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General requirements for cyber-physically controlled smart machine tool systems (CPSMT) —

Part 1: Overview and fundamental principles

Exigences générales relatives aux systèmes de machines-outils intelligents à commandes cyber-physiques (CPSMT) —

Partie 1: Vue d'ensemble et principaux fondamentaux

Reference number
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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO 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).

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This document was prepared by Technical Committee ISO/TC 184 *Automation systems and integration*, Subcommittee SC 1, *Industrial cyber and physical device control*.

A list of all parts in the ISO 23704 series can be found on the ISO website.

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

Introduction

A machine tool is a key device in manufacturing since it is used indispensably in the production of machine parts used in various industrial areas. Many institutions have long been devoted to technological development from the viewpoint of reducing downtime and defects and are considering smart technologies such as the Internet-of-Things (IoT) as a new means to achieve this.

From the market perspective, there is a variety of so-called smart machine tools incorporating smart technologies based on their own concepts using, e.g. local terminologies by machine tool builders (MTBs), machine tool control, e.g. computerized numerical control (CNC) vendors, solution vendors and service providers, which can be confusing to stakeholders, including end-users. For this and other reasons, standards and substantial modelling for smart machine tool systems are needed.

From the standards perspective, RAMI 4.0 (IEC PAS 63088) and IEC TR 63319[1)] TR-SMRM provide a reference model for Industry 4.0 and smart manufacturing on a high level. The ISO 23247 series defines a generic framework to support the creation of a digital twin of observable manufacturing elements. Furthermore, although some existing standards deal with Industry 4.0 enabling technologies, e.g. OPC-UA (IEC/TR 62541-1), MTConnect (ANSI/MTC1.4-2018), ISO/IEC 30141, the IEC 62769 series, and many machine tool standards from ISO TC39, no standard yet exists for smart machine tools for realizing smart manufacturing / Industry 4.0 in the shop floor via cyber-physical systems (CPSs).

The ISO 23704 series specifies general requirements on smart machine tools for supporting smart manufacturing in the shop floor via cyber-physical system control scheme, namely cyber-physically controlled smart machine tool systems (CPSMT).

Figure 1 shows the overall structure of the ISO 23704 series, including:

— Overview and fundamental principles of a CPSMT in ISO 23704-1,

— Reference architecture of a CPSMT for subtractive manufacturing in ISO 23704-2, and

— Reference architecture of a CPSMT for additive manufacturing in ISO 23704-3[2)].

Other related parts such as implementation guidelines or reference architectures for other types of manufacturing will be added if and when necessary.

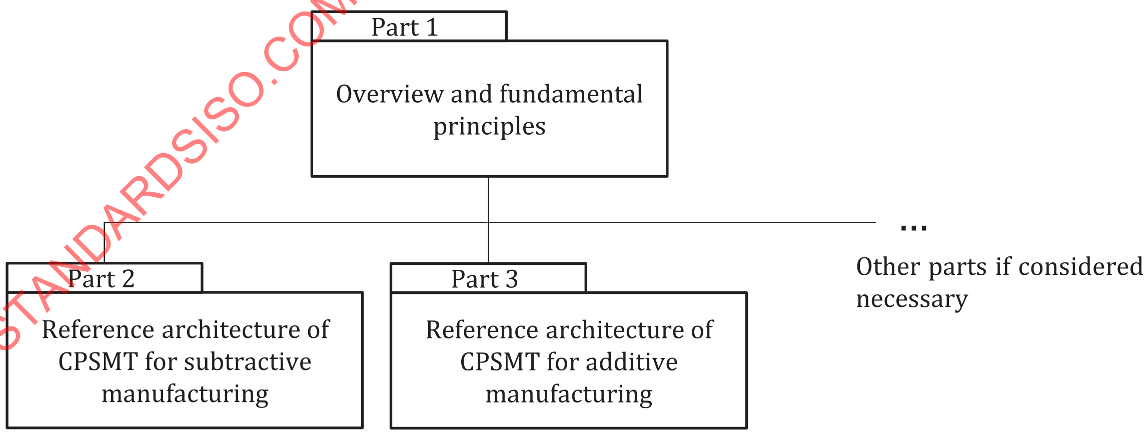


Figure 1 — Overall structure of the ISO 23704 series on general requirements for cyber-physically controlled smart machine tool systems (CPSMT)

This document can be used as a reference and guidelines for users such as, but not limited to:

a) Design engineers in the area of smart machine tools,

1) Under development. Stage at the time of publication: IEC/DTR 63319.

2) Under development. Stage at the time of publication: ISO/DIS 23704-3.

b) System architects in the area of smart machine tools,

c) Software engineers at the MTBs in the area of smart machine tools,

d) Machine tool control vendors in the area of smart machine tools,

e) Solution and service providers in the area of smart machine tools, and

f) End users, such as factory operators working with smart machine tools.

General requirements for cyber-physically controlled smart machine tool systems (CPSMT) —

Part 1: Overview and fundamental principles

1 Scope

This document specifies the concept and fundamental principles of cyber-physically controlled smart machine tool systems (CPSMT) and requirements, including

— the reference architecture of a CPSMT,

— the key components and interfaces which together make up the reference architecture of a CPSMT, and

— the capabilities of a CPSMT.

This document also provides:

— the background for a CPSMT,

— the concept of a shop floor device system (SFDS), and

— example use cases of the reference architecture of a CPSMT.

This document does not specify physical or implementation architecture.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

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

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

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

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

3.1 Terms and definitions

3.1.1
abnormality
deviation from a standard condition

EXAMPLE Chatter, tool wear above prescribed limits, geometric inaccuracy, energy over-consumption.

[SOURCE: ISO 13372:2012, 4.1, modified — EXAMPLES added.]

3.1.2
additive manufacturing
process of joining materials to make parts from 3D model data, usually layer upon layer, as opposed to *subtractive manufacturing* (3.1.29) and formative manufacturing methodologies,

[SOURCE: ISO/ASTM 52900:2015, 2.1.2, modified — Notes 1 and 2 to entry deleted.]

3.1.3
administration shell
virtual digital and active representation of an *Industry 4.0 component* (3.1.18) in the Industry 4.0 system (3.1.19)

[SOURCE: Industrie 4.0 – Begriffe/Terms VDI Status report Industrie 4.0 (April 2017) modified — Notes 1 and 2 to entry deleted.]

3.1.4
computerized numerical control
CNC
automatic control of a process performed by a device that makes use of numerical data introduced while the operation is in progress

[SOURCE: ISO 2806:1994, 2.1.1]

3.1.5
cyber-physically controlled smart machine tool systems (CPSMT) associated system
CPSMT associated system
set of *CPSMT* (3.1.10) components to interface with the *CPSMT primary system* (3.1.6), including *shop floor device system (SFDS)* (3.1.24), *shop floor control system (SFCS)* (3.1.23), and *unified interface system (UIS)* (3.1.30)

3.1.6
cyber-physically controlled smart machine tool systems (CPSMT) primary system
CPSMT primary system
set of *cyber-physically controlled machine tool (CPSMT)* (3.1.10) components including *cyber-physically controlled machine tool (CPCM)* (3.1.9) and *cyber-supporting system for machine tool (CSSM)* (3.1.12)

3.1.7
cyber-physical manufacturing system
CPMS
manufacturing system based on an analogy of RAMI 4.0 from a cyber-physical perspective, comprised of a) a physical manufacturing system, composed of an office floor and shop floor, and b) the *cyber-supporting system (CSS)* (3.1.11), supporting the physical manufacturing system via monitoring, analysis, planning, and execution based on big data analytics / artificial intelligence, and *digital twin* (3.1.14) (MAPE / BD).

