INTERNATIONAL STANDARD

ISO 16400-1

First edition
2020-09

Automation systems and integration — Equipment behaviour catalogues for virtual production system —

Part 1:
Overview

COPYRIGHT PROTECTED DOCUMENT

Contents

Page

Foreword

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

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

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

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

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

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

A list of all parts in the ISO 16400 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

The ISO 16400 series introduces the concept of an equipment behaviour catalogue (EBC), addresses the requirements of EBC and proposes a guideline to generate an executable representing the dynamic behaviour of a nominal or a physical instance of a piece of equipment. Such executable plays a vital role when configuring virtual production systems used for simulation and verification of a future process as well as monitoring of a current process. Therefore, EBCs will constitute an important part of smart manufacturing evolution.

An EBC enables an efficient and standardized way for a provider of a piece of equipment to communicate its dynamic behaviour.

Automation systems and integration — Equipment behaviour catalogues for virtual production system —

Part 1:
Overview

1   Scope

This document specifies the concept and structure of the ISO 16400 series. This series specify a methodology for preparing a template and items of an equipment behaviour catalogue (EBC) as a basis to structure a virtual production system.

2   Normative references

There are no normative references in this document.

3   Terms and definitions

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

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

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

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

3.1
equipment behaviour catalogue
EBC
group of one EBC template and its EBC items

3.2
EBC template
schema representing a model for each equipment type including behaviour

3.3
behaviour
activity how an element acts and reacts in contexts of realizing its external interaction

[SOURCE: ISO 14258:1998 2.2.2, modified — "in contexts of realizing its external interaction" has been added at the end of the original definition.]

3.4
EBC item
instance of an EBC template

Note 1 to entry: An EBC item represents properties of a piece of equipment including its behaviour.

3.5
EBC repository
set of EBCs

　　　　　　　　　　　　　　　　　　　　　　　　　　　1

3.6
nominal equipment instance model
executable model of a piece of equipment as designed

Note 1 to entry: An executable model is constructed from an EBC item and related data of an equipment design.

3.7
physical equipment instance model
executable model of an individual piece of equipment which exists in the physical world

Note 1 to entry: An executable model is constructed from an EBC item and related data of an equipment individual.

4 Abbreviated terms

AAS   Asset Administration Shell

CDD   Common Data Dictionary

JSON   JavaScript Object Notation

UML   Unified Modeling Language

XML   eXtensible Markup Language

5 Concept of EBC

5.1 Requirements for an EBC

Requirements for an EBC are addressed as follows.

— an EBC shall provide an equipment's behaviour description to a given production system through equipment instance model.

— an EBC shall be described using common machine-readable language.

    EXAMPLE   XML and JSON.

— an EBC shall be bound by the terms (name) based on common taxonomy.

    EXAMPLE   CDD.

An EBC is the basis for the construction of an equipment instance model, whose purpose is to be implemented in a virtual production system. An equipment instance model shows its performance as the result of its behaviour. A performance can be different depending on the state of the equipment.

EXAMPLE   The consumed energy for a machine is different depending on conditions such as stand-by state and in operation state. Consumed energy and spent operation time are as well dependent on the target product and the operations. They are simulated in the virtual production system. Annex A is a simple use case of EBC.

5.2 Conceptual structure of an EBC

An EBC is a group of one EBC template and its EBC items resulting from use of the EBC template. The EBCs are registered in a shared repository, as shown in Figure 1. EBC templates and EBC items shall be prepared by following the specifications.
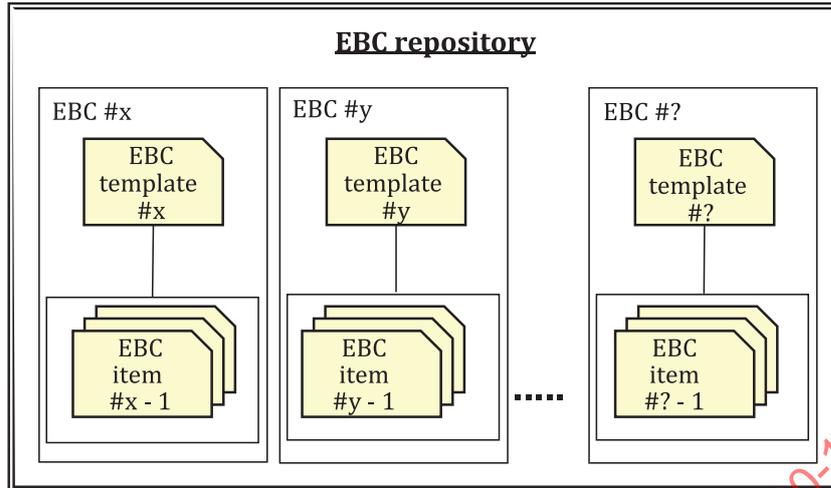
Figure 1 — Repository of EBCs

An EBC template and an EBC item are required to include descriptions which specify properties, behaviour resulting from equipment's activities, and external interactions. Figure 2 shows a conceptual structure of an EBC template.

