications to be met by the concerned application. In respect to MARD, the application design is then elaborated using adequate formalisms for various design artefacts addressing mainly:

— the application global structure;

— its capability units;

— their interdependencies; and

— its configuration and deployment.

The adopted design formalisms are generally graphical and textual those are to describe manufacturing processes as well as the related design artefacts in detail.

The 16300 series addresses the requirements of users and suppliers of manufacturing applications regarding the interoperability of MCUs in the area of industrial automation. User requirements include:

— building a manufacturing application system by combining capability units;

— selecting appropriate capability units, substituting one capability unit with another; and

— verifying capability unit in reference to the required capability profile.

Supplier requirements shall specify the precise capability of their corresponding interoperability.

The manufacturing application processes shall be composed of designed and planned activities and operations of various types (human, mechanical, electrical, hardware, networking, and/or computing, etc.). For each process, the manufacturing application design indicates its functional role inside the manufacturing application, its individual control flow as well as its underlying specific activities and functions. For the manufacturing processes implementation, the design shall specify the required manufacturing resources and their specific capabilities considered as necessary for the manufacturing execution. These manufacturing resources are of different types (i.e. mechanical, electrical, hardware, networking, software, etc.) (see ISO/TR 18161), where corresponding capabilities units shall be described using the dedicated profile template presented in Annex A. A capability unit profile includes several fields describing various structural, functional and qualitative characteristics of manufacturing resource unit capabilities.

To accomplish the specified manufacturing goal, the design of manufacturing processes shall indicate the required interoperability specifying when, where, and how the processes interoperate. It shall indicate the concerned types of required interoperability related to message communications, data sharing, data exchanges, or service calling, etc., between interacting manufacturing processes. Subsequently, a capability unit profile specifies its provided facilities and mechanisms for interoperability. Also, the manufacturing application execution is associated with various implemented or coded processes activated to behave according to the process designed model. They shall interact using interoperability mechanisms and facilities as decided at the application design phase. Manufacturing resources related to manufacturing processes such as devices, hardware units, software units, etc., shall interact using various types of interoperating facilities indicated as a part of the capability profile.

5.2 MSU interoperability verification and validation

Since the processes are executed using a set of appropriate MRCUs, the verification of processes interoperability should examine the MRCU profiles used, to check whether they provide the required processes interoperability.

The interoperability of MCUs should be recognized by the individual MCU capability profiles that contain a set of MRCU profiles.

This document focuses on MSUs interoperability verification and validation. For the design and development of the framework, the subset MSU is considered as being a major and central part of the MCU. In this document, only the interoperability of MSUs is considered for verification and validation.