Note 1 to entry: The definition is based on reference [33].

Note 2 to entry: More details on the MAPE/BD concept are given in reference [36].

3.1.8
cyber-physical system
CPS
physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core

Note 1 to entry: The definition is taken from Rajkumar et al.[30]

3.1.9
cyber-physically controlled machine tool
CPCM
physical machine tool system, controlled by a cyber-physical control scheme, providing a more advanced control function via *cyber-physical system (CPS)* (3.1.8) unit in addition to the conventional machine control

Note 1 to entry: The CPS unit is the part of the reference architecture for different technologies responsible for performing the CPS function

3.1.10
cyber-physically controlled smart machine tool system
CPSMT
smart machine tool system, supporting smart manufacturing and Industry 4.0 on the shop floor via a *cyber-physical system* (3.1.8) control scheme

3.1.11
cyber-supporting system
CSS
cyber-system that supports a physical system for the enhancement of performance of a physical system via monitoring, analysis, planning, and execution based on big data analytics / artificial intelligence, and *digital twin* (3.1.14) (MAPE / BD)

3.1.12
cyber-supporting system for machine tool
CSSM
cyber-supporting system (3.1.11) for *cyber-physically controlled machine tools (CPCMs)* (3.1.9) that provides decisions from the viewpoint of *abnormality* (3.1.1) resolution, and provides CPCM abnormality data to a *shop floor control system (SFCS)* (3.1.23) and external systems including humans, life cycle aspects, and hierarchy level

3.1.13
data
reinterpretable representation of information in a formalized manner suitable for communication, interpretation, or processing

Note 1 to entry: Data can be processed by humans or by automatic means.

[SOURCE: ISO/IEC 2382-1:1993, 2121272, modified — Notes 2 and 3 to entry were deleted.]

3.1.14
digital twin
digital replica of physical assets (physical twin), processes and systems that can be used for various purposes or a fit-for-purpose digital representation of something outside its own context with data connections that enable convergence between the physical and virtual states at an appropriate rate of synchronization

Note 1 to entry: The definition is from the ISO TC184 Ad Hoc Group on the digital twin.

Note 2 to entry: The digital twin is used by the cyber supporting system for the machine tool (CSSM) as an interrogable cyber model of the machine tool for analysis and planning stages of the MAPE.

3.1.15
event
noteworthy occurrence that happens at a point in time or during a temporal interval

[SOURCE: ISO/IEC 15938-5:2003, 3.3.2.14.]

3.1.16
event-driven
methodology that focuses on *events* (3.1.15) and their dependency

3.1.17
hard-real time
time based operational characteristic in which processing of data by a computer in connection with another process outside the computer is incorrect if results are not produced according to specified timing requirements

Note 1 to entry: The hard-real time definition is based on reference [12].

3.1.18
Industry 4.0 component
globally uniquely identifiable participant with communication capability consisting of an *administration shell* (3.1.3) and an asset (corresponds to classification of Communication and Presentation (CP) 24, CP34 or CP44) within an *Industry 4.0 system* (3.1.19) which offers services with defined quality of service characteristics

Note 1 to entry: CP24, CP34 and CP44 are classifications of Communication and Presentation for Industry 4.0. The first digit indicates the communication capability and the second the degree of familiarity. CP24 means "capable of passive communication" and "managed as an entity". CP34 means "capable of active communication" and "managed as an entity". CP44 means "capable of I4.0 conformal communication" and "managed as an entity".

[SOURCE: Industrie 4.0 — Begriffe/Terms VDI Statusreport Industrie 4.0 (April 2017), modified: Notes 1 and 2 to entry deleted, Communication and Presentation (CP) added.]

3.1.19
Industry 4.0 system
system, consisting of *Industry 4.0 components* (3.1.18) and components of a lower Communication and Presentation (CP) classification, which serves a specific purpose, has defined properties and supports standardized services and states

[SOURCE: Industrie 4.0 — Begriffe/Terms VDI Statusreport Industrie 4.0 (April 2017), modified: CP expanded to "Communication and Presentation (CP)", Notes 1, 2 and 3 to entry deleted]

3.1.20
key performance indicator
KPI
quantifiable level of achieving a critical objective

Note 1 to entry: The KPIs are derived directly from or through an aggregation function of physical measurements, data and / or other KPIs.

[SOURCE: ISO 22400-1:2014, 2.1.5]

3.1.21
machine tool
mechanical device that is fixed (i.e. not mobile) and powered (typically by electricity and compressed air), typically used to process workpieces by selective removal / addition of material or mechanical deformation

Note 1 to entry: Machine tool operation can be mechanical, controlled by humans, or by computers. Machine tools may have a number of peripherals used for machine tool cooling / heating, process conditioning, workpiece and tool handling (workpiece feeding excluded), recyclables and waste handling, and other tasks connected to their main activities.

[SOURCE: ISO 14955-1:2017, 3.16]

3.1.22
reference architecture
core architecture that captures the high-level architecture concept of domain architecture

[SOURCE: ISO/IEC 26552:2019, 3.9, modified — "and application architecture" deleted.]

3.1.23
shop floor control system
SFCS
system that controls a shop floor system including a *shop floor device system (SFDS)* (3.1.24) and a *cyber-physically controlled machine tool (CPCM)* (3.1.9) in a collaborative fashion for the enhancement of the performance of the shop floor

3.1.24
shop floor device system
SFDS
set of devices, including production facilities and material handlers, on the shop floor

Note 1 to entry: A shop floor device x with the controller is regarded as having its own cyber-physically controlled x (CPCx), and cyber-supporting system x (CSSx).

3.1.25
smart machine tool
machine tool (3.1.21) that supports the vision, characteristics, and capabilities of smart manufacturing

Note 1 to entry: Details of smart manufacturing are described in IEC TR 63319[24].

3.1.26
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 collaborate with other domains within enterprise value chains

Note 1 to entry: The definition is from IEC TR 63319[26]

3.1.27
smart manufacturing reference model
SMRM
framework for understanding significant relationships among the entities involved in smart manufacturing and for the development of consistent standards or specifications that support smart manufacturing

Note 1 to entry: The definition is from IEC TR 63319[26]

3.1.28
soft-real time
time-based operational characteristic in which processing of data by a computer in connection with another process outside the computer is degraded if results are not produced according to specified timing requirements

Note 1 to entry: The soft-real time definition is based on reference [12].

3.1.29
subtractive manufacturing
process of machining, grinding or reducing a larger bulk object to create a smaller detailed three-dimensional object using computer-aided design software and computer-aided manufacturing methods

[SOURCE: ISO 18739:2016, 3.1.37]

3.1.30
unified interface system
UIS
system that incorporates interfaces with: a) a *cyber-physically controlled machine tool (CPCM)* (3.1.9), b) a *cyber-supporting system for machine tool (CSSM)* (3.1.12), c) a shop floor device system (SFDS), d) a shop floor control system (SFCS), e) humans, f) life cycle aspects and g) hierarchy level

Note 1 to entry: The UIS is an advanced concept of human-machine interface incorporating a wide range of systems, including the life cycle aspect and hierarchy level.