In Figure 2, a behaviour is a composition of a state transition with each state description, operation programs, related data, calculation formulas and/or mathematical models.

EXAMPLE   Consumed energy is calculated using the appropriate formula including variables. Values of variables can be provided when simulation is executed on the virtual production system.

Examples of EBC templates are shown in Annex B.

Figure 2 — Conceptual structure of an EBC template

5.3   Preparation of an EBC

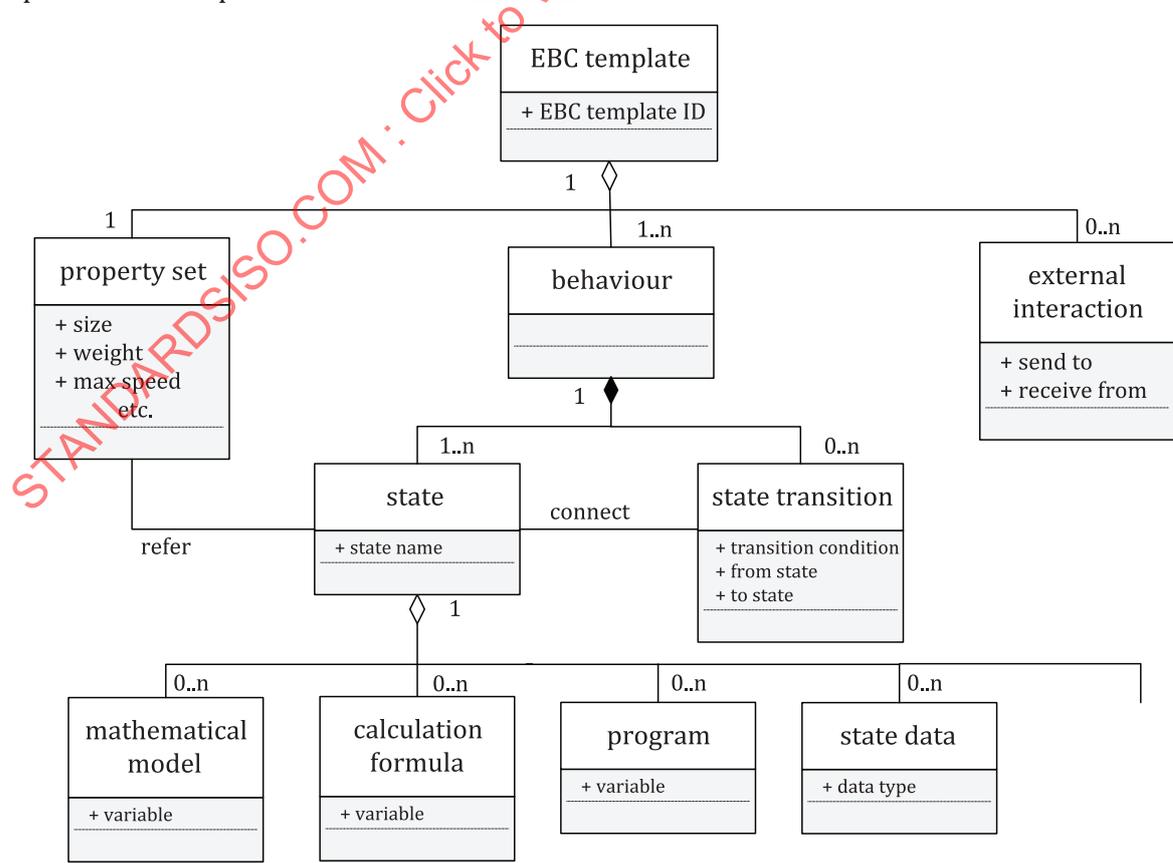An EBC provider, such as an equipment supplier and a manufacturing device vendor, develops an EBC item of an equipment using a corresponding EBC template. An EBC template shall be prepared for each equipment type by following the specifications.
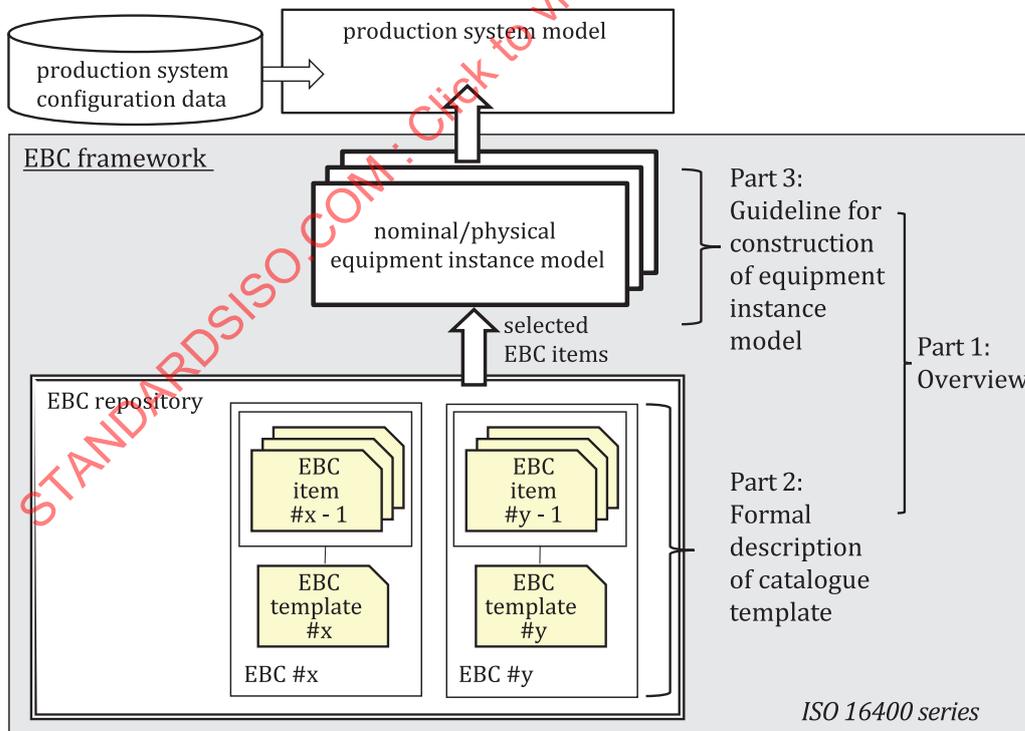
6   EBC framework

