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

**Part 2:
Reference architecture of CPSMT for
subtractive manufacturing**

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

Partie 2: Architecture de référence des CPSMT pour la fabrication soustractive

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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 of 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 www.iso.org/iso/foreword.html.

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 63319¹⁾ 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 23704-3²⁾.

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

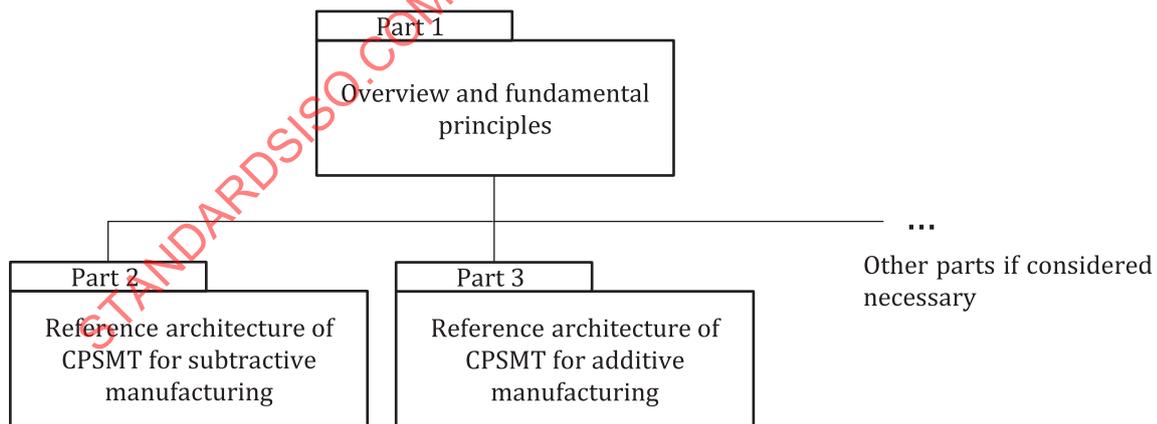


Figure 1 — Overall structure of the ISO 23704 series on general requirements for cyber-physically controlled smart machine tool systems (CPSMT)

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.

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

Part 2: Reference architecture of CPSMT for subtractive manufacturing

1 Scope

This document specifies a reference architecture of cyber-physically controlled smart machine tool systems (CPSMT) for subtractive manufacturing based on the reference architecture of a CPSMT as provided in ISO 23704-1.

The reference architecture of a CPSMT for subtractive manufacturing includes:

- the reference architecture of a cyber-physically controlled machine tool (CPCM),
- the reference architecture of a cyber-supporting system for machine tools (CSSM), and
- the interface architecture of a CPSMT.

This document also provides:

- a conceptual description of a shop floor device system (SFDS),
- a conceptual description of a shop floor control system (SFCS),
- a conceptual description of a unified interface system (UIS), and
- example use cases of a reference architecture of a CPSMT for subtractive manufacturing.

This document does not specify physical or implementation architecture.

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 23704-1:2022, *General requirements for Cyber-Physically Controlled Smart Machine Tool Systems (CPSMT) — Part 1: Overview and fundamentals principles*

3 Terms, definitions and abbreviated terms

For the purposes of this document, the terms and definitions given in ISO 23704-1 and the following 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

context data

data specifying in which circumstances the *state data* (3.1.16) is obtained from the various perspectives, e.g. products, processes, tool paths and process variables

3.1.2

cyber-physical system unit

CPS unit

instance of a cyber-physical system (CPS) according to the reference architecture

Note 1 to entry: The CPS unit provides advanced control functionalities for the machine tool unit (see 3.1.12), interfacing with data from sensors, numerical control kernel / programmable logic controller, the cyber-supporting system for machine tool (CSSM), shop floor control system (SFCS), and unified interface system (UIS).

3.1.3

data model

graphical and/or lexical representation of data, specifying their properties, structures and interrelationships.

[SOURCE: ISO/IEC 19778-1:2015, 3.1.7]

3.1.4

data processing unit

DPU

instance of data processing according to the reference architecture of cyber-physically controlled smart machine tool (CPSMT) for subtractive manufacturing

3.1.5

digital twin unit

instance of a digital twin according to the reference architecture of cyber-physically controlled smart machine tool (CPSMT) for subtractive manufacturing

Note 1 to entry: The digital twin unit describes the digital replica or digital representation of a machine tool system and its surrounding environment.

Note 2 to entry: The perspective of digital representation of the machine tool system contains: a) machine body, b) cutting tool, c) workpiece, and d) environment.

Note 3 to entry: The digital representation of the machine tool consists of the data model and behaviour model.

3.1.6

element

component or part as a constituent function in a *unit* (3.1.17)

3.1.7

engineering phase context data

part of the context data for machining specified in the engineering phase, e.g. computer-aided design, process planning and manufacturing data

Note 1 to entry: Example data is included in, e.g. the ISO 14649 series, ISO 6983-1, ISO 13399-1.

3.1.8

external interface unit

unit (3.1.17) that receives data from a) the *data processing unit* (3.1.4), b) the *MAPE unit* (3.1.13) via execution element, and transmits that data to a shop floor control system (SFCS) and a unified interface system (UIS) instance of interface with external entities according to the reference architecture for subtractive manufacturing

3.1.9**inner-loop element**

part of the cyber-physical system (CPS) unit (3.1.2) that detects and resolves abnormalities for the machine tool unit (3.1.12) in hard-real time

3.1.10**inter-loop element**

part of the cyber-physical system (CPS) unit (3.1.2) that generates event-driven control instructions for the machine tool unit (3.1.12) based on data from a shop floor control system (SFCS) for the sake of collaboration

3.1.11**intra-loop element**

part of the cyber-physical system (CPS) unit (3.1.2) that generates control instructions for the machine tool unit (3.1.12) based on the data from a cyber-supporting system for machine tools (CSSM) in soft-real time

3.1.12**machine tool unit****MTU**

instance of machine tool according to the reference architecture for subtractive manufacturing

Note 1 to entry: According to ISO 14955-1, 3.12: 2017, the machine tool function of a machine tool unit consists of machine tool operation (machining process, motion and control), process conditioning, workpiece handling, tool handling or die change, recyclables and waste handling and machine tool cooling / heating. This functionality is used for determining areas for abnormalities.

3.1.13**monitoring, analysis, planning, and execution unit****MAPE unit**

instance of monitoring, planning, and execution according to the reference architecture

3.1.14**numerical control kernel****NCK**

component for controlling the servo motors consisting of, e.g. an interpreter, interpolator, acceleration / deceleration controller and position controller

Note 1 to entry: Numerical control kernel is the key module not only of the computerized numerical control (CNC) but it is also a typical position control for servo motors^[38].

3.1.15**operation phase context data**

set of data specified at the machine tool before machining operation start, including, e.g. setup data of machine tool, cutting tool and workpiece

3.1.16**state data**

set of data on the state of the machine tool unit (3.1.12) during machining operation from which the key performance indicators (KPIs) of the machine body, cutting tool, workpiece and environment can be identified

Note 1 to entry: Typical means for obtaining the state data are various sensors and a computerized numerical control (CNC) on the machine tool components.

3.1.17

unit

group of *elements* (3.1.6) that constitutes part of the reference architecture of a cyber-physically controlled machine tool (CPCM) and a cyber-supporting system for machine tools (CSSM) for subtractive manufacturing

Note 1 to entry: The term “unit” in this document is used as an instance of a collection of elements.

3.2 Abbreviated terms

CAx	computer-aided-x
CNC	computerized numerical control
CPCA	cyber-physically controlled autonomous guided vehicle
CPCM	cyber-physically controlled machine tool
CPCR	cyber-physically controlled robot
CPCS	cyber-physically controlled storage
CPS	cyber physical system
CPSMT	cyber-physically controlled smart machine tool
CSSA	cyber supporting system for autonomous guided vehicle
CSSM	cyber supporting system for machine tool
CSSR	cyber supporting system for robot
CSSS	cyber supporting system for storage
FFT	fast Fourier transform
HMI	human machine interface
MAPE	monitoring, analysis, planning, execution
MTB	machine tool builder
MTU	machine tool unit
NCK	numerical control kernel
PLC	programmable logic controller
SFCS	shop floor control system
SFDS	shop floor device system
UIS	unified interface system

4 Conformance with the CPSMT reference architecture for subtractive manufacturing

To claim conformance, the definition of specific system architecture 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 for subtractive manufacturing

The CPSMT reference architecture for subtractive manufacturing describes an architecture of smart machine tool systems for subtractive manufacturing based on the generic reference architecture specified in ISO 23704-1. It provides guidance for designers developing smart machine tool systems

for subtractive manufacturing 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) vendors, solution vendors, service providers, customers and end-users.