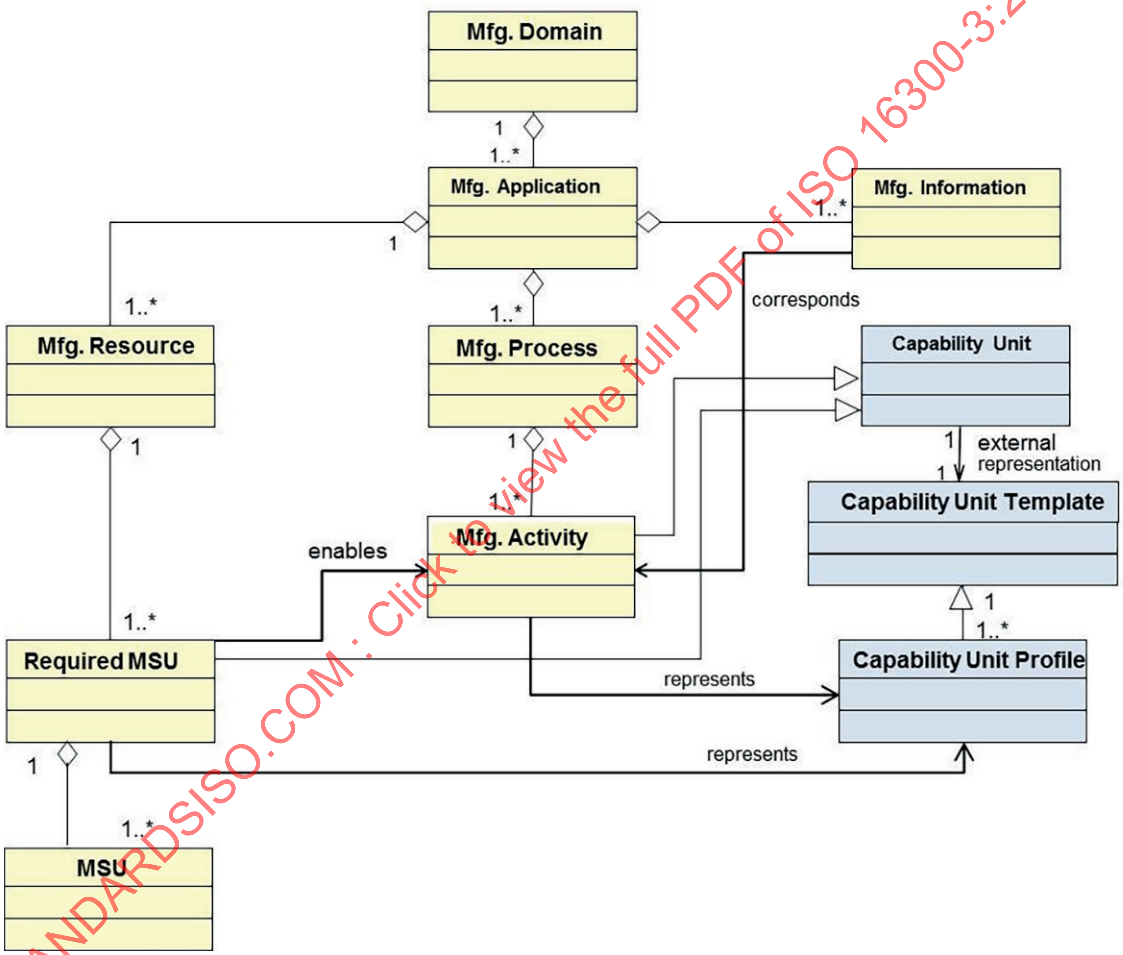

Figure 1 — Main description entities of MCUs general context

The procedure for verification and validation shall be described as a set of steps to follow, applied on associated artefacts, to verify and validate the interoperability among designed processes and the corresponding required MSUs. The MSUs are to be developed or already implemented and ready to be reused.

Starting from the interoperability framework of ISO 15745-1 and ISO 16100-1, a software interoperability framework is described based on the aspects related to:

— the syntax and semantics shared between MSUs;

— the functional relationships between the MSUs;

— the services, interfaces and protocols provided by the MSUs;

— the ability to provide MSUs capability profiling.

The last aspect dealt with at length in the ISO 16100 series. Nevertheless, the verification and validation processes of interoperability among MSUs are concerned by the whole set of these enumerated aspects.

The verification and validation processes of interoperability among MSUs shall be necessary to check the extent to which the effective working interoperability among MSUs implements its design and meets the interoperability requirements. In the general context of MSUs within a manufacturing domain application (Figure 1), application artefacts shall be issued from three major development phases corresponding to three description levels: requirements definition level, design level, and implementation level. Four major sets of artefacts called A, B, C and D, defined in Table 1, shall be considered for interoperability verification and validation.

Table 1 — Four major sets of artefacts

Set of artefact	Description
A	composed of design schemas of expected activities of MSUs and associated interoperability mechanisms that shall be designed to meet requirements of data sharing, messages exchange, services invocation and exchange, or procedure call which can occur among MSUs.
B	composed of code parts implementing the effective capabilities of MSUs and working interoperability mechanisms permitting to concerned MSUs to accomplish associated activities
C	composed of the quality model elements specifying the expected interoperability quality criteria as they shall be fulfilled by the implemented interoperability mechanisms and services. These criteria and corresponding characteristics, sub-characteristics and properties shall be specified according to ISO/IEC 25000 quality model with effective quality characteristics, sub-characteristics, and properties of implemented MSUs interoperability (see Annex B).
D	composed of the quality reports providing the numerical values or ranking values of effective quality characteristics specified in the instantiated quality model.

Sets A and B are composed of artefacts corresponding to the design of expected interoperability mechanisms necessary for the targeted execution of the current application. Sets C and D correspond to the designed interoperability quality and the quality of its corresponding working implementation.

The term "expected" refers to what was adopted at the design level and shall be met at the implementation level. Therefore, the expected interoperability shall describe different types of interoperability mechanisms adopted and designed to be implemented for the operating MSUs.

The term "effective" refers to what was implemented according to the interoperability design and how the required types of interoperability mechanisms were effectively implemented to meet their description at the design phase.

The first type of compliance assessment between two artefacts sets A and B is the goal of interoperability verification process. This compliance shall be achieved by examining the matching level between the design artefacts with the corresponding implementation artefacts. The design of individual MSUs shall take into account the specification of their individual capability profile.

The second type of compliance assessment shall be based on examining that the quality design of interoperability described by the artefacts of set C matches the quality of effective interoperability described by the artefacts of set D. The assessment of the compliance level shall be the goal of the interoperability validation process.

5.3 Interoperability levels

The interoperability quality shall depend to the level of interoperability occurring between MSUs. Major interoperability levels are considered in Table 2.

Table 2 — Interoperability levels

Interoperability levels	Description
1	technical level of interoperability that shall concern the data exchange among MSUs. At this level, the used networks and protocols shall be considered and evaluated.
2	syntactic interoperability level concerning common data structure that shall be used to exchange information among the MSUs. For this objective, a common data format shall be adopted and strictly utilized.
3	common reference model for information exchange, where the information exchanged shall share a common semantic with a unique shared meaning of exchanged data
4	collaborative interoperability corresponding to the case of interoperable manufacturing applications, manufacturing processes or MSUs that shall recognize the behaviour of functions and services provided by each other. This level requires that the preceding levels are already reached.
5	conceptual interoperability achieved when the conceptual models are based on the engineering methods that shall enable their interpretation and evaluation by the developers of the concerned applications or processes. This shall be based on the common conceptual model with the common semantic.

The first three interoperability levels shall be used in conjunction with the quality model defined by ISO/IEC 25010 for interoperability validation.

ISO/IEC 25010 shall provide a detailed description of software quality which shall be used for interoperability validation. It shall be adapted to define required quality of MSUs interoperability and its instantiation that shall assess the quality of implemented interoperability.

6 Interoperability verification and validation goals

6.1 Considered interoperability mechanisms

The interoperability verification and validation are considered in the context of manufacturing application MSUs development where the requirement document is defined by the application development team. The corresponding design of the targeted MSUs is elaborated according to the concerned manufacturing application specifications expressed in MARD. The design shall be developed to take into account three main types of requirements: process requirements, resource requirements, and qualitative requirements. The capability profile of each individual MSU includes only the functional requirements.

In order to accomplish interoperability verification and validation, the artefacts mentioned in 5.2 shall be developed to include the functional requirements, interoperability requirements and corresponding quality criteria.