EBC framework consists of a set of EBC repository and equipment instance models as shown in Figure 3. An equipment instance model is divided into two categories:

—   a nominal equipment instance model, and

—   a physical equipment instance model.

An equipment instance model is constructed from the selected EBC item according to ISO 16400-3. If the corresponding physical equipment exists, the physical equipment data are applied. A nominal equipment instance model is a model of an equipment as designed including the behaviour. A physical equipment instance model is a model of an equipment as physically realized including the behaviour. An equipment instance model can be installed as a software agent.

The ISO 16400 series specifies a methodology for constructing an EBC template and its EBC items. An EBC template and EBC items specific to a particular equipment are out of scope of the ISO 16400 series. An EBC is prepared by following ISO 16400-2.

This document specifies the concept and structure applied in the ISO 16400 series. ISO 16400-2 provides the formal structure of descriptions for EBC templates, a building method and rules for EBC. ISO 16400-3 specifies a guideline to construct equipment instance models using an EBC. Figure 3 shows the framework of EBC and the structure of the ISO 16400 series.

Figure 3 — Framework of an EBC and structure of the ISO 16400 series

7   Application guide for EBC

7.1   Benefits of using EBC

The EBC user such as a production system designer, an operator, or a manager, shall construct an equipment instance model from an appropriate EBC item selected from the repository for the virtual production system of interest. Then the EBC user can monitor the performance and operation method of the equipment. The benefits are as follows:

— an equipment instance model can be constructed easily, and then, a virtual production system can be structured quickly;

— performance of the equipment can be evaluated:

— performance of the existing equipment and a newly introduced equipment can be compared;

— operation of the equipment can be evaluated;

— planning and operation costs of a production system can be reduced.

The EBC framework provides the equipment manufacturer with the possibility to describe the behaviour of an equipment prior to delivery. The EBC user