The CPSMT reference architecture for subtractive manufacturing supports the following important standardization objectives:

- a) To ensure clear and unambiguous communication between all interested parties of smart machine tools for subtractive manufacturing.
- b) To ensure the interoperability of smart machine tools with related hardware devices, software, service, and manufacturing system for subtractive manufacturing.
- c) To ensure the quality / capability of smart machine tools for subtractive manufacturing.
- d) To ensure the use of smart machine tools for subtractive manufacturing.
- e) To ensure systematic development, modification of smart machine tools for subtractive manufacturing.

[Figure 2](#) illustrates the context of how the CPSMT reference architecture for subtractive manufacturing is derived and viewed from various perspectives based on the architecture description defined in ISO/IEC/IEEE 42010:2011^[29].

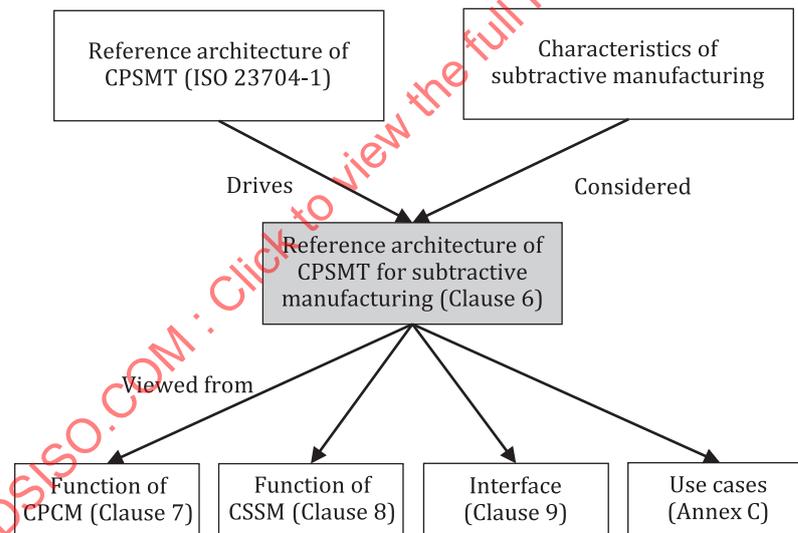


Figure 2 — Context of the CPSMT reference architecture for subtractive manufacturing

Based on [Figure 2](#), this document includes the following descriptions:

- The reference architecture of a CPSMT for subtractive manufacturing in [Clause 6](#).
- The reference architecture of a CPCM viewed from functionality perspective in [Clause 7](#).
- The reference architecture of a CSSM viewed from functionality perspective in [Clause 8](#).
- The reference architecture of a CPSMT viewed from the interface perspective in [Clause 9](#).
- The use cases of the reference architecture in [Annex C](#).

6 Reference architecture of a CPSMT for subtractive manufacturing

Based on the reference architecture for a CPSMT of ISO 23704-1:2022, Clause 7, [Figure 3](#) displays the reference architecture of a CPSMT for subtractive manufacturing.

The structure is as follows:

- The CPSMT primary system for subtractive manufacturing is composed of a cyber-physically controlled machine tool (CPCM) and a cyber-supporting system for machine tools (CSSM). It has the primary function to deal with machine tool abnormalities in autonomous fashion (see ISO 23704-1:2022, 10.2).
- The CPSMT associated system for subtractive manufacturing is composed of a shop floor device system (SFDS), a shop floor control system (SFCS), and a unified interface system (UIS). An SFDS and an SFCS have capabilities as described in ISO 23704-1:2022, 10.3 and 10.4.
- Through the UIS, the CPSMT for subtractive manufacturing interfaces with external entities, e.g. humans, life cycle aspects, and hierarchy levels, according to ISO 23704-1:2022, 10.5, 10.6, and 10.7.

Details on units and elements of a CPCM and a CSSM for subtractive manufacturing and their interfaces, are specified in [Clauses 7, 8, and 9](#). Details on an SFDS, an SFCS and a UIS are given in [Annex A](#) and [Annex B](#).

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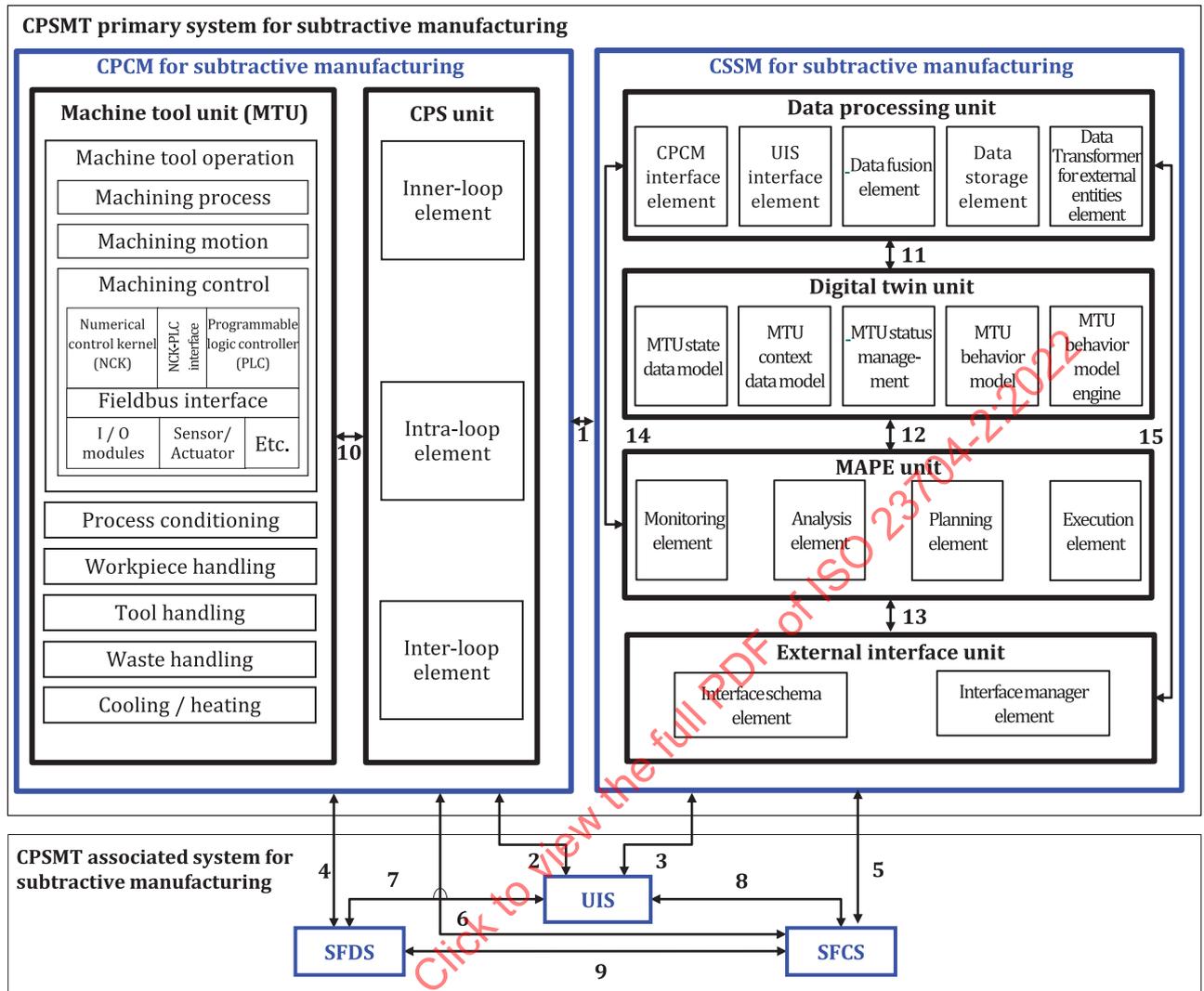


Figure 3 — Reference architecture of a CPSMT for subtractive manufacturing

7 Functional view of a CPCM for subtractive manufacturing

7.1 General

This clause provides a set of requirements for constituent elements that make up a CPCM.