The artefacts of set A include the specification of functions and services to be provided by the MSU profile. The classification of MSUs is presented in detail in ISO 16100-2. These artefacts include the design of the required interoperability mechanisms to be implemented to meet the application MSU's requirements in terms of:

— services exchange;

— functions calling;

— messages communication;

— global resources sharing;

— files sharing;

— information sharing;

— access to and update of a common database;

The invoked interoperability design is a specific part which is composed of distinguished elements inside the whole design of manufacturing application including MSUs design. Subsequently, each required interoperability mechanism shall have its own textual or graphical design description and corresponding semantic. The chosen design language for the current application should then provide specific textual or graphical elements which are able to clearly represent the required interoperability to be used among MSUs. In order to be realized, each required designed mechanism shall have one or more implementation solutions provided by the development environment. The selection among possible implementations shall be accomplished according to the required quality criteria of the current application in terms of reliability, performance, efficiency, security, or other quality criteria (Figure 2).

The interoperability validation is performed by considering the quality definition and quality assessment of MSUs interoperability as instantiated using the quality model.

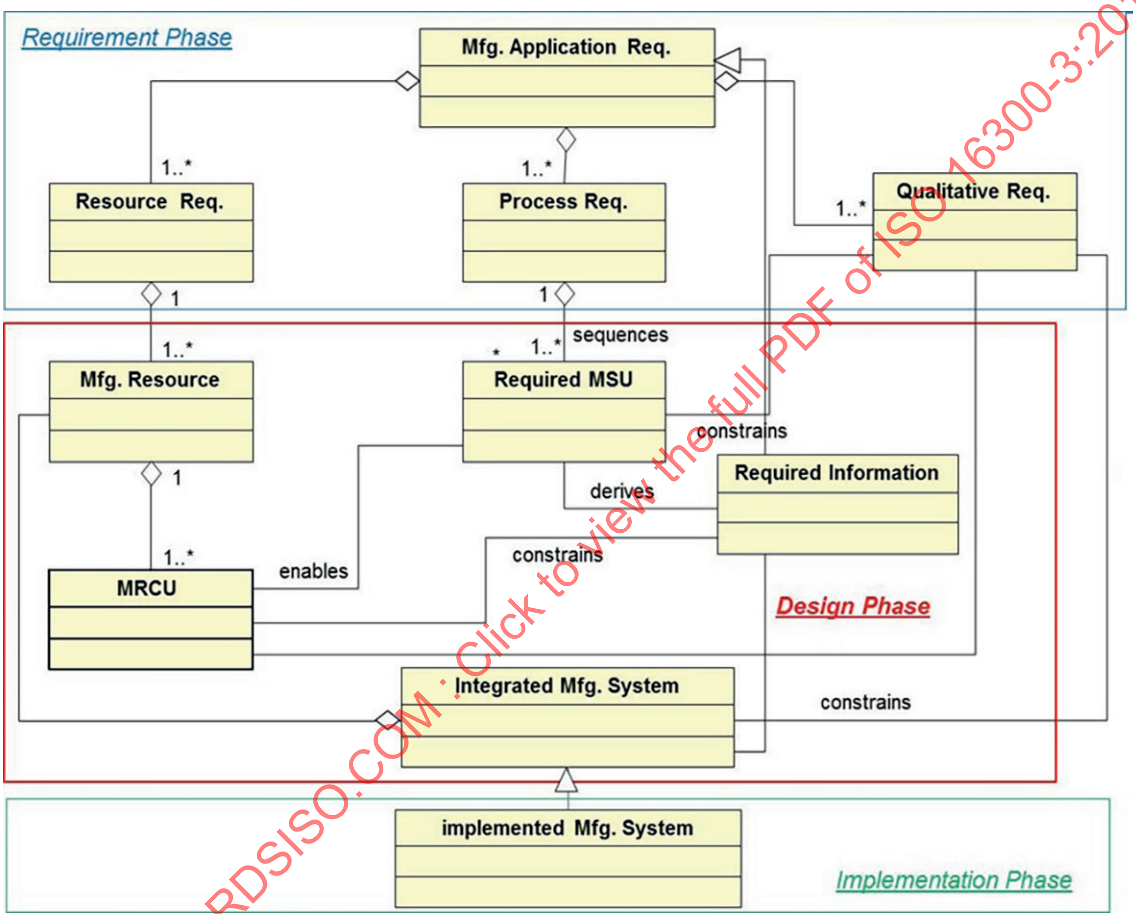

Figure 2 — Artefact elements for verification of interoperability among MSUs

The artefacts of set A describe the expected capabilities and interoperability of MSUs, while the artefacts of set B describe the effective interoperability. The verification is then based on the examination of the matching level between the artefacts of the two sets.

Also, the artefacts of set C describe the expected quality of the MSUs interoperability, while those of set D describe the effective quality of the implemented MSUs. The interoperability validation examines the how the expected quality characteristics, sub-characteristics, and properties of MSUs described by set C comply with the effective interoperability quality criteria described by set D. The last set of artefacts is built on the data and metric values gathered according to Clauses 4 and 5, and more precisely described in ISO/IEC 25020:2007, Annex A.

6.2 Interoperability verification goal

The verification process aims at examining:

— the matching level between the expected interoperability capability profile, and the effective interoperability capability profile of the implemented MSUs (Figure 3);

— the matching level between the interoperability requirement specification of the designed MSUs and the effective interoperability provided by the implemented (or acquired) MSUs;

— the interoperability mechanisms and facilities provided by the software environment hosting the operated MSUs.