3.2 Abbreviated terms

CNC	computerized numerical control
CP	communication and presentation
CPCM	cyber physically controlled machine tool
CPMS	cyber physical manufacturing system
CPS	cyber physical system
CPSMT	cyber-physically controlled smart machine tool
CRM	customer relationship management
CSS	cyber supporting system
CSSM	cyber supporting system for machine tool
ERP	enterprise resource planning
HMI	human machine interface
KPI	key performance indicator
MAPE/BD	monitoring, analysis, planning and execution based on big data and digital twin
MES	manufacturing execution system
MTB	machine tool builder
RAMI 4.0	reference architecture model industries 4.0
SCM	supply chain management
SFCS	shop floor control system
SFDS	shop floor device system
SMRM	smart manufacturing reference model
UIS	unified interface system

4 Conformance with the CPSMT reference architecture

To claim conformance, the definition of a specific system architecture, as provided by a vendor or system integrator, should use the terminology, architectural concepts, and have the capabilities defined in this document, within the scope of their specific use cases.

5 Goals and objectives of the CPSMT reference architecture

The CPSMT reference architecture describes generic smart machine tools to support Industry 4.0 and smart manufacturing via a cyber-physical system (CPS). It provides guidance for designers developing smart machine tool systems and aims to give a better understanding of smart machine tools to the stakeholders of such systems.

NOTE Examples of stakeholders are MTBs, computerized numerical control (CNC) and other machine control vendors, solution vendors, application developers, service providers, customers and end-users.

A CPSMT reference architecture supports the following standardization objectives:

a) To ensure clear and unambiguous communication between all interested parties of smart machine tools.

b) To ensure the interoperability of smart machine tools with related hardware devices, software, service and manufacturing systems.

c) To ensure the quality / capability of smart machine tools.

d) To ensure the use of smart machine tools.

e) To ensure systematic development, modification of smart machine tools.

Figure 2 illustrates the context of the CPSMT reference architecture, which is derived and viewed from various perspectives based on the architecture description defined in ISO/IEC/IEEE 42010:2011[18].

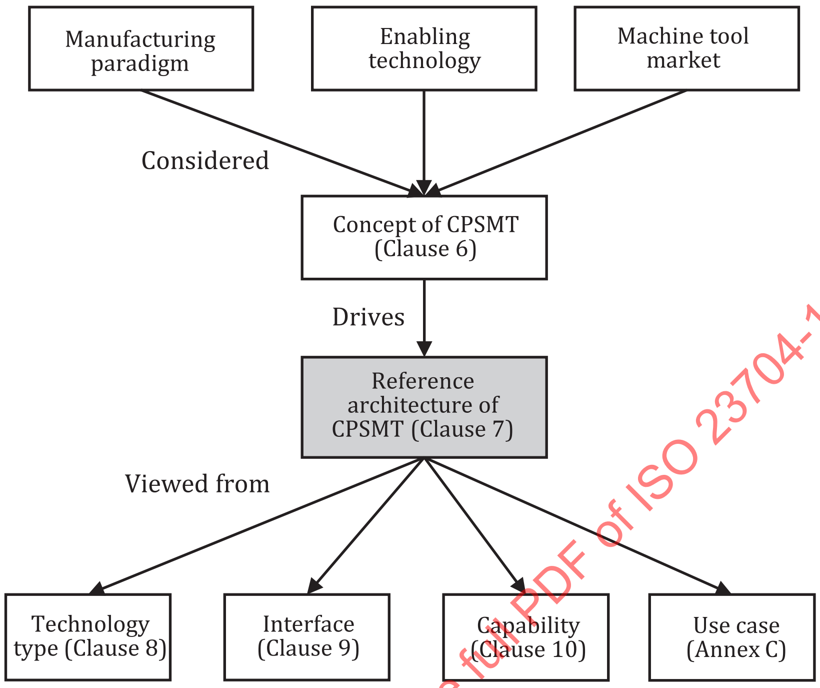


Figure 2 — Context of a CPSMT reference architecture

Based on Figure 2, this document includes the following descriptions:

— The concept of a CPSMT in Clause 6.

— The reference architecture of a CPSMT in Clause 7.

— The reference architecture of a CPSMT viewed from the manufacturing technology type perspective in Clause 8.

— The reference architecture of a CPSMT viewed from the interface perspective in Clause 9.

— The reference architecture of a CPSMT viewed from the capability perspective in Clause 10.

— The reference architecture of a CPSMT viewed from the use case perspectives in Annex C.

Clauses 7, 8, 9, and 10 deal with the fundamental principles of a CPSMT.

6 Concept of a CPSMT

In order to conform with the definition in 3.1.25, a smart machine tool shall support smart manufacturing on the shop floor.

Based on this and the definition in 3.1.10, the role of a CPSMT is to be a smart machine tool system realizing smart manufacturing at the shop floor via a CPS.

The concept of a CPSMT is derived based on:

— High level paradigms, e.g.

 — Smart manufacturing[26],

  - RAMI 4.0[25],
  - Cyber-physical manufacturing systems (CPMS)[33],
- Implementation technology based on the contemporary smart machine tool related product systems presented in the major machine tool fairs.
- State-of-the-art technology, e.g.
  - Machine tools / machining technology,
  - IoT / information and communication technology (ICT),
  - Autonomous control,
  - Digital twin,
  - Prognostic health maintenance,
  - Big data analytics,
  - Artificial intelligence,
  - Modelling and simulation,
  - Edge / fog / cloud computing,
  - Shop floor control system (SFCS),
  - Computer-aided X and legacy interfaces.

The capabilities of CPSMT are:

a) Autonomously dealing with machine tool abnormalities (see 10.2) based on big data analytics, artificial intelligence, and digital twin technology, via:

   1) Monitoring,

   2) Analysis,

   3) Planning, and

   4) Execution,

b) Interfacing with smart manufacturing systems (see Clause 9) of a manufacturing enterprise in a federated fashion for the optimization of manufacturing systems, composed of:

   1) A shop floor, and

   2) An office floor

NOTE For more details, see Annex A.