A CPCM consists of

- a) a machine tool unit, and
- b) a cyber-physical system (CPS) unit.

7.2 Machine tool unit (MTU)

7.2.1 Function of the MTU

The physical system to be monitored, analyzed, and for which decisions are made about possible abnormalities. (see ISO 23704-1:2022, 3.1) is the MTU. Depending on the viewpoints, the MTU can be classified in several ways, as specified in ISO 13399-1, ISO 14649-201, ISO 14955-1 which deal with different aspects of the MTU. Here, the definitions from ISO 14955-1 are used as a basis for the MTU functionality.

According to ISO 14955-1, every machine tool, independent of the technology, can be described by the following general functions:

- Machine tool operation (machining process, motion and control),
- Process conditioning,
- Workpiece handling,
- Tool handling,
- Recyclables and waste handling, and
- Machine cooling / heating.

NOTE 1 See ISO 14955-1 for an extensive description of the functions and subfunctions of a machine tool.

The machining control subfunctions in the machine tool operation function should:

- Control the machine tool operation and all other functions of the MTU,
- Manage the part program (e.g. the ISO 14649 series or ISO 6983-1) received from the UIS,
- Generate status signals of all MTU functions via sensors and I/O modules,
- Transmit the collected data to the CSSM, the UIS, and the CPS unit, and
- Receive control instructions from the CPS unit.

NOTE 2 Typical machine tool components for the subfunction "machining control" are, e.g. CNC system, programmable logic controller, display, sensors, relays, touch probes, based on ISO 14955-1.

NOTE 3 Computerized numerical control (CNC) system can consist of numerical control kernel, programmable logic controller, fieldbus interface, and their interfaces^[38].

The MTU interfaces with:

- The CPS unit for retrieving control instructions and transmission of data,
- The UIS for retrieving context data, including part program, and

- The SFDS for coordination.

NOTE 4 Coordination is a recommended capability of a CPSMT, as specified in ISO 23704-1:2022, 10.2.

7.2.2 Abnormalities of the MTU

A machine tool's performance can decrease over time, especially by repeated machining operation, e.g. due to degradation of mechanical properties (fatigue, impact, hardness, corrosion).

Abnormality can be viewed not only from the functionality of the MTU but also key performance indicators (KPIs) of the machine tool. See [8.3](#) for a more detailed description.

The status of the MTU should be monitored, analysed, planned and executed utilizing data from the MTU, CSSM and a UIS in order to:

- Prevent failure,
- Use the machine tool efficiently,
- Achieve prognosis health maintenance, and
- Optimize the use of the machine tool.

7.3 Cyber-physical system (CPS) unit

7.3.1 General

Compared with the conventional machine tool system, the CPS unit is an additional control function that enables the CPCM to realize the two capabilities of a CPSMT:

- Autonomously dealing with abnormalities (see ISO 23704-1:2022, 10.2) by interfacing with sensors, machine controller, e.g. numerical control kernel (NCK), programmable logic controller (PLC) and UIS, and
- Autonomously collaborating with an SFCS (see ISO 23704-1:2022, 10.4) by interfacing with an SFCS.

To fulfil these tasks, a CPS unit should consist of:

- An inner-loop element,
- An intra-loop element, and
- An inter-loop element.

NOTE Physical deployment of the CPS unit should be determined in the implementation phase. A CPS unit can be in the machine tool controller, outside of the machine tool controller, or both.

7.3.2 Inner-loop element

As defined in [3.1.9](#), inner-loop element is the part of the CPS unit that detects and resolves abnormalities for the MTU in hard-real time.

NOTE Inner-loop can be used as a means for adaptive control for the optimization of material removal rate, for instance.

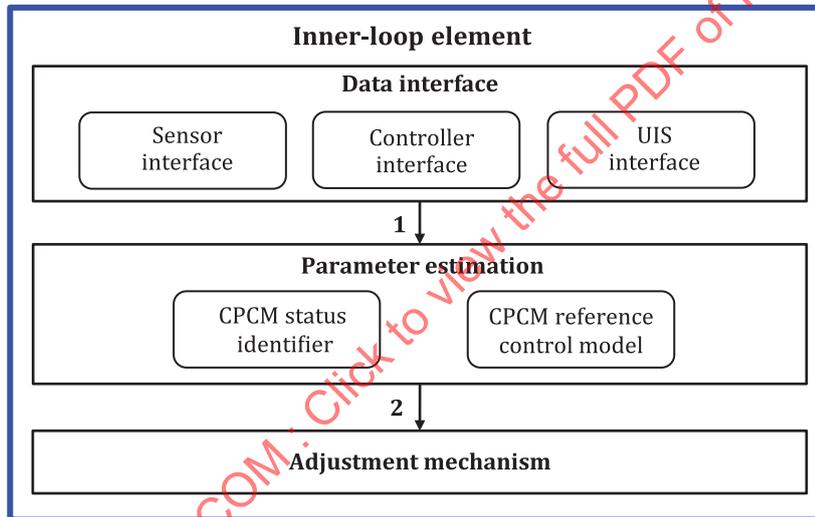
To this end, the inner-loop element should:

- Receive the data from the MTU (e.g. sensor and controller) and the UIS for engineering context data, including part program as specified in, e.g. the ISO 14649 series or ISO 6983-1,
- Identify the current CPCM status based on data from the MTU,

- Compare the current state of the MTU with the reference state,
- Generate control instructions for improving operation of the MTU,
- Transmit the generated control instructions to the MTU, and
- Transmit the generated data to the UIS.

Figure 4 is a recommended functional structure of the inner-loop element composed of:

- Data interface component composed of sensor interface, controller interface, and a UIS interface to obtain sensor, controller data from the MTU, engineering context data, a part program, Controller elements can be: Numerical Control Kernel (NCK) / Programmable Logic Controller (PLC), for example.
- Parameter estimation component composed of a CPCM status identifier and a CPCM reference control model to receive the data from the data interface and identify the current status or difference from reference status of the MTU, and
- Adjustment mechanism component to receive output from parameter estimation and generate control instructions for transmission to the MTU.



Key

- 1 transmission of collected data from the data interface to parameter estimation
- 2 transmission of generated feature from the parameter estimation component to the adjustment mechanism

Figure 4 — Functional structure of the inner-loop element

7.3.3 Intra-loop element

As defined in 3.1.11, intra-loop element is the part of the CPS unit that generates control instructions for the controller (machining control) based on the data from a CSSM in soft-real time.

Compared with the capability of the inner-loop element, the intra-loop capability is more powerful in many respects, including, e.g. detectability of abnormality, adjustment of the machine tool parameters for the next operations.

To this end, the intra-loop element should:

- Receive the control command data from the CSSM,
- Receive the status of the controller from the MTU,

- Convert the control command for the MTU,
- Make a decision as to whether the proposed command can be accommodated, based on data from the MTU,
- Generate an override command for the MTU, and
- Transmit the generated command to the MTU.

[Figure 5](#) is a recommended functional structure of the intra-loop element composed of:

- A CSSM interface to receive the output from a CSSM,
- A machine tool unit interface to get data from the MTU,
- A CSSM interpreter for machine tool to convert the output from a CSSM to a form executable by the MTU,
- A checker for override to examine whether the MTU can accommodate the output from a CSSM to operate the MTU with the current status, and
- An override command generator to transmit the converted command to the MTU.