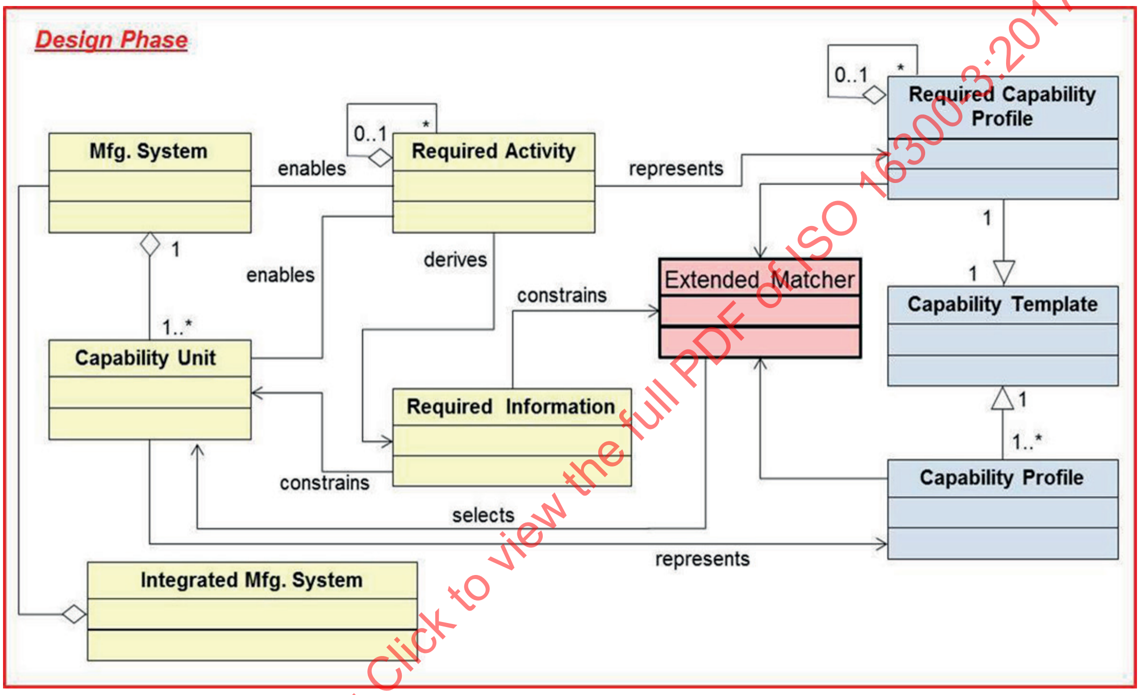

Figure 3 — Verification of coherence between required interoperability (expected) and implemented interoperability (effective)

The extended matcher shall provide the mechanisms for comparing the required capability profiles, including interoperability of MSUs, with the effective capability profiles of used MSUs. The extended matcher should also provide the mechanisms to accomplish the interoperability verification in reference to the functional set of properties. The interoperability validation is realized in reference to the artefacts describing the required qualitative characteristics and the artefacts describing their effective implementation.

6.3 Interoperability validation goal

Starting from the specification of interoperability quality criteria to be met by the interoperability and mechanisms used, the interoperability validation process aims at examining:

— the extent to which the interoperability quality criteria are met,

— the interoperability mechanisms having low matching level and then low rating in reference to the targeted quality criteria,

— the risk level of each interoperability mechanism used in terms of functionality, reliability, response time, security, performance or portability.

7 Interoperability verification process

7.1 Required artefacts for verification

To realize the verification process, the interoperability requirements specification shall be defined at the design level of the manufacturing activities as a part of the capability profiles of MSUs.

It is therefore necessary to specify the interoperability requirements to identify the various interoperability mechanisms required for targeted working of the current manufacturing application:

— the MSUs capability profile;

— their capabilities in terms of interoperability, more precisely the units interface profile they provide to interoperate;

— the hosting operating environment of the manufacturing units.

The concerned activities are designed to be carried out by the considered manufacturing process of the considered manufacturing application. The verification shall be based on the compliance assessment between the required interoperability of the designed MSUs, and the effective interoperability of the MSU implementing the manufacturing activities within a manufacturing process. Compliance is achieved through the assessment of the matching level between the artefacts of set A describing the required interoperability, and the interoperability of the effective working MSUs of set B.

In order to develop interoperability requirements specification, the design of manufacturing processes shall be a main reference. The processes should be designed using representation diagrams, a UML diagram activity or any other diagram providing a representation of the interactions and relationships between processes. Within a process, each workflow activity is described through a devoted activity diagram which specifies the required interoperability mechanisms. An interoperability mechanism can execute one or more operations, explicitly represented by the activity diagram as being:

— a memory access shared by two or more MSUs;

— a required access to a file shared by two or more MSUs;

— a required access to a database shared by two or more MSUs;

— a message sent to one or more MSU software;

— a message received by specific MSUs. Messages are sent and received using a communication protocol available for the manufacturing application environment;

— a direct invocation of function or service provided by other MSUs;

— an indirect call of function or service provided by other MSUs. This type of call requires an adequate software infrastructure. One or more middleware such as OMG CORBA, RMI JAVA, and OPC can be used according to the programming languages and operating systems of the hosting environment of the MSUs.

The steps of interoperability requirements specification shall be described as shown in ISO/PAS 19450:2015, Annex C. See Figure 4.