7 Reference architecture of a CPSMT

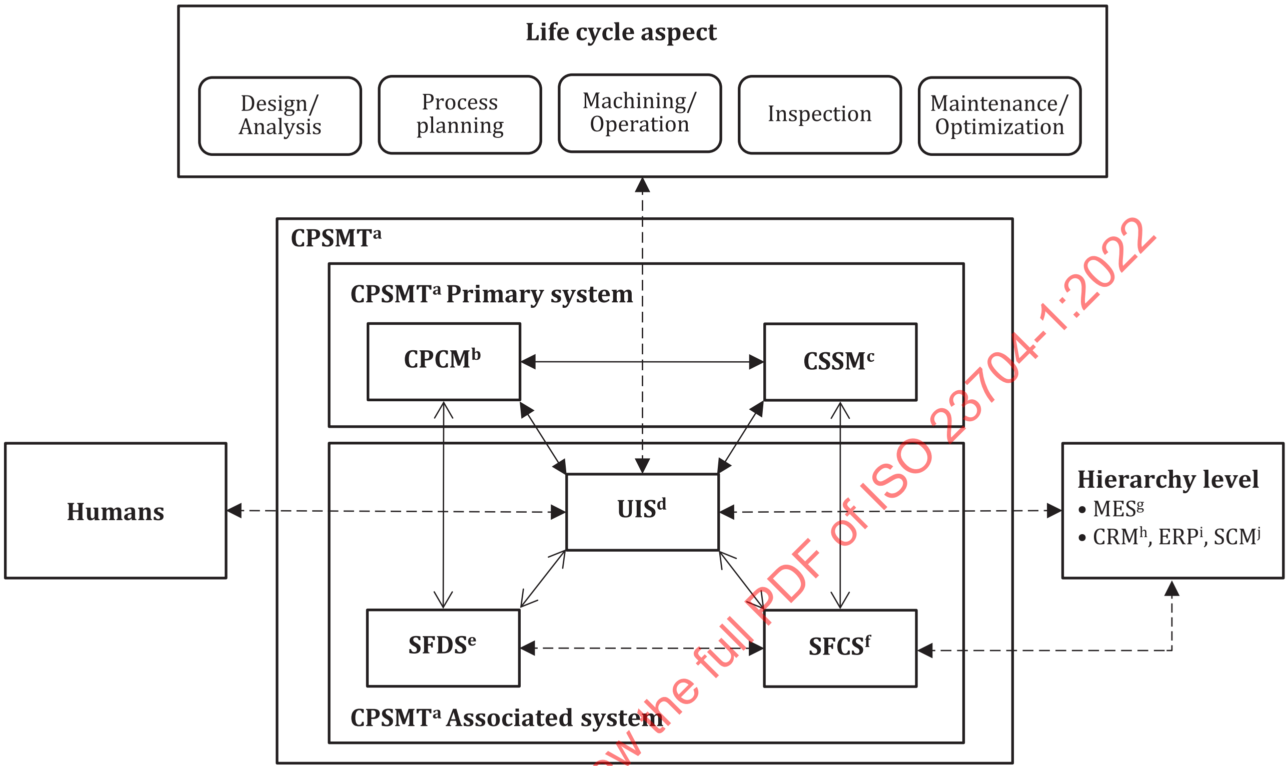
7.1 General

The CPSMT reference architecture is a system of systems. The single systems are connected in federated and integrated ways. Figure 3 shows the reference architecture of a CPSMT.

The reference architecture of a CPSMT can be viewed in a variety of ways. The viewpoint depends on the objective, scope and capability of a stakeholder.

The reference architecture of a CPSMT in this document is provided from the control and operation viewpoint. Systems communicate internally and externally via interfaces.

NOTE 1 Use cases of the reference architecture for a CPSMT are in Annex C.



Key

◄──►	internal interface
<──>	shop floor system interface
◄- - -►	external interface

a Cyber-physically controlled smart machine tool system (CPSMT).

b Cyber-physically controlled machine tool (CPCM).

c Cyber supporting system for machine tool (CSSM).

d Unified interface system (UIS).

e Shop floor device system (SFDS).

f Shop floor control system (SFCS).

g Manufacturing execution system (MES).

h Customer relationship management (CRM).

i Enterprise resource planning (ERP).

j Supply chain management (SCM).

Figure 3 — Reference architecture of a CPSMT

Specifically, a CPSMT consists of

a) a CPSMT primary system, and

b) a CPSMT associated system.

As defined in 3.1.6, a CPSMT primary system consists of a cyber-physically controlled machine tool (CPCM) and a cyber-supporting system for machine tools (CSSM). Its capability is described in 10.2.

NOTE 2 An example of a CPCM is a machine tool equipped with advanced process control and automated connection environment to a material handling robot.

NOTE 3 An example of a CSSM is a computer or computing device for the machine tool that acquires vibration, acoustic emission sensor data and performs tool wear detection and remaining useful life prediction.

As defined in 3.1.5, a CPSMT associated system consists of an SFDS, an SFCS, and a UIS. Its capabilities are described in 10.3, 10.4, 10.5, 10.6, and 10.7.

NOTE 4 An example of an SFDS is a set of shop floor devices for loading or unloading parts or transportation devices, interfacing with a machine tool system.

NOTE 5 An example of an SFCS is a shop floor controller which is used for tracking, scheduling, and reporting on the progress of shop floor operations.

NOTE 6 An example of a UIS is an advanced machine control console or external human machine interface (HMI) which has capabilities of communication with external entities and machine tool systems.

A CPSMT interfaces with external entities, e.g. humans, life cycle aspects, and hierarchy levels, through the connections between a UIS and a CPCM / CSSM, an SFDS and an SFCS.

7.2 Cyber-physically controlled machine tool (CPCM)

A CPCM shall be operated by the cyber-physical control scheme (see ISO 23704-2:2022, Clause 7 for subtractive manufacturing). This enables capabilities as specified in 10.2 to 10.4. It exchanges and utilizes data with a CSSM, an SFCS, an SFDS, a UIS, sensors, and a machine controller.

The cyber-physical control scheme in CPCM shall perform generation of control instructions for machine control -based on data:

a) received from the controller, a UIS, and sensors with hard-real time intelligence, and

b) for machine control based on data from a CSSM with soft-real time.

Specific types of controller (e.g. programmable logic controller, machine controller, motor controller, laser controller) should be determined in the implementation phase.

The cyber-physical control scheme should provide control instructions for the machine tool based on data from an SFCS, whether event-driven or periodically.

A CPCM shall receive and manage engineering context data from a UIS and / or humans, e.g. data on machine body, and part program (ISO 14649-1, ISO 6983).

Interaction with an SFDS should be established. This may be done by direct access to the machine tool control system via a suitable control signal interface.

The collected data from a CPCM shall be transmitted to a UIS and a CSSM.

NOTE Details of the CPCM depend on the specific types of manufacturing technology. For more details, see ISO 23704-2 for subtractive manufacturing and ISO 23704-3 for additive manufacturing.

7.3 Cyber-supporting system (CSS)for machine tool (CSSM)

A CSSM shall acquire

— machine tool data through sensors and controllers, and

— context data on machine tools such as part program (ISO 14649-1, ISO 6983) from a UIS or humans.

A CSSM shall perform monitoring functions.

It is recommended that a CSSM performs analysis (including prediction and diagnosis) and planning (including simulation and optimization) functions.

The data generated in a CSSM during monitoring, analysis and planning should be stored.

The data generated or stored in a CSSM should be transmitted to a CPCM, an SFCS and to a UIS.

NOTE Details of a CSSM depend on the specific types of manufacturing technology. For more details, see ISO 23704-2 for subtractive manufacturing and ISO 23704-3 for additive manufacturing.

7.4 Shop floor device system (SFDS)

There are two types of shop-floor device:

a) with controllers, and

b) without controllers.

For a shop floor device x with a controller, it can have its own CPS unit for x (CPCx), and cyber-supporting system for x (CSSx).

Each device in an SFDS can receive context data by requesting it from a UIS.

Interaction with a CPCM should be established. This may be done with a control signal interface, such as ISO 21919.

In addition, an SFCS output can be transmitted to each device to align with the shop floor level operation. The collected and generated data from an SFDS can be transmitted to a UIS and an SFCS.

NOTE 1 Details of an SFDS depend on the specific types of manufacturing technology. For more details, see ISO 23704-2 for subtractive manufacturing and ISO 23704-3 for additive manufacturing.