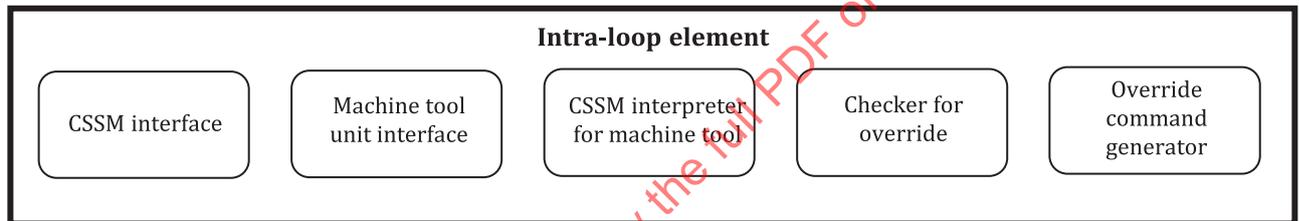


Figure 5 — Functional structure of the intra-loop element

7.3.4 Inter-loop element

As defined in [3.1.10](#), inter-loop element is the part of the CPS unit that generates event-driven control instructions for the controller (machining control) based on data from an SFCS for the sake of collaboration.

NOTE Example situations can be: a) resource reallocation or rescheduling of the shop floor devices due to failure and delay of some shop floor devices, b) special request from manufacturing execution system due to unexpected situation in, e.g. customer relationship management, supply chain management.

To this end, the inter-loop element should:

- Receive outputs (e.g. task allocation plan) from an SFCS,
- Receive the status of the controller from the MTU,
- Convert the control command for the MTU,
- Make a decision as to whether the proposed command can be accommodated, based on data from the machine tool unit,
- Generate override commands for the MTU, and
- Transmit the generated commands to the MTU.

[Figure 6](#) is a recommended functional structure of the inter-loop element composed of:

- An SFCS interface to receive the output from a CSSM,

- An MTU interface to get data from the MTU,
- An SFCS interpreter for the machine tool to convert the output from an SFCS to a form executable by a MTU,
- A checker for override to examine whether the MTU can accommodate the output from an SFCS to operate the MTU with the current status, and
- An override command generator to transmit the converted command to the MTU.

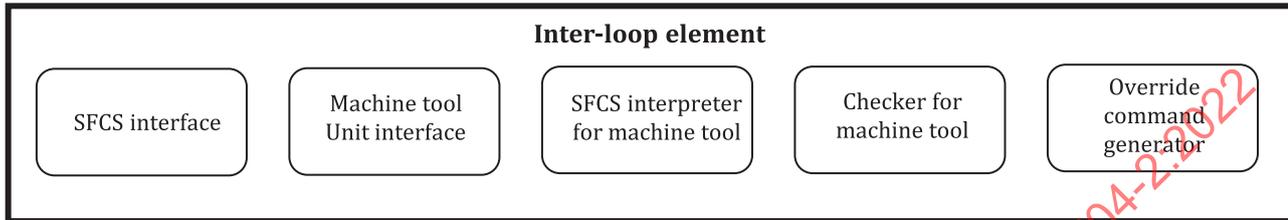


Figure 6 — Functional structure of the inter-loop element

8 Functional view of a CSSM for subtractive manufacturing

8.1 General

This clause provides a set of requirements for constituent elements that make up a CSSM.

A CSSM is mainly to support the performance of a CPCM. This is done by identifying the current status of the MTU based on the data related to the machine tool status.

Subsequently, decisions can be made based on reasoning for the enhancement of KPIs of the MTU. To this end, the CSSM consists of:

- a) The data processing unit (DPU),
- b) Digital twin unit,
- c) A MAPE unit, and
- d) External interface unit.

In addition, a CSSM interfaces with an SFCS and external entities, including life cycle aspects and hierarchy level via a UIS.

8.2 Data processing unit (DPU)

8.2.1 General

A DPU is a set of functions to process the acquired data for the use of the digital twin unit, a MAPE unit, and external interface unit.

The DPU consists of:

- A CPCM interface element,
- A UIS interface element,
- A data fusion element,
- A data storage element, and

- A data transformer for external entities element.

8.2.2 A CPCM interface element

The CPCM interface element is the element that acquires data related to machine tool status from the MTU of a CPCM.

To this end, the CPCM interface element should:

- Retrieve the state data and operation phase context data, and
- Transmit the retrieved data to the data fusion element.

This document does not specify industrial communication protocols for the CPCM interface (e.g., Profibus, Modbus and EtherCAT). Communication protocol should be determined based on the purpose of implementation, e.g. required latency threshold, system configuration type (edge, fog and cloud), the amount of data.

8.2.3 UIS interface element

The UIS interface element is the element that acquires context-related data of the MTU, such as engineering phase context data, to be used for identifying the status of machine body, cutting tool, workpiece, and environment.

To this end, the UIS interface element should:

- Retrieve engineering phase context data, and
- Transmit the retrieved data to the data fusion element.

This document does not specify industrial communication protocols for the UIS interface (e.g. Profibus, Modbus and Ethernet). Communication protocol should be determined based on the purpose of implementation, e.g. required latency threshold, system configuration type (edge, fog and cloud), the amount of data.

8.2.4 Data fusion element

The data fusion element is the element that integrates multiple data sources from a CPCM and a UIS interface elements for the sake of producing consistent, accurate, and useful data.

To this end, the data fusion element should perform:

- Data cleansing function a) to search for and correct (or remove) corrupted or inaccurate data items in the collected data, b) to identify incomplete, inaccurate, or irrelevant parts of the data, and c) to replace, modify, or delete the data,
- Data formatting function to organize cleansed data to fit in a predefined specification that is defined by the MTU state data model (see [8.3.3](#)) and MTU context data model (see [8.3.2](#)) in the digital twin unit, and
- Data grouping function to group the data items that are involved in each abnormality on the machine tool with specific contexts.

8.2.5 Data storage element

The data storage element is the element that stores the deliverables of a CSSM, including the output of data fusion, the output of monitoring, analysis, and the planning function.

To this end, the data storage element should store and manage:

- The processed data from the data fusion element (see [8.2.4](#)),

- The output of the MAPE unit (see [8.4](#)), and
- The output of the MTU behaviour model engine (see [8.3.6](#)) in the digital twin unit.

8.2.6 Data transformer for external entities element

The data transformer for external entities element transforms the output of the data fusion element to a data structure in the external interface unit. (see [8.5](#))

The data transformer for the external entities element should transform the DPU data to fit into the data structure based on the interface schema element (see [8.5.2](#)) of the external interface unit.

8.3 Digital twin unit

8.3.1 General

The digital twin for manufacturing systems is the digital model of physical assets such as man, machine, material, and method, collectively known as 4M and the environment (1E) in the shop floor of the smart manufacturing system. Synchronization and the state of the digital twin model for the sake of enhancement of a KPI is an important aspect of the digital twin.

In the case of a manufacturing system, the health of the machine, the health of the cutting tool, the health of the workpiece product (quality), and the health of the environment (e.g. energy, emission, waste) can be the performance indicators of machine tools.

From the CPSMT perspective, the digital twin is a digital replica or digital representation of a machine tool system for the sake of autonomously dealing with machine tool abnormalities, such as those involving:

- Machine tool body,
- Cutting tool,
- Workpiece, and
- Environment via monitoring, analysis, planning, and execution (MAPE).

NOTE The inner-loop element of the CPS unit is capable of dealing with the MTU abnormalities in a limited way due to the hard-real time constraint (see [7.3.2](#)).

Compared with the inner-loop element, the digital twin unit is capable of dealing with an abnormality in a deeper way from the perspective of accuracy and time span in MAPE in a structured fashion within the allowed soft-real time.

To this end, the digital twin unit consists of:

- Machine tool context data model,
- Machine tool state data model,
- Machine tool state management,
- Machine tool behaviour model, and
- Machine tool behaviour model engine.

8.3.2 Machine tool unit context data model

The MTU context data model is the data model in which circumstances the state data were obtained, including products, processes, tool paths and process variables.

The context should be divided into

- a) the operation phase, and
- b) the engineering phase.

NOTE 1 See [3.1.15](#) for the definition of operation phase context data and [3.1.7](#) for the definition of engineering phase context data.

The specific scope and contents of the context data model should be determined based on the purpose of implementation.

NOTE 2 Refer to "VDW and OPC foundation: OPC UA information model for CNC systems"^[36] for more details on the operation phase context data.