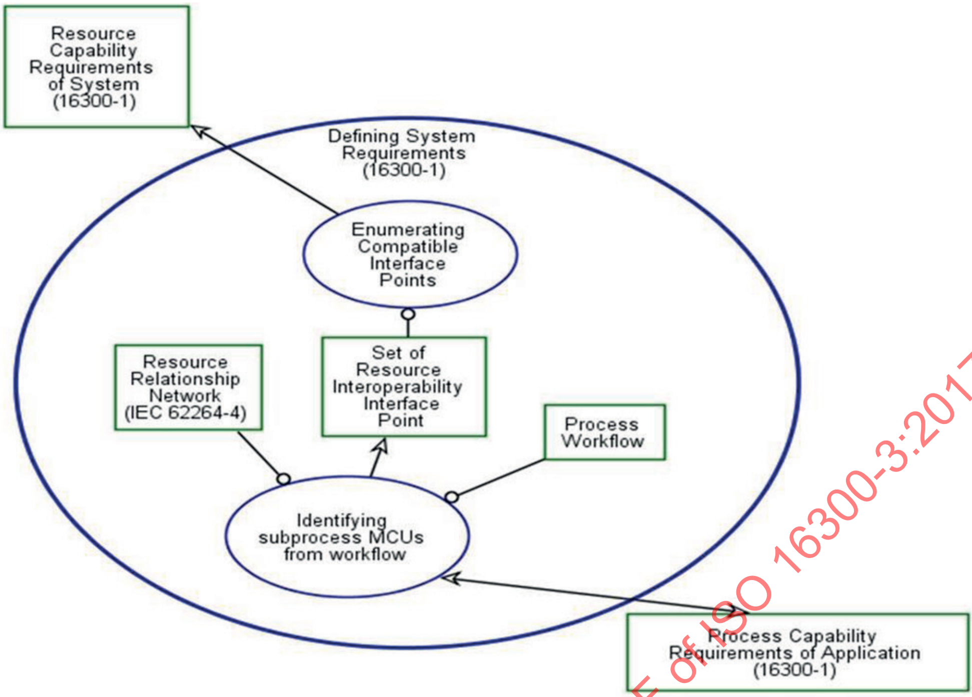

Figure 4 — Steps for interoperability requirements specification

The interoperability requirements specifications include the whole set of interoperability facilities of which the provision by the MSUs has been identified by the development team of the current manufacturing application as being necessary in order to perform their activities. These activities interoperate through data exchange, message exchange, activity call, service exchange, and other possible forms of interoperability.

7.2 Verification through matching process

A matching process is applied to examine whether the available facilities of the manufacturing environment and the MSU profiles match the interoperability requirements specification. The matching process is applied on each individual MSU to examine the matching level between:

a) individual MSU interoperability requirements (UIR);

b) the interoperability facility set (IFS) provided by the manufacturing software environment; and

c) software interoperability sequences (SIS) implementing or using the adequate interoperability mechanisms as part of the implemented (or adopted) MSU profile, in order to meet the required designed interoperability.

A matching level can be assessed in reference to the compliance between the UIR set and the conjunction of two sets IFS and SIS.

8 Interoperability validation process

8.1 Required artefacts for validation

In a manufacturing environment, a manufacturing execution system is composed of MSUs devoted to the manufacturing control, managing, monitoring work-in-process, and to keep track of all manufacturing information and receiving real-time data from various equipment. The MSUs need to share data, exchange messages, and to execute or call services provided by other units.

In order to accomplish interoperability verification and validation between MSUs, it is necessary to consider the specific constraints associated with each used interoperability mechanism between MSUs to evaluate corresponding required quality criteria. These are defined as required artefacts related to the compliance between the artefacts of sets C and D (5.2).

To validate functioning interoperability under consideration between MSUs, a set of constraints can make the interoperability validation difficult regarding the specific associated quality criteria that need to be dealt with. The parameters below, such as programming language, operating system, hosting platform, etc., specify the considered interoperability between MSUs:

— Programming language version –when different interoperating MSUs are coded using different versions of a programming language.

— Programming languages –when different interoperating MSUs are coded using different programming languages.

— Operating system version – when different interoperating MSUs are executed within distinct versions of an operating system or an environment.

— Operating systems or environments – when different interoperating MSUs are executed on different operating systems or environments.

— Hosting platform versions – when different interoperating MSUs are executed using different versions of software development platforms.

— Hosting platform – when different interoperating MSUs are executed using different software development platforms.

— Communication protocol.

— Objects rights access – concerning the right access for reading, writing, or executing:

  — simple data access;

  — complex data access;

  — procedure access;

  — method access;

  — service access;

  — file access;

  — database access.

In the list above, the running of any parameter used shall be qualified in reference to a set of quality criteria such as reliability, efficiency, performance, security, or other quality criterion. Subsequently, each element shall be assessed as being less efficient, reliable, or secure.

The interoperability validation needs, as major artefact, a quality model to be developed for the required interoperability mechanisms. The interoperability quality model constitutes a reference to be met by the implemented interoperability among MSUs. For the targeted interoperability quality model, it is recommended to use the model proposed by ISO/IEC 25000 which is initially addressed to system and software quality evaluation.

8.2 Validation through matching process

As a first approach for interoperability validation, the ISO quality standard shall be adapted to match the interoperability pertinent characteristics. ISO/IEC 25010 for interoperability shall be used as reference for the interoperability validation process. The validation shall focus more particularly on some characteristics including:

1) **Functionality:** The capability of the MSUs to provide functions and interoperability which meet stated and implied needs when the MSUs are used under specified conditions;

2) **Reliability:** The capability of the of MSUs interoperability to maintain the level of performance of the system when it is used under specified conditions;

3) **Usability:** The capability of the MSUs interoperability to be understood, used, and appreciated by the developer;

4) **Efficiency:** The capability of the MSUs interoperability to provide the required performance relative to the amount of resources used, under stated conditions;

5) **Maintainability:** The capability of the MSUs interoperability to be modified;

6) **Portability:** The capability of the MSUs interoperability to maintain its behaviour when hosted on a different hosting environment.