NOTE 2 For more details of an SFDS, see Annex B of this document and ISO 23704-2:2022, Annex A for subtractive manufacturing.

7.5 Shop floor control system (SFCS)

An SFCS should interface with a CPCM and a CSSM to receive all relevant data.

An SFCS can interface with an SFDS to deliver decisions to each device in an SFDS for shop floor optimization of key performance indicators (KPIs).

An SFCS can interface with a UIS to exchange data.

An SFCS can perform monitoring, analysis (including prediction and diagnosis), planning (including simulation and optimization), and execution based on data processing and digital twin technology analogous to a CSSM.

The output of an SFCS (e.g. task allocation plan) should be transmitted to a CPCM and can be transmitted to devices in an SFDS. The other data generated in an SFCS can be stored or transmitted to the hierarchy level, life cycle aspects, and humans via a UIS.

NOTE For more details on an SFCS, see ISO 23704-2:2022, Annex A for subtractive manufacturing.

7.6 Unified interface systems (UISs)

A UIS shall receive data from

— a CPCM, e.g. sensor data and controller data, and

— a CSSM.

A UIS shall deliver data from humans to

— a CPCM, and

— a CSSM.

A UIS should deliver context data from the hierarchy level and life cycle aspects to:

— a CPCM, and

— a CSSM.

A UIS can deliver context data from the hierarchy level, life cycle aspects and humans to:

— an SFDS, and

— an SFCS.

The specific structure of a UIS should be determined based on the purpose of implementation, which is out of scope of this document. A UIS can be implemented as a CNC console in an advanced fashion or external HMI, as noted in 7.1.

A UIS should not be implemented as a detour for direct connections between CPCM, CSSM, SFDS and SFCS.

NOTE For more details on a UIS, see ISO 23704-2:2022, Annex B for subtractive manufacturing.

8 Reference architecture of a CPSMT from the manufacturing technology perspective

A machine tool is a crucial manufacturing resource of the equipment class for manufacturing of products by various technologies, e.g.

— subtractive manufacturing (e.g. cutting),

— additive manufacturing (e.g. layering),

— formative manufacturing (e.g. bending), and

— other manufacturing technologies.

The reference architecture of a CPSMT can vary depending on the type of manufacturing technology. This includes components and interfaces between the components of a CPSMT.

The reference architecture of a CPSMT is specified:

a) In ISO 23704-2 for subtractive manufacturing, and

b) In ISO 23704-3 for additive manufacturing.

9 Interfaces in a CPSMT

9.1 General

This clause specifies interface requirements for the architecture of a CPSMT.

9.2 Interface between a CPCM and a CSSM

A CPCM and a CSSM are connected via a direct interface. The aim of this interface is the handling of abnormalities in the machine tool system (see 10.2) based on data analytics and digital twinning via:

— monitoring,

— analysis,

— planning, and

— execution.

Establishing this interface is required.

9.3 Interface between a CPCM and an SFDS

A CPCM and an SFDS are connected via a direct interface. The aim of this interface is the exchange of data in an autonomous fashion (see 10.3), including:

— auto setup on the workpiece pallet,

— tool delivery system,

— material handling devices, e.g. robots.

Establishing this interface is recommended.

9.4 Interface between a CPCM and an SFCS

A CPCM and an SFCS are connected via a direct interface. The aim of this interface is the exchange of data to contribute to the enhancement of KPIs (see 10.4), including:

— operation re-scheduling, and

— device re-allocation.

Establishing this interface is recommended.

9.5 Interface between a CPSMT and life cycle aspects through a UIS

A CPSMT interfaces with the life cycle aspects through a UIS. The aim of this interface is the exchange of life cycle data (see 10.5), including:

— design / analysis,

— process planning,

— machining / operation,

— inspection, and

— maintenance / optimization.

Establishing this interface is recommended.

9.6 Interface between a CPSMT and hierarchy level through a UIS

A CPSMT interfaces with the hierarchy level through a UIS. The aim of this interface is the exchange of data (see 10.6), including:

— monitoring,

— analysis,

— scheduling,

— diagnosis,

— simulation, and

— alarm.

Establishing this interface is recommended.

9.7 Interface between a CPSMT and humans through a UIS

A CPSMT interfaces with humans through a UIS. The aim of this interface is the exchange of data on machine tool and shop floor (see 10.7), including:

— monitoring,

— analysis,

— scheduling,

— diagnosis,

— simulation, and

— alarm.

Establishing this interface is required.

10 Capabilities of a CPSMT

10.1 General

The architecture of a CPSMT should be designed such that the capabilities defined in the following subclauses are satisfied.

NOTE As specified in the Scope, this document does not define how those capabilities are to be implemented.

10.2 Machine tool that autonomously deals with its abnormalities

A CPSMT primary system shall be able to deal with abnormalities in an autonomous fashion.

NOTE 1 Types of abnormality on the machine tool depend on the specific types of manufacturing technology. For more details, see ISO 23704-2 for subtractive manufacturing and ISO 23704-3 for additive manufacturing.

NOTE 2 Throughout the ISO 23704 series, the capability of dealing with abnormalities is emphasized due to the fact that:

— In principle, total optimization of the manufacturing process, is done by: a) off-line optimization (via CAx, for instance), followed by b) on-line ‘faithful’ execution,

— Faithful execution can be done by autonomously dealing with abnormalities; the deviations from the normal status optimally planned off-line.

NOTE 3 Classes of abnormality emphasized in the market are given in A.4.

10.3 Machine tool that coordinates autonomously with various devices in the shop floor

A CPSMT primary system should be able to interface with various devices in an autonomous fashion, e.g. handling system, robots.

10.4 Machine tool that collaborates autonomously with the shop floor control system (SFCS)

A CPSMT primary system should be able to collaborate with a SFCS in an autonomous fashion to contribute to enhancing shop floor level operation KPIs, e.g. production time, production quality, production cost.

NOTE A detailed list of KPIs for manufacturing operation management is described in ISO 22400-2.

10.5 Machine tool that interfaces with life cycle aspects

A CPSMT should be able to exchange data on life cycle aspects including design / analysis, process planning, machining and operation, inspection, maintenance, and optimization.

NOTE This is for a CPSMT to access data in legacy systems, e.g. Computer-Aided Design, engineering, process planning, manufacturing, inspection, to be used for carrying out CPSMT capabilities. Alternatively, by sending control and operation result data from a CPSMT to legacy systems, life cycle data can be updated. In this way, paradigms of closed-loop machining, life cycle optimization, and the evolution of digital twin can be realized.

10.6 Machine tool that interfaces with hierarchy level

A CPSMT should be able to exchange data on the hierarchy level.

NOTE This capability contributes to displaying monitoring, analysis, related to KPI management of the factory for the hierarchy level. In this way, the machine tool on the shop floor can be aligned with the dynamic change of the manufacturing enterprise, a characteristic of Industry 4.0.

10.7 Machine tool that supports machine tool stakeholders

A CPSMT shall be able to support machine tool stakeholders by providing various functions, e.g. displaying data on monitoring, and analysis related to machine tool operation and maintenance.

Annex A
(informative)

Background of cyber-physically controlled smart machine tool systems (CPSMT)

A.1 General

Manufacturing means to produce products by so-called 4M and 1E (Man, Machine, Material, Method, and Environment).