NOTE 3 Refer to related standards, including a) the ISO 14649 series and ISO 10303-238, b) ISO 6983-1, c) ISO 10303-242, and d) ISO 13399-1, for more details on the engineering phase context data.

The MTU context data model can be used as:

- A data format for the UIS interface element and CPCM interface element,
- A criterion for classifying state data into specific contexts such as a certain product, tool, or process variable when performing grouping operations in a data fusion element, and
- A criterion for specifying the scope that the MTU behaviour model can be applied.

8.3.3 Machine tool unit state data model

8.3.3.1 General

The MTU state data model is a data model that includes data correlated to each abnormality in the MTU. It is recommended to specify this data model for identifying data items related to each type of abnormality.

Depending on the viewpoints, the abnormality of the machine tool can be defined in many ways. The group of abnormalities dealt with in the CPSMT are:

- Machine body state data model,
- Cutting tool state data model,
- Workpiece state data model, and
- Environment state data model.

The MTU state data model can be used as:

- A format for the data from a CPCM interface element, and
- A criterion for classifying state data into specific types of abnormality (e.g. chatter and unsuitable surface roughness) when performing grouping operations in the data fusion element.

8.3.3.2 Machine body state data model

From the data models listed in [8.3.3.1](#), the machine body state data model is the data model of the abnormalities occurring in the machine tool components, e.g. spindle, feed drive.

The abnormality of the machine body is mainly due to the degradation of machine components, but others can be defined depending on the purpose.

NOTE 1 Machine degradation is an undesired departure in the operational performance of any device, equipment or system from its intended performance imposed on the machine body.

NOTE 2 Other types of abnormality can be incorporated in the implementation phase.

To deal with abnormality of the machine body, the digital twin unit should have a machine body state data model for the use of data fusion elements.

8.3.3.3 Cutting tool state data model

The cutting tool state data model is the data model of abnormalities occurring in the cutting tool.

The tool abnormality can be described by, e.g. tool wear, tool breakage.

NOTE 1 Tool wear is the change in the shape of the cutting part of a tool from its original shape, resulting from the progressive loss of material during cutting.

NOTE 2 Tool breakage is the particle size reduction of a cutting tool resulting from impact and / or compression.

NOTE 3 Other types of abnormality can be incorporated in the implementation phase.

To deal with abnormality of the cutting tool, the digital twin unit should have a machine cutting tool state data model for the use of the data fusion element.

8.3.3.4 Workpiece state data model

The workpiece state data model is the data model of the abnormalities occurring in the workpiece.

The abnormality of the workpiece can be due to many factors related to the quality of machined parts. Workpiece abnormality can be described by:

- Low geometric accuracy, and
- Unsuitable surface roughness.

NOTE 1 Low geometric accuracy is when the actual workpiece measurement exceeds the tolerance specification.

NOTE 2 Unsuitable surface roughness is surface irregularities with relatively small spacing, which usually include irregularities resulting from the method of manufacture being used and / or other influences.

NOTE 3 Other types of abnormality can be incorporated in the implementation phase.

To deal with abnormality of the workpiece, the digital twin unit should have a workpiece state data model for the use of data fusion elements.

8.3.3.5 Environment state data model

The environment state data model is the data model of the abnormalities occurring in the environment.

The abnormality of the environment is related to many factors. The environment abnormality can be described by:

- Unsuitable energy consumption,
- Unsuitable emission,
- Unsuitable noise, and
- Unsuitable waste.

NOTE 1 Energy consumption is the quantity of energy applied. Energy is electricity, fuels, steam, heat, compressed air, and other like media. This document considers that energy means the electrical capability of a system to perform machine tool operation.

NOTE 2 Emission is the discharge of pollutants associated with machine tool operation.

NOTE 3 Noise is an unwanted sound that can lead to hearing loss or stress or to interfere with the ability to hear other sounds or to communicate.

NOTE 4 Waste is any material or object, which is intended to be discarded or is required to be discarded.

NOTE 5 Other types of abnormality can be incorporated in the implementation phase.

NOTE 6 This environment state data model can be referred to when performing specific performance evaluation of manufacturing systems (see ISO 20140-1).

To deal with abnormality of the surrounding environment, the digital twin unit should have an environment state data model for the use of data fusion elements.

8.3.4 Machine tool unit state management element

The MTU state management element is the element that manages the set of data values which have gone through the data fusion element, on current and past timestamps for transmitting the data to the elements that generate value-added data (e.g. a MAPE unit and behaviour model engine).

The MTU state management element should:

- Receive the data from the data fusion element,
- Maintain the data from the data fusion element by a timestamp value, and
- Transmit the right data to the behaviour model engine (see [8.3.6](#)), MAPE unit (see [8.4](#)).

8.3.5 Machine tool unit behaviour model

The MTU behaviour model is a set of models that describe the behaviour of the MTU for the MAPE unit.

The MTU behaviour model should:

- Be able to generate value-added data about abnormalities occurring in machine bodies, cutting tools, workpieces, and environments, which is hard to get directly from the DPU,
- Be designed for calculating value-added data, which is utilized in the MAPE unit, and
- Be executed in the MTU behaviour model engine (see [8.3.6](#)) to generate outputs.

NOTE 1 The MTU behaviour model, in general, can be grouped by the quantitative model (e.g. machine learning and physical models), qualitative models (e.g. rule-based system), numerical model (e.g. finite element model). The details are out of the scope of this document.

NOTE 2 The specific algorithm and structure of the behaviour model should be determined based on the purpose of implementation, including, e.g. the type of abnormalities, degree of complexity and accuracy goal, collected data items.

8.3.6 Machine tool unit behaviour model engine

The MTU behaviour model engine is the element that runs the behaviour model with the input from 'MTU state management element' (see [8.3.4](#)) and 'data storage element' (see [8.2.5](#)) in digital twin unit for history data.

As mentioned in [8.3.5](#), the behaviour model should be executed in the MTU behaviour model engine for getting value-added data by executing the behaviour model.

The MTU behaviour model engine should transmit the output of the behaviour model to:

- The MAPE unit, and

- The data storage element in the DPU.

8.4 MAPE unit

8.4.1 General

The MAPE unit is the unit that monitors, analyses, plans, and executes for the machine tool based on the data and behaviour models for the enhancement of KPIs of the machine tool defined in the digital twin unit.

To this end, the MAPE unit consists of:

- Monitoring element,
- Analysis element,
- Planning element, and
- Execution element.

8.4.2 Monitoring element

The monitoring element is the element that calculates KPI values from the viewpoints of the machine body, cutting tool, workpiece, and environment for determining whether or not the abnormality occurs in the time span of control.

NOTE The concrete function structure should be determined based on the purpose of implementation, e.g. given the physical structure of the machine tool, the configuration of the control system, types of abnormality.

The monitoring element should:

- Generate the KPI values at the moment of current machine tool operation from the perspective of machine body, cutting tool, workpiece, and environment, and
- Evaluate the KPI value to determine whether the current operation state is abnormal or not.

To this end, the monitoring element should receive:

- The data from the MTU state management element,
- The historical data from the data storage element, and
- The output of the behaviour model from the MTU behaviour model engine.

8.4.3 Analysis element

The analysis element is the element that:

- Predicts the future KPI values from the viewpoint of machine body, cutting tools, workpiece, and environment, and
- Conducts diagnosis for finding the cause of the problematic KPI values.

The analysis element should:

- Generate the expected future KPI values from the perspective of the machine body, cutting tool, workpiece, and environment to clarify whether or not the abnormality occurs in the future, and
- Diagnose the cause of inappropriate KPI values generated in the monitoring element.

To this end, the analysis element should receive:

- The data from the MTU state management element,
- The historical data from the data storage element,
- The output of the behaviour model from the MTU behaviour model engine, and
- The output of the monitoring element.

NOTE 1 Diagnosis of future KPI values (generated in the analysis element) can be performed.

NOTE 2 The concrete function structure should be determined based on the purpose of implementation, e.g. given the physical structure of the machine tool, the configuration of the control system, types of abnormality.