Interoperability validation is based on checking the extent to which the implemented quality corresponding measured criteria are compliant with the expected quality as specified at the interoperability design phase. This shall be based on the matching level between the expected qualitative level and the implemented quality level. In both cases, the quality evaluation refers to the adopted quality criteria and corresponding measuring metrics.

In ISO 16100-1, the accomplished functions of the manufacturing execution system depend on interoperability criteria to be fulfilled by the interoperability facilities provided by the manufacturing application software platform. They also depend on the quality of concerned MSUs' capabilities. Therefore, the validation process shall be based on interoperability quality criteria by examining their matching to the effective working interoperability. In order to use ISO/IEC 25000 methodology, interoperability criteria discussed in previous clauses shall be mapped into ISO/IEC 25010 quality model using the following Table 3.

Table 3 — Interoperability quality criteria defined by applying ISO/IEC 25010

Interoperability quality criteria	ISO/IEC 25010	Clause in ISO/IEC 25010
Interoperability level		
Reliability	Reliability	4.2.5
Availability	Availability	4.2.5.2
Safety	Freedom from risk	4.1.4
Security	Security	4.2.6

Annex A
(informative)

Conceptual structure of a capability profile including extension related template to interoperability

As mentioned in ISO 16100-5:2009, 6.3.1, a capability profile template contains a common part in accordance with ISO 16100-2:2003, 6.3 and ISO 16100-3:2005, 7.2.2; and a specific part in accordance with ISO 16100-2:2003, 6.3. The specific part shall at least contain the elements identified in ISO 16100-2, along with the following additional elements (Table A.1):

— Reference MDM name;

— MDD description format (e.g. list of MDD objects);

Table A.1 — Conceptual structure of a capability profile template

Common part			
	Template ID		
	Capability class name and reference CCS		
	Software unit ID		
		Vendor name	
		Version number and history	
		Computing facilities required	
			Processor
			OperatingSystem&Options
			Language
			RuntimeMemory
			DiskSpace
			MultiUserSupport
			RemoteAccess
			AddOns&PlugIns
		Measured performance of the unit	
			ElapsedTime
			NumberOfTransactionsPerUnitTime
		Reliability data of the unit	
			UsageHistory
			NumberOfShipments
			IntendedSafetyIntegrityLevel
			CertificationBody
		Support policy	
		Price data	
	Capability class reference dictionary name		
	Number of profile attributes		
	Number of methods		
	Number of resources		

Table A.1 *(continued)*

	Number of constraints	
	Number of extensions	
	Number of lower levels	
	Number of subtemplates at next lower level	
Specific part for capability class		
	Reference MDM name	
	MDD description format	
	MDD description	
		Set of MDD objects
		List of MDD objects
		Time ordered MDD objects
		Event ordered MDD objects
		Interoperability MDD objects
	List of capability class attributes	
	List of capability class methods	
	List of capability class resources	
	List of capability class constraints	
	List of capability class extensions	
	List of capability class lower levels	
	List of capability class subtemplates	

— MDD description (e.g. time ordered access to MDD objects).

The above capability profile template contains an additional field "interoperability MDD objects" under which the template users to specify the interoperability mechanisms which shall be used by the concerned capability units.

Annex B
(informative)

Adaptation example of ISO/IEC 25000 quality model for interoperability validation of MSUs

The interoperability validation process requires to exam the matching between the specified qualitative requirements of interoperability between MSUs and its corresponding implementation.

This Annex aims to provide guidelines and to illustrate the series of ISO/IEC 25000 quality standards addressing all aspects related to: quality requirements specification, quality model, product quality, quality evaluation and quality measurement. For each quality aspect, a set of ISO standards have been elaborated. A set of standards constitutes a “division” aiming at a specific aspect related to system or software quality.

To put into practice, the main concepts and models provided in the ISO/IEC 25000 series, the framework encompassing and structuring the whole set of standards is called SQuaRE (Software product Quality Requirements and Evaluation). SQuaRE is composed of five divisions intended to cover the wide range of aspects related to system and software quality specification, as well as its modelling, assessment, and measurement (Figure B.1).