Smart manufacturing is 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 collaborate with other domains within enterprise value chains[26].

The vision and characteristics of smart manufacturing have products embedded as a part of the automation solution and technologically advanced devices capable of computational work and autonomous decision-making. A big difference from conventional manufacturing is the improved ICT capability, affordability for a wide range of stakeholders, enabling data to be captured, analysed, and shared, resources to be intelligent, and everything and everyone connected to one another.

NOTE 1 For details of smart manufacturing, refer to IEC TR 63319 WG21_N136_TR-SMRM[26].

NOTE 2 See the ISO 23247 series[13] for a generic framework to support the creation of digital twin of observable manufacturing elements.

The machine tool is a core means for manufacturing, which has been advanced through enabling technologies together with manufacturing paradigms. A manufacturing paradigm is a concept that refers to a system of cognition that fundamentally defines people's views or thoughts, or the theoretical framework or system of things in a specific time range in the manufacturing domain. With emerging ICT development, data is available in a direction that supports smart manufacturing.

A.2 Analogy of RAMI 4.0 from the cyber-physical perspective

RAMI 4.0 is a representative smart manufacturing reference model (SMRM).

RAMI 4.0 is the reference model of Industry 4.0 and gives a structured description of fundamental ideas. See IEC PAS 63088:2017, Introduction.

The fundamental purpose of Industry 4.0 is to facilitate cooperation and collaboration between technical objects, i.e. they have to be virtually represented and connected. In this context, a technical object is an object that is of value to an organization. Therefore, it means not only physically tangible objects but also intangible objects, e.g. ideas, archives, and software.

In Figure A.1, RAMI 4.0 is shown as a three-dimensional map showing how to approach the issue of industry 4.0, consisting of:

— Hierarchy level axis (or aspect): the levels of functional hierarchy models that describe the levels of functions and domains of control associated within manufacturing organizations. The levels provide different functions and work at different time scales. Field devices and the products are included as components constituting the physical production process,

— Layers axis (or aspect): the structure for describing architectural aspects of Industry 4.0 components and Industry 4.0 systems,[29] and

— Life cycle value stream: the continuous number of processes, which an item passes from creation to dissolution[23].

NOTE 1 For a detailed description of the hierarchy level, see IEC 62264-1 and IEC 61512.

NOTE 2 For the definition of the layers, see IEC PAS 63088:2017.

NOTE 3 For details on the life cycle aspect, see IEC 62890.

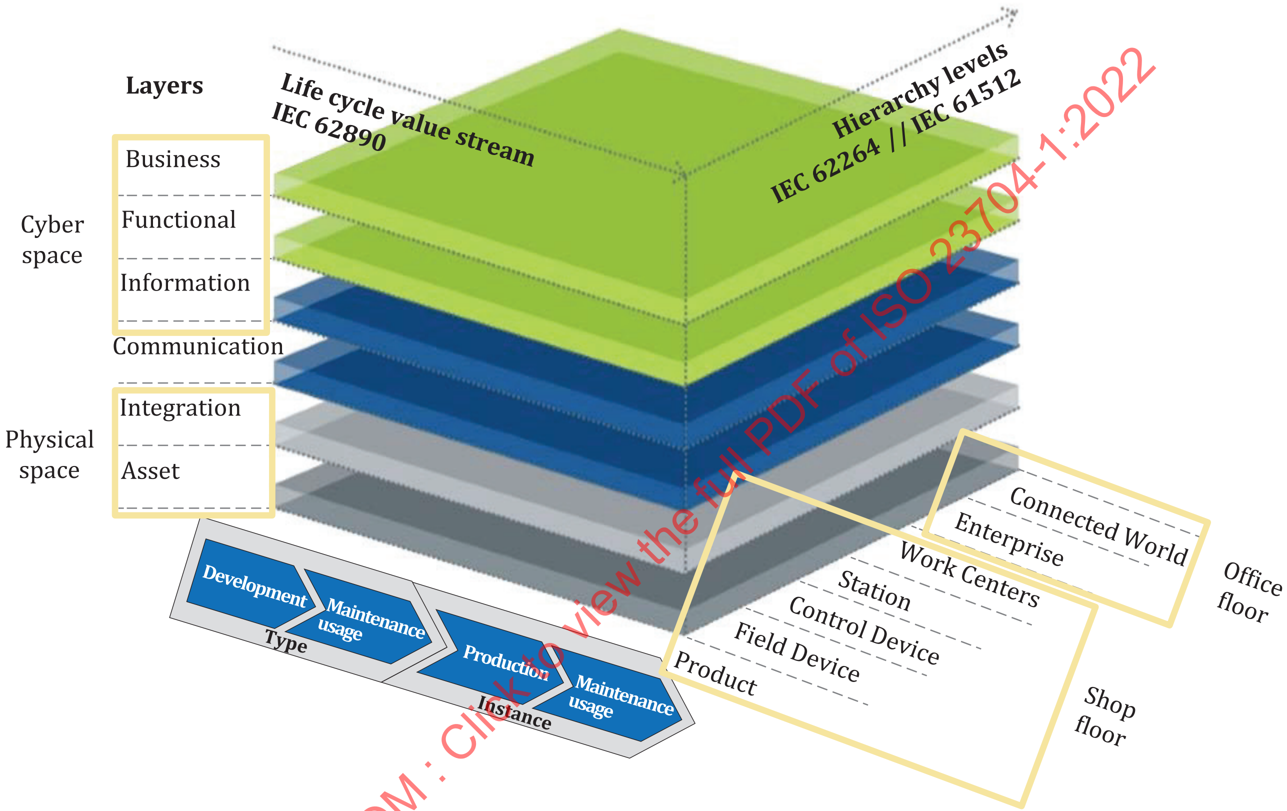


Figure A.1 — Analogy of RAMI 4.0 from the cyber-physical perspective (based on IEC PAS 63088:2017, Figure 8, modified by the addition of yellow boxes)

NOTE 4 Figure A.1 is reproduced with permission from IEC PAS 63088:2017, Figure 8: Reference architecture model Industry 4.0 (RAMI4.0) (modified by the addition of yellow boxes). IEC has no responsibility for the placement and context (including other content or accuracy) in which the extracts are reproduced, nor is IEC in any way responsible for the other content or accuracy therein.[3)].

Viewed from the cyber-physical perspective, RAMI 4.0 can be analysed using the yellow boxes given in Figure A.1 as follows.

Layers axis (or aspect) of RAMI 4.0 bifurcated into two:

— 'Physical space' including asset and integration, communicating with, and

— 'Cyber space' including other layers, including information, functional, and business.

Hierarchy level axis (or aspect) of RAMI 4.0 bifurcated into two:

— 'Office floors' including connected world, enterprise, and

— 'Shop floors' including product, field device, control device, station, and work centres.

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Life cycle value stream axis (or aspect) applies to both physical and cyber spaces.

A.3 Cyber-physical manufacturing system (CPMS)

Based on the analogy, according to A.2, RAMI 4.0 for manufacturing systems can be transformed into a model of a CPMS.

The concept of a CPMS is shown in Figure A.2 as follows:

— In addition to the three aspects of RAMI 4.0, it has a cyber-physical aspect resulting in four aspects in total,

— The physical space is represented by the manufacturing system composed of a shop floor and office floor, communicating with the cyber space, and

— The cyber space is represented by the CSS.