8.4.4 Planning element

The planning element is the element that

- a) redefines the machining parameters or decides the action, and
- b) verifies the planning output.

The planning element should:

- Redefine the machining parameters or decide the action to take that contributes to the enhancement of machine tool operation from the viewpoint of the machine body, cutting tools, workpiece, and the environment in case the results of the analysis are not promising, and
- Verify the redefined parameters via simulation.

To this end, the planning element should receive:

- The data from the MTU state management element,
- The historical data from the data storage element,
- The output of the behaviour model from the MTU behaviour model engine,
- The output of the monitoring element, and
- The output of the analysis element.

8.4.5 Execution element

The execution element is the element that executes the results of the monitoring, analysis, and planning elements in the form of executable to the CPCM and related elements within a DPU and an SFCS.

To this end, the execution element should:

- Receive the output from the monitoring element, the analysis element, and the planning element, and
- Convert to executable (readable) form / data for the CPCM (intra-loop elements), the EIU, and the DPU elements (i.e. data storage element).

The execution element should transmit the output to the intra-loop element of a CPCM.

8.5 External interface unit

8.5.1 General

The external interface unit is the unit that receives data from the DPU via data transformer for the external entities element and data storage element, the MAPE unit via the execution element, and transmits that data to an SFCS and a UIS for the sake of

- a) collaboration with an SFCS,
- b) data exchange with life cycle aspects,
- c) data exchange with hierarchy level, and
- d) data exchange with humans.

NOTE OPC-UA^[32], MTConnect^[37] are representative standards for ensuring interoperability.

To this end, the external interface unit consists of:

- An interface schema element, and
- An interface manager element.

8.5.2 Interface schema element

The interface schema element is the element that represents the data structure in a CSSM to share with the system such as a UIS and an SFCS.

The interface schema makes a UIS and an SFCS refer to and find the right data in a CSSM.

To this end, the interface schema element should:

- Manage the table of contents on a CSSM for an SFCS and a UIS, and
- Provide the data schema to the interface manager element.

NOTE Examples of the table of contents are a) manifest in the administration shell of IEC PAS 63088, b) XML schema of OPC-UA.

Depending on the purpose of implementation, the structure of the interface schema should be determined.

8.5.3 Interface manager element

The interface manager element is the element that manages the collected data from the DPU and the MAPE unit and transmits them to an SFCS and a UIS.

The interface manager element should:

- Communicate with and transmit data to an SFCS and a UIS, based on the table of contents defined in the interface schema element.,
- Receive the schema from the interface schema element, and
- Manage the collected data from the DPU and the MAPE unit.

NOTE OPC-UA server in IEC TR 62541-1 and MTConnect agent are examples of interface manager elements.

9 Interface view of a CPSMT for subtractive manufacturing

9.1 General

This clause defines interfaces from the perspective of six capabilities of a CPSMT as specified in ISO 23704-1:2022, Clause 10 viewed from the interfaces within the CPSMT primary system and between a CPSMT primary system and associated system.

NOTE Communication protocols in the interface are out of scope of this document, but should be determined based on the purpose of implementation considering required latency threshold, system configuration type (e.g. edge, fog and cloud), and the amount of data.

9.2 Interfaces for the capability of autonomous handling of machine tool abnormalities

9.2.1 General

The system-level interface for the capability "autonomous handling of machine tool abnormalities" as specified in ISO 23704-1:2022, 9.2 should be through the interface between a CPCM and a CSSM.

9.2.2 Data from a CPCM to a CSSM

The interface from a CPCM to a CSSM should be established through the connection between the MTU and the DPU (a CPCM interface element).

Based on [8.3.2](#) and [8.3.3](#), data from a CPCM to a CSSM are mapped to the context and state data model in the digital twin unit of a CSSM.

NOTE This interface corresponds to key 1 in [Figure 3](#).

Especially, for the state data model, machine body data is grouped into machine tool operation, process conditioning, workpiece handling, tool handling, waste handling, and cooling / heating.

The cutting tool data is grouped into tool wear, tool breakage.

The workpiece data is grouped into low geometric accuracy, unsuitable surface roughness.

The environment data is grouped into energy consumption, emission, noise, waste production.

9.2.3 Data from a CSSM to a CPCM

The interface from a CSSM to a CPCM should be established through the connection between the MAPE unit (execution element) and the CPS unit (intra-loop element).

NOTE This interface corresponds to key 1 in [Figure 3](#).

Based on [8.2](#), data from a CSSM to a CPCM are grouped into a form from which control instructions for: machine tool operation, process planning, workpiece handling, tool handling, waste handling, and cooling / heating can be extracted in the CPCM.

9.3 Interfaces for the capability of autonomous coordination with various shop floor devices

The system-level interface for the capability "autonomous coordination with various shop-floor devices," as specified in ISO 23704-1:2022, 9.3, should be through the interface between a CPCM and an SFDS.

NOTE This interface corresponds to key 4 in [Figure 3](#).

The interface between a CPCM and an SFDS is established through the connection between the MTU (machining control subfunction) and corresponding unit / elements in each device consisting of an SFDS (e.g. programmable logic controller in the robot).

To this end, the ISO 21919 series can be used.

9.4 Interfaces for the capability of autonomous collaboration with the SFCS

9.4.1 General

The system-level interface for the capability "autonomous collaboration with shop-floor control system", as specified in ISO 23704-1:2022, 9.4, should be through the interface between a CPCM and an SFCS, and a CSSM and an SFCS.

9.4.2 Interface between a CSSM and an SFCS

For the collaborative capability, an interface between a CSSM and an SFCS should be established through the connection between the external interface unit of a CSSM and the corresponding external interface unit of an SFCS (e.g. a CSSM interface).

NOTE 1 This interface corresponds to key 5 in [Figure 3](#).

The data contents from a CSSM to an SFCS are mainly composed of the output of DPU, digital twin unit, and MAPE unit in the CSSM for which the SFCS can make decisions for enhancement of the performance of the shop floor from the system perspective.

NOTE 2 The output of the MAPE unit is grouped into a) machine body, b) cutting tool, c) workpiece, and d) environment.

Data transmission from SFCS to CSSM is not specified in this document, but can be incorporated in implementation.

9.4.3 The interface between an SFCS and a CPCM

For the collaborative capability, an interface between a CPCM and an SFCS should be established through the connection between the CPS unit (inter-loop element) of a CPCM and the corresponding external interface unit of an SFCS (e.g. a CPCM interface).

NOTE 1 This interface corresponds to key 6 in [Figure 3](#).

The data contents from a SFCS to CPCM includes:

- Operation re-scheduling, and
- Device re-allocation.

Additionally, an SFCS can, for example, deliver these data to devices in an SFDS based on the current status of each device. A shop floor device which is equipped with a controller has its own CPS unit and the output of an SFCS goes to the inter-loop element of the individual device.

NOTE 2 See [Annex A](#) for more description on SFCS and SFDS.

Data transmission from CPCM to SFCS is not specified in this document, but can be incorporated in implementation.

9.5 Interfaces for the capability of exchange with the life cycle aspects, hierarchy level, and humans through a UIS

9.5.1 General

For the external interface capability, the interface between a CPSMT primary system and external entities, e.g. human, life cycle aspects, and hierarchy levels, as specified in ISO 23704-1:2022, 9.5, 9.6 and 9.7, should be established through a UIS. A CPCM and CSSM can interface with a UIS for the data interface with external entities.

9.5.2 Interface between a CPCM and a UIS

The interface between a CPCM and a UIS can be established through the connection between the CPS unit (inner-loop element), MTU (machining control subfunction), and corresponding unit / elements in the UIS.

NOTE 1 This interface corresponds to key 2 in [Figure 3](#).

The data from a CPCM to a UIS include:

- The data output of the MTU (e.g. sensor and controller data), and
- The output of parameter estimation in the inner-loop element for identification of the current machine tool status or difference between current and reference status.

The data from a UIS to CPCM include:

- Human input (e.g. modification of setup parameter such as tool offset),
- Data from the life cycle aspect (e.g. part program aligned with the ISO 14649 series or ISO 6983), and
- Data from the hierarchy level (e.g. daily production plan).