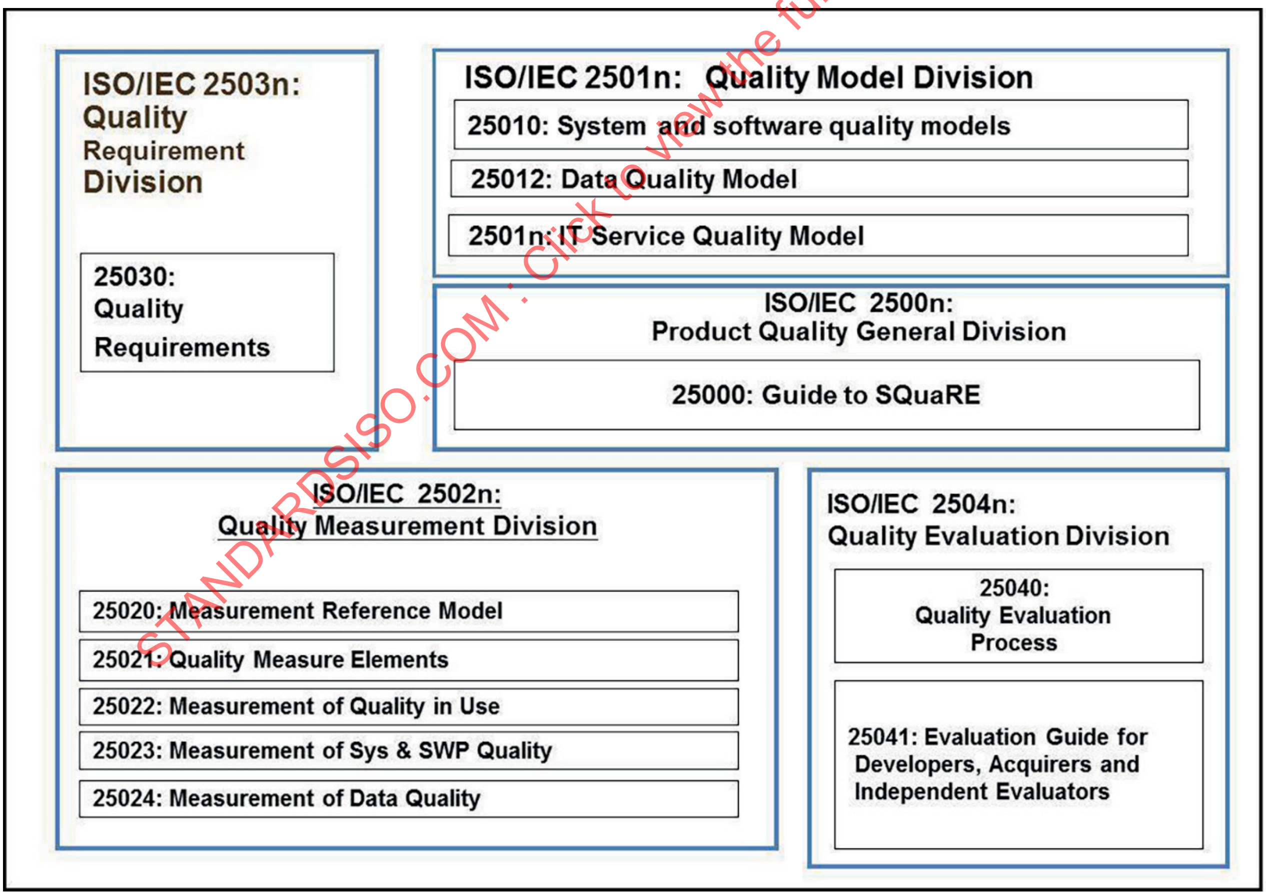

Figure B.1 — Global architecture of ISO/IEC 25000 SQuaRE

The ISO standards of SQuaRE make a distinction between three major types of quality (Figure B.2) reflecting the perception of the quality by the developers and users. The major quality types are:

— the quality in use;

— the external quality; and

— the internal quality.

To validate the developed interoperability of manufacturing application, SQuaRE proposes for each quality type (in use, external, and internal) the examination of conformity between expected specified quality of system or software and the effective quality of implemented system or software.

In order to specify the required quality of interoperability, three sets of requirements shall be elaborated.

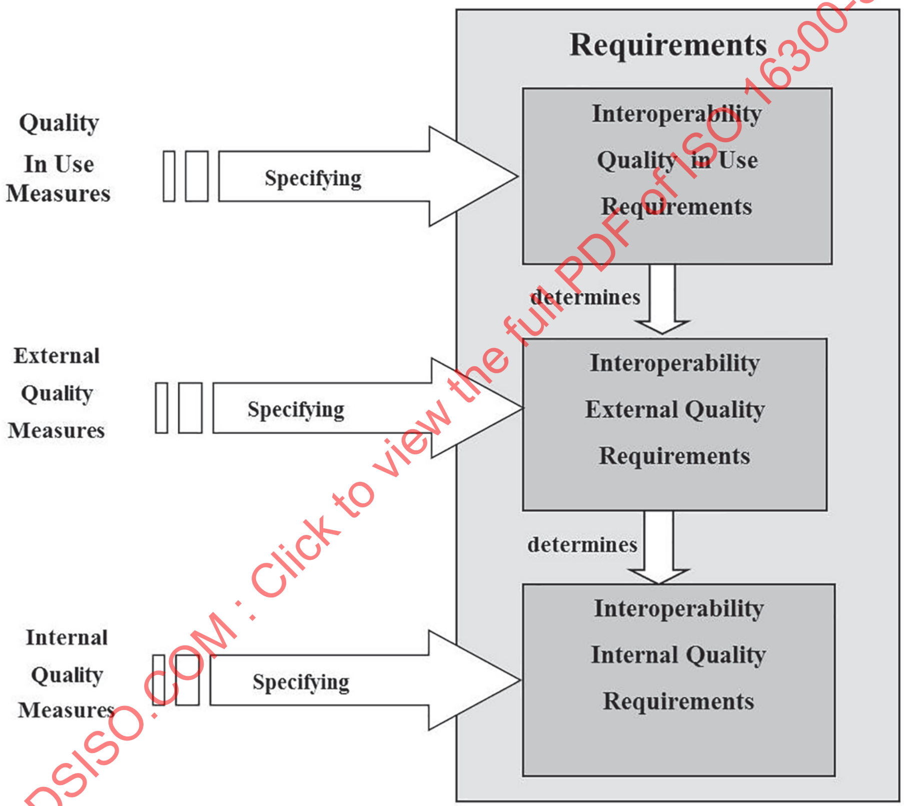

Figure B.2 — Specification of interoperability quality requirements

At each hierarchical quality level, a quality model shall be built in terms of quality characteristics, sub-characteristics, and properties. This task is generally done by the quality expert of the current application. Subsequently, three tree-like quality models for interoperability are to be elaborated and merged. for the internal and external quality and characteristics, as well as for the quality in use.