Based on the principle of smart manufacturing systems[32], a CPMS can be composed as follows:

— An 'Office floor' consisting of customer relationship management (CRM), product life cycle management (PLM) / enterprise resource planning (ERP), supply chain management (SCM),

— A 'Shop floor' consisting of product, process, and resource (to which the machine tool belongs), and

— The CSS consisting of monitoring, analysis, planning, and execution based on big data analytics and digital twin.

Applying three aspects of RAMI 4.0 to the cyber-physical aspect can be mapped as follows:

— 'Product,' 'device,' 'control,' 'station,' and 'work centre' can be mapped to 'shop floor,'

— 'Enterprise' and 'connected world' can be mapped to 'office floor,'

— 'Information,' function,' and 'business' can be mapped to 'cyber-supporting system,' and

— 'Type and instance' of life cycle aspects in generic manufacturing can be mapped to a typical life cycle of manufacturing system consisting of 'Design,' 'Engineering,' 'Operation,' 'Maintenance,' 'Service,' and 'Optimization.'

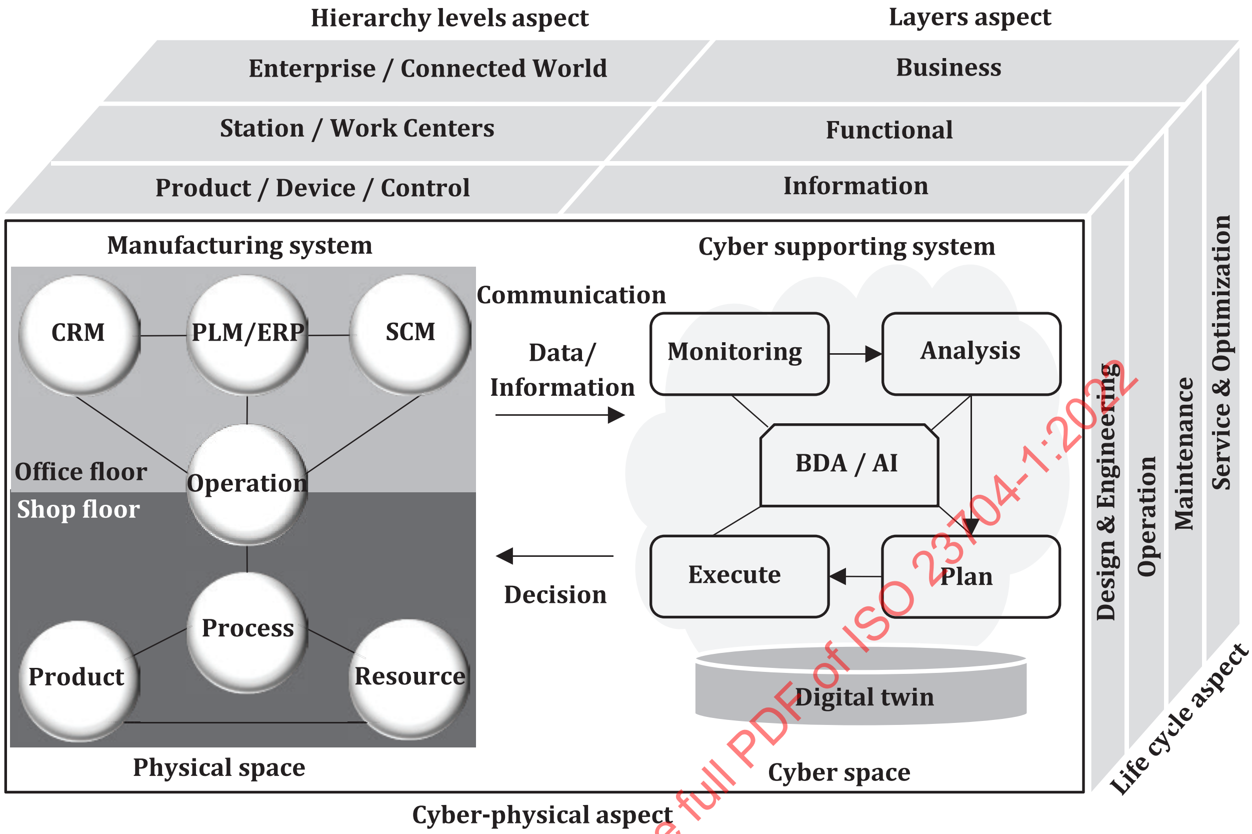


Figure A.2 — Cyber-physical manufacturing system (CPMS)

A.4 Cyber-physically controlled smart machine tool systems (CPSMT)

The concept of a CPSMT shown in Figure A.3 can be captured by replacing the manufacturing system in the physical space of a CPMS (see Figure A.2) with a machine tool.

In the cyber-physical aspect, the machine tool in the physical space interfaces with the CSS to realize intelligence based on monitoring, analysis, planning, and execution function based on big data analytics and digital twin thru a bi-directional interface. The machine tool interfaces with the shop floor as an element of the shop floor system.

In the hierarchy level aspect, the machine tool directly interfaces with 'Product,' 'Device,' 'Control,' 'Station,' and 'Work centre.' The machine tool indirectly interfaces with 'Enterprise' and 'Connected world.'

In the layer aspect, 'business' does not mean much for the machine tool, i.e. the layer aspect of the machine tool consists of 'Asset,' 'Integration,' 'Communication,' 'Information,' and 'Functional.'

In the life cycle aspects, the machine tool for the manufacture of a product can be set as:

a) Design (Computer-Aided Design),

b) Analysis (Computer-Aided Engineering),

c) Process planning (Computer Aided Process Planning),

d) CNC machining (CNC),

e) Inspection (Computer-Aided Inspection), and

f) Maintenance and optimization.

In the market, the intelligence of the smart machine tool system is often meant by 'zero-downtime' and 'zero-defect,' emphasizing the abnormalities of:

— Machine body,

— Cutting tools,

— Workpiece (quality), and

— Environment (energy, emission, and waste).

For the sake of intelligence, the status of the machine tool during the entire operation should be monitored, analysed, planned, and executed based on big data analytics and digital twin through bi-directional communication.