NOTE 2 Details of data items from human input, hierarchy level, and life cycle aspect can be defined in the implementation phase.

9.5.3 Interface between a CSSM and a UIS

The interface between a CSSM and a UIS can be established through the connection between the external interface unit (interface manager element) and the corresponding unit / elements in the UIS.

NOTE 1 This interface corresponds to key 3 in [Figure 3](#).

The data contents from a CSSM to a UIS are mainly composed of the output of DPU, digital twin unit, and MAPE unit in the CSSM which the external entities can deal with. The output of the MAPE unit in the external interface unit is grouped into

- a) machine body,
- b) cutting tool,
- c) workpiece, and
- d) environment.

The data from a UIS to a CSSM include:

- Human input (e.g. modification of setup parameters such as tool offset),
- Data from the life cycle aspect (e.g. part program aligned with the ISO 14649 series or ISO 6983, output of numerical analysis on machining process), and

- Data from the hierarchy level (e.g. master data including tool specification, machine tool specification).

NOTE 2 Details of data items from human input, hierarchy level, and life cycle aspect can be defined in the implementation phase.

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Annex A (informative)

Concept model of shop floor system

A.1 General

The shop floor system consists of the shop floor device system (SFDS) and the shop floor control system (SFCS).

A.2 Shop floor device system (SFDS)

An SFDS is a set of devices, including production facilities and material handlers, on the shop floor to enable coordination with shop floor devices.

There are two types of shop floor device:

- a) with controllers, and
- b) without controllers.

For shop floor device x with a controller, it is regarded as having its own cyber-physically controlled x (CPC x), and cyber supporting system x (CSS x).

NOTE 1 In this document, an SFDS does not include materials such as products, cutting tools, fixtures, etc., but it can interface with the CPCM through RFID readers.

For the interface between devices, see the ISO 21919 series. It specifies interfaces for automated machine tending. These interfaces are the link between automated machine tending devices and machines used for production.

Machine tending means a functional unit transporting parts without changing their physical properties.

NOTE 2 Examples of machine tending systems are robots, conveyors, gantries, bar feed systems, and handling systems.

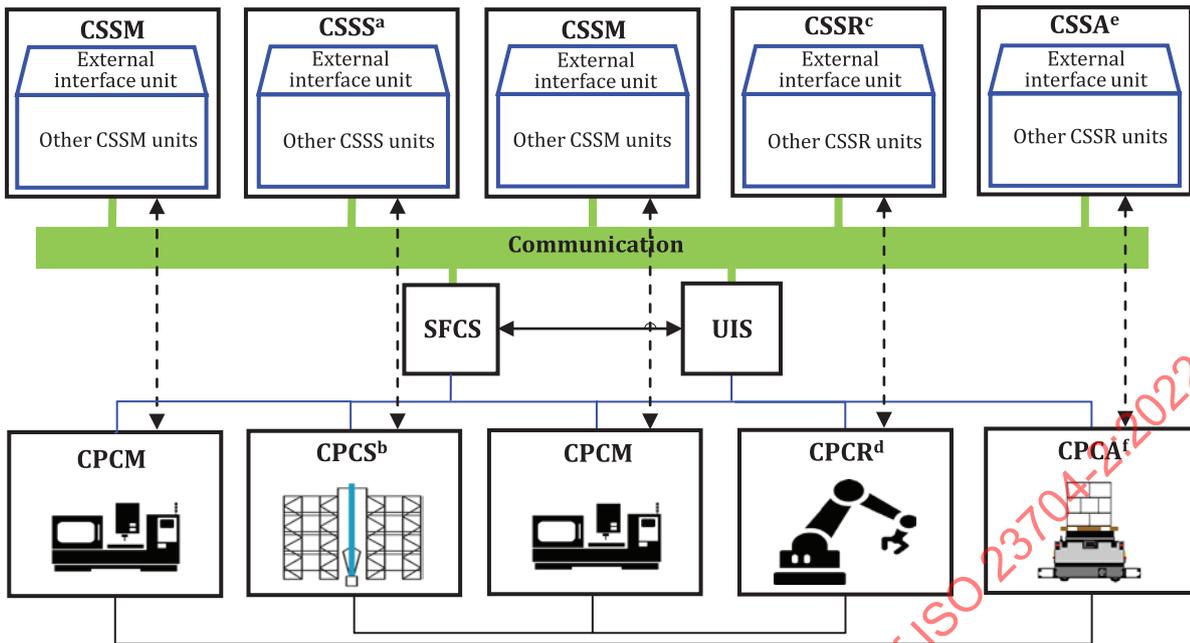
Each device x interacts with an SFCS through its own CSS x . [Figure A.1](#) shows the SFDS concept based on the administration shell of IEC PAS 63088 from the perspective of the interaction between a CSS x and an SFCS. A dotted line indicates interaction between a CPC x and a CSS x .

Finally, the output of an SFCS goes to the inter-loop element of the individual device. The blue line indicates interaction between an SFCS and each device. Lines connecting devices denote machine to machine interaction, whose reference standard is the ISO 21919 series.

NOTE 3 See details as given in ISO 23704-1:2022, Annex B for the SFDS viewed from the administration shell of the Industry 4.0 component.

NOTE 4 The machine tool is considered to be a set of hardware controlled by a single control system, i.e., machine tool hardware that is controlled by another control system is not regarded as (part of) the machine tool but belongs to an SFDS.

NOTE 5 See details as given in [Clause 7](#) for the functional structure of a CPCM.



Key

- a Cyber supporting system for automated storage and retrieval system.
- b Cyber-physically controlled automated storage and retrieval system.
- c Cyber supporting system for robot.
- d Cyber-physically controlled robot.
- e Cyber supporting system for automated guided vehicle.
- f Cyber-physically controlled automated guided vehicle.

Figure A.1 — Concept of an SFDS (based on IEC PAS 63088:2017, Figure 13)

NOTE 6 Figure A.1 is developed based on the principle or concept of IEC PAS 63088:2017, Figure 13 — Diagram of an I4.0 administration shell.

A.3 Shop floor control system (SFCS)

An SFCS is the cyber supporting system for an SFDS for the realization of the capability of a CPSMT, collaborating with shop floor operation, as specified in ISO 23704-1:2022, 10.4.

An SFCS interfaces with a CPCM, a CSSM, an SFDS, and a UIS to receive the relevant data, to deliver decisions to each device in an SFDS for the sake of shop floor optimization of KPIs, and to deliver the data to hierarchy level, life cycle aspects, and humans via a UIS.

An SFCS performs MAPE on abnormalities on shop floor level operation. The output of an SFCS is delivered to each device x in an SFDS for the enhancement of the KPIs of an SFS.