For this goal, ISO/IEC 25010 proposes a generic quality model and corresponding, characteristics, sub-characteristics for the concerned major quality levels: internal quality, external quality and quality in use. These quality models are to be instantiated and adapted with respect to the interoperability to be developed for the MSUs of the concerned manufacturing application. The generic quality model to be instantiated proposes six characteristics and 27 sub-characteristics, indicating the links of dependency between each individual characteristic and the corresponding sub-characteristics. The six major quality characteristics shall be adapted to interoperability such as:

1) **Functionality:** The capability of the MSUs to provide functions and interoperability which meet stated and implied needs when the MSUs are used under specified conditions;

2) **Reliability:** The capability of the of MSUs interoperability to maintain the level of performance of the system when it is used under specified conditions;

3) **Usability:** The capability of the MSUs interoperability to be understood, used, and appreciated by the developer;

4) **Efficiency:** The capability of the MSUs interoperability to provide the required performance relative to the amount of resources used, under stated conditions;

5) **Maintainability:** The capability of the MSUs interoperability to be modified;

6) **Portability:** The capability of the MSUs interoperability to maintain its behaviour when hosted on a different hosting environment.

SQuaRE proposes the breakdown of the characteristics into sub-characteristics, which shall be adapted to the interoperability quality as described in Table B.1.

Table B.1 — Characteristics and sub-characteristics of SQuaRE schema adopted for the quality of interoperability between MSUs

Quality characteristics of MSU interoperability	Quality sub-characteristics of MSUs interoperability
Functionality	Suitability Accuracy Security
Reliability	Testability Fault tolerance Recoverability
Usability	Understandability Learnability Testability
Efficiency	Time behaviour Resource utilization
Maintainability	Adaptability Analysability Changeability Testability
Portability	Adaptability Installability Replaceability

Each individual sub-characteristic is to be defined by the quality engineer of the current application specifying its contextual meaning and the way to assess the extent to which each characteristic is met. Moreover, in a given application, sub-characteristics shall have different priorities. The priority of each sub-characteristic depends on the hierarchical scale established between sub-characteristics according to the specific functional and qualitative priorities of the whole current application.

To each individual sub-characteristic, the quality engineer shall adapt a set of metrics addressed to quantitatively assess the extent to which a sub-characteristic is met in reference to the expected values decided at the phase of qualitative requirements specifications.

The interoperability quality evaluation shall be based on the three quality trees instantiated by the quality engineer for the quality in use, external quality and internal quality.

The interoperability validation shall be based, for each characteristic or sub-characteristic, on the examination of shifting between:

— Numerical values obtained by application of metrics devoted to interoperability characteristic or sub-characteristic. These numerical values constitute the evaluation of the quality characteristics of the implemented interoperability between MSUs.

— Expected values of metrics specified by the quality team at the phases of interoperability requirements specification and interoperability design for the MSUs of the considered application.

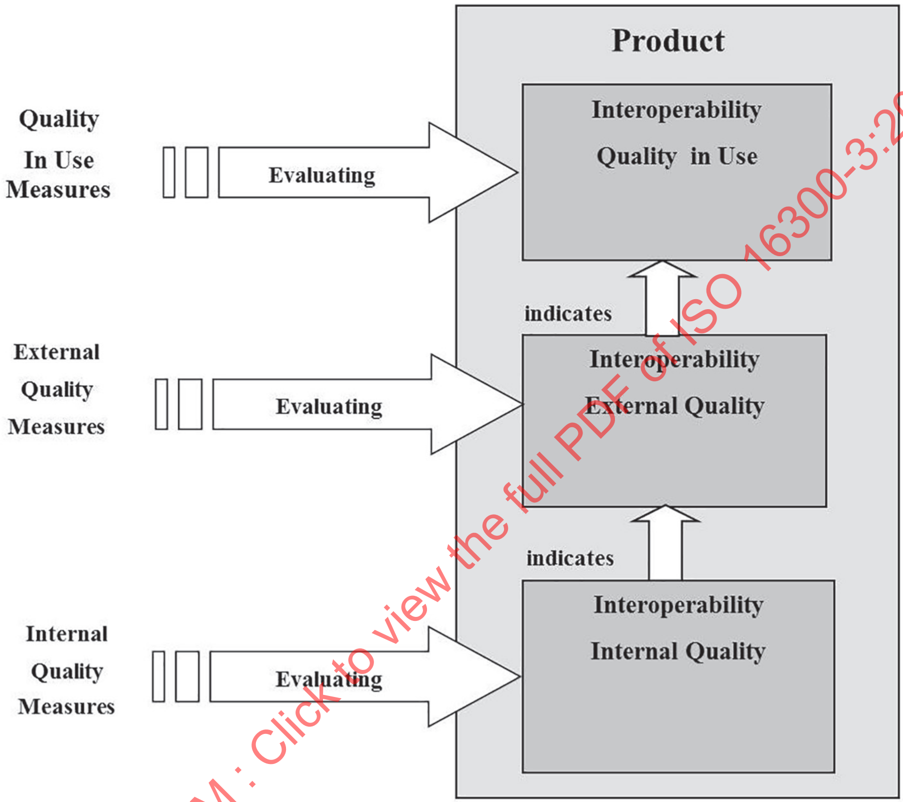

Figure B.3 — Types of interoperability quality evaluation

The interoperability validation shall be processed as indicated by the SQuaRE schema below (Figures B.3 and B.4)