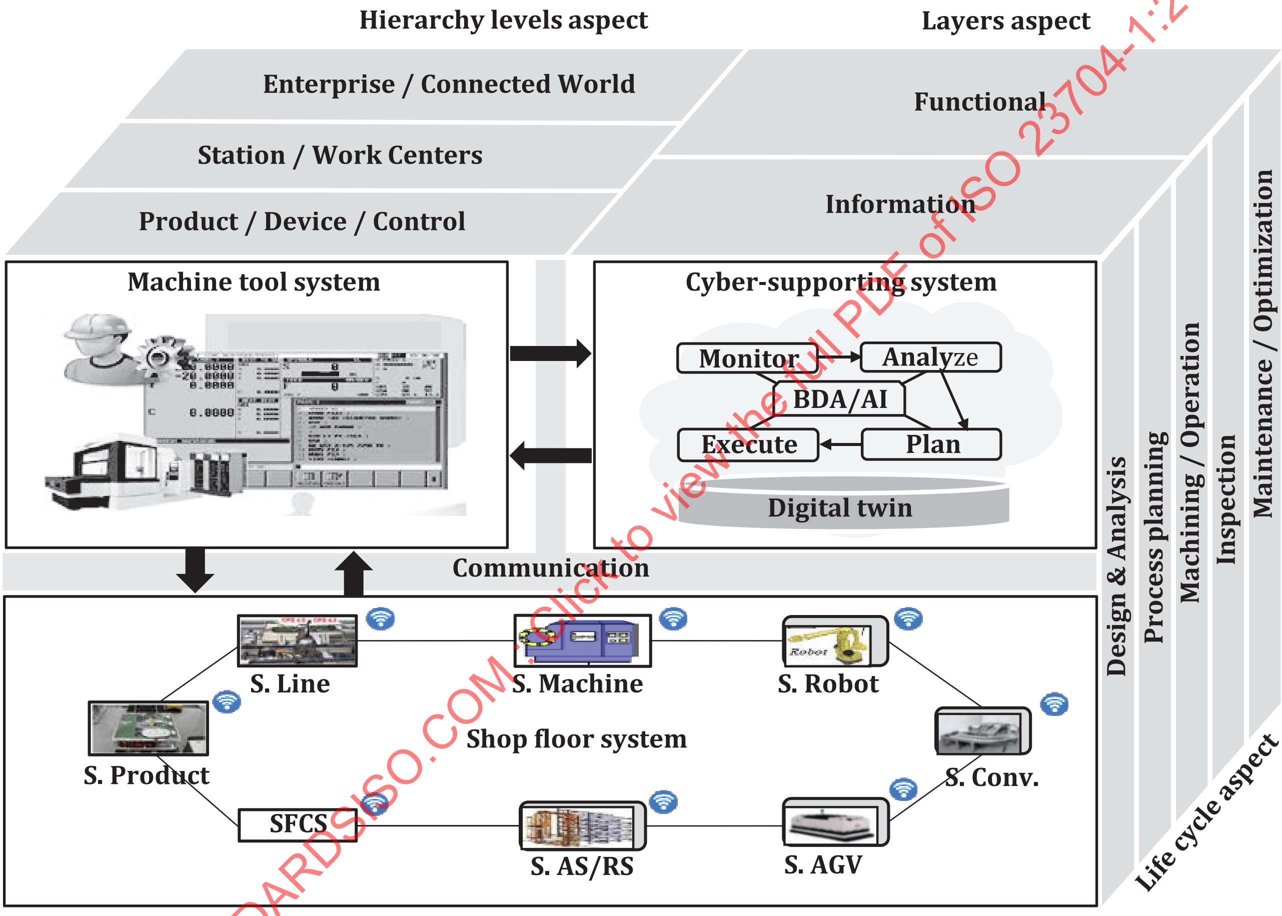


Figure A.3 — Concept of cyber-physically controlled smart machine tool systems (CPSMT)

Annex B
(informative)

SFDS viewed from Industry 4.0 component and administration shell

B.1 General

As defined in 3.1.18, an Industry 4.0 component is a worldwide identifiable participant consisting of an administration shell and asset within an Industry 4.0 system, which offers services with the defined quality of service characteristics[29].

An administration shell and Industry 4.0 components serve as the basis for collaborating with the shop floor level operation (see 10.3), interface with life cycle aspects (see 10.4), interface with hierarchy level (see 10.5), and interface with the stakeholders (see 10.6) as the scheme for platform-independent data exchange. Communication via an administration shell is referred to as "Industry 4.0 compliant communication." Each CSSx has an interface whose function is mapped to the function of the administration shell.

NOTE 1 Details of an administration shell and Industry 4.0 component are given in IEC PAS 63088:2017.

Figure B.1 illustrates the concept of an SFDS viewed from an Industry 4.0 component and administration shell as follows:

— A CPS equipped machine tool (CPCM) communicates with a cyber-physical system equipped robot (CPCR) for coordination of motion via device-to-device communication,

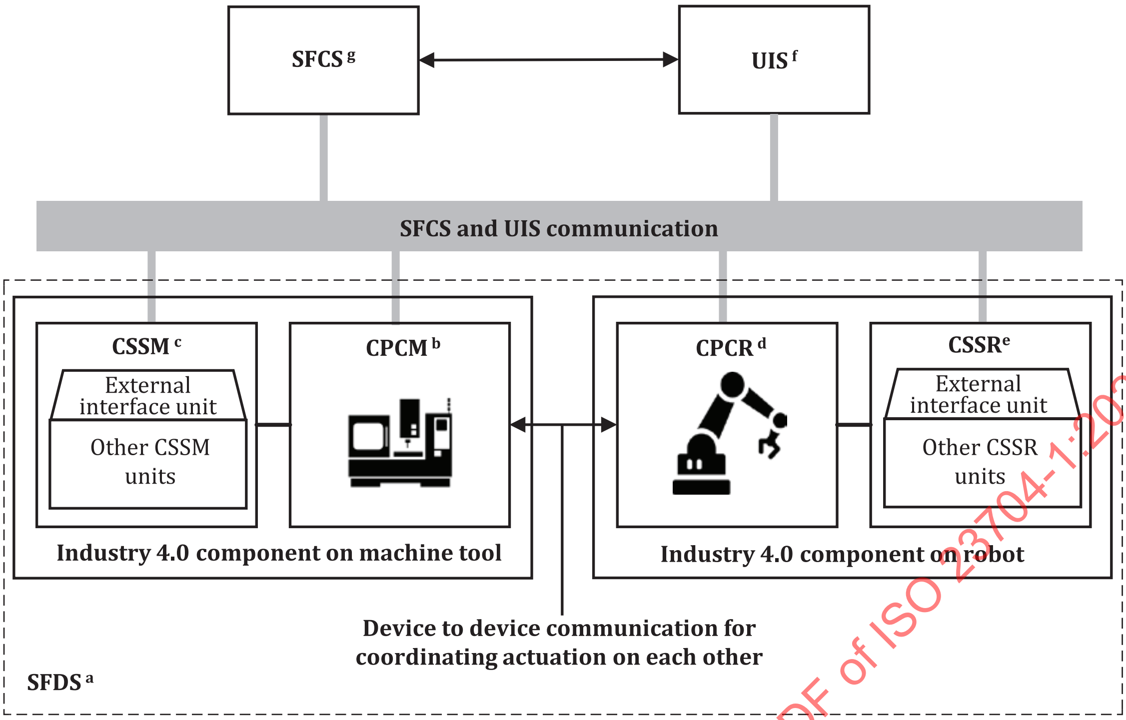
— A CPCM interfaces with a CSSM for intelligence,

— A CPCR interfaces with a CSSR for intelligence,

— A CPCM, a CSSM, a CPCR and a CSSR interface with an SFCS for collaboration, and

— A CPCM, a CSSM, a CPCR, and a CSSR interface with a UIS for data exchange.

NOTE 2 Details of the interface defined as the external interface unit are specified in ISO 23704-2:2022, 8.5.



a Shop floor device system (SFDS).
b Cyber-physically controlled machine tool (CPCM).
c Cyber supporting system for machine tool.
d Cyber-physically controlled robot (CPCR).
e Cyber supporting system for robot (CSSR).
f Unified interface system (UIS).
g Shop floor control system (SFCS).

Figure B.1 — SFDS viewed from Industry 4.0 component and administration shell