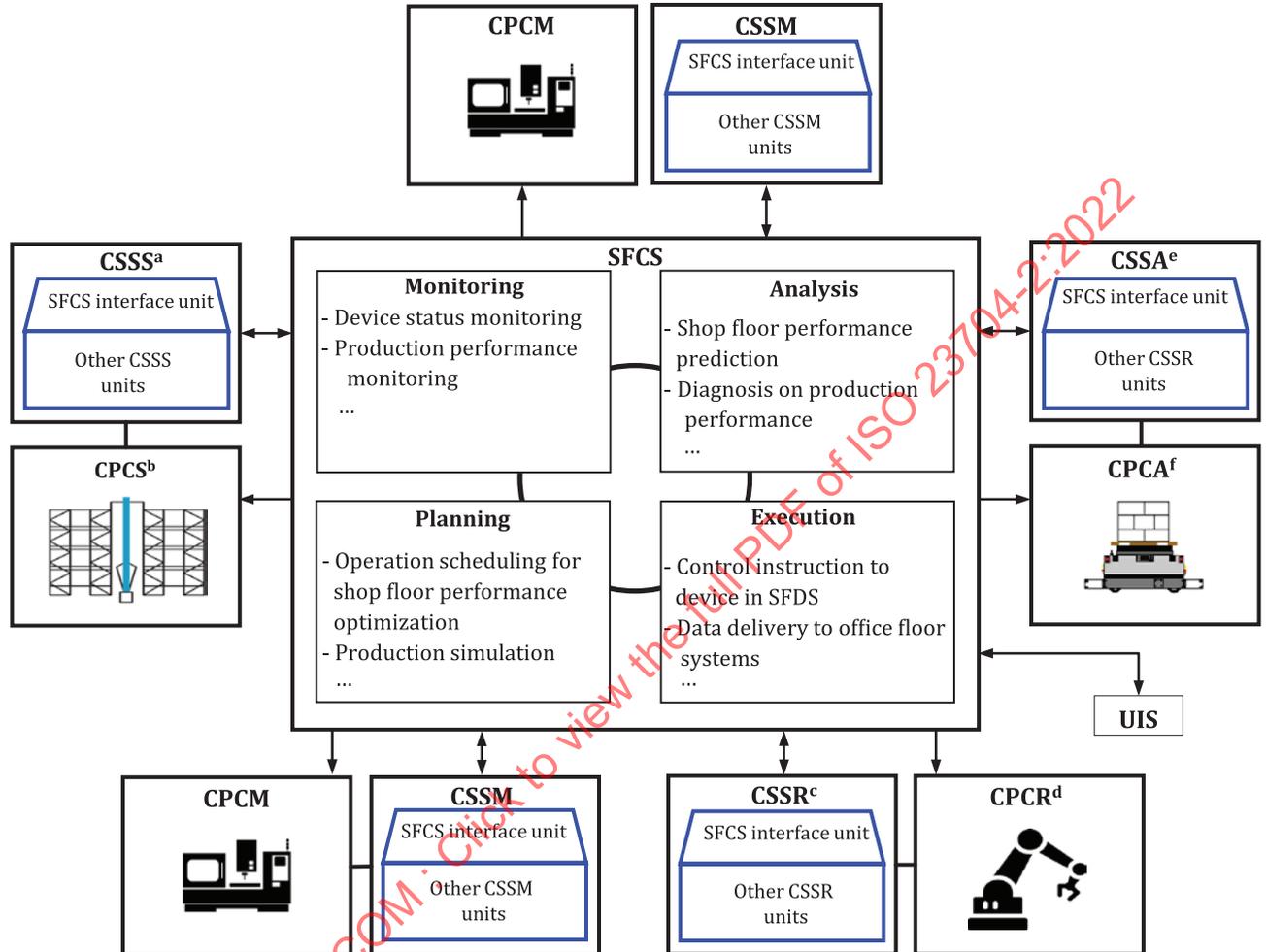
Figure A.2 shows the concept of an SFCS and example functionalities.

Monitoring is the function that calculates the KPIs of an SFS. The analysis is the function that:

- a) predicts the future KPIs of an SFS, and
- b) conducts diagnosis.

Planning is the function that redefines the machining parameters that contribute to the optimization for the shop floor operation and verifies these through simulation. Execution is the function that transmits the output of planning to an SFDS.

NOTE The detailed functions and architecture of an SFCS are outside the scope of this document.



Key

- a Cyber supporting system for automated storage and retrieval system.
- b Cyber-physically controlled automated storage and retrieval system.
- c Cyber supporting system for robot.
- d Cyber-physically controlled robot.
- e Cyber supporting system for automated guided vehicle.
- f Cyber-physically controlled automated guided vehicle.

Figure A.2 — Concept of an SFCS

Annex B (informative)

Concept of unified interface system (UIS)

As shown in [Figure B.1](#), a UIS is a system that incorporates interfaces with

- CPCM,
- CSSM,
- SFDS,
- SFCS,
- humans,
- life cycle aspects, and
- hierarchy level.

A UIS is an advanced concept of human-machine interface (HMI), incorporating a wide range of smart manufacturing, including lifecycle aspects and hierarchy level, in a systematic fashion.

A UIS displays not only the state of a single machine tool (a CPCM and a CSSM) but the state of the SFDS as well as the internals of an SFCS. The main functions of a UIS are:

- system interface,
- communication management,
- data management, and
- data forwarding.

'System interface' is the collection of interface objects. Each interface object is classified to:

- CPCM,
- CSSM,
- SFDS,
- SFCS,
- humans,
- life cycle aspects, and
- hierarchy level.

'Communication management' manages interface objects in the system interface. Management means to add, update, and delete the object in the system interface. It also transforms messages from 'Data Forwarding' to a form suitable for each type of interface object and delivers collected data from 'System Interface' to 'Data Management'.

'Data Management' means to manage the data structure in a UIS with a unified format so that various interfaces can be interoperable. 'Data Forwarding' generates forwarding messages based on input from 'Data Management' with a unified format. Based on the forwarding message, 'Communication Management' sends it to the appropriate system interface.

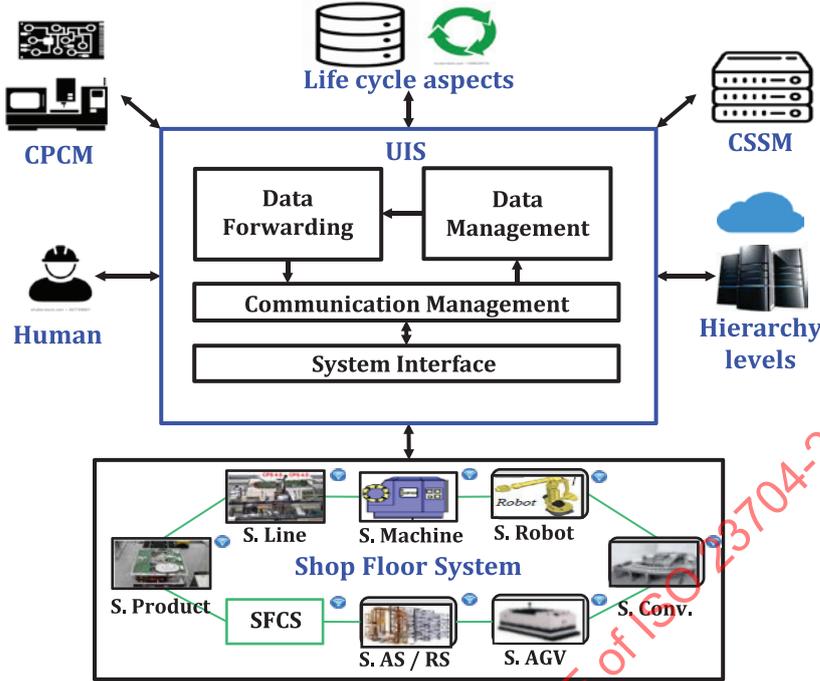


Figure B.1 — Concept of a UIS

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Annex C (informative)

Example use cases of a CPSMT reference architecture for subtractive manufacturing

C.1 General

A CPSMT reference architecture can provide guidelines for various stakeholders, mainly for the supplier side, including machine control vendors, MTBs, researchers (RTD), and service providers.

Included in this Annex are example use cases of the reference architecture for subtractive manufacturing as a reference in developing solution architectures in a systematic fashion.

Compared with the ad hoc manner, standard-based development can bring the following advantages:

- Improvement of design reliability,
- Reduction of design lead time,
- Reduction of errors in system implementation,
- Easier management of design changes,
- Sharing common viewpoints among stakeholders, and
- Better traceability of decision making.

C.2 Example use case for intelligent human-machine interface (HMI) by machine tool builder, computerized numerical controller

C.2.1 Situation

The HMI is the component of an interactive system (software or hardware) that provides the data and controls necessary for the user to accomplish specific tasks with the interactive system. Legacy human-machine interface has a limited number of physical inputs and pre-installed software that are vendor-dependent, which makes the flexible expansion of human-machine interface functionalities hard.

For end-users on the shop floor, in addition to functions provided by existing human-machine interfaces, including, e.g. parameter setting, part program editing, machining monitoring, they want to be provided with advanced data on machine tool abnormalities with a MAPE perspective that are independent of computerized numerical controller vendors. This helps to make more optimized decisions from the machine tool operation perspective.

For end-users on the office floor, they want to be provided with advanced data on machine tool abnormalities and status to the office floor system, which helps to make more optimized decisions from the whole enterprise perspective.

In view of this, a machine tool builder wants to develop an intelligent human-machine interface supporting:

- a) various functionalities dealing with machine tool abnormalities,
- b) connectivity to other external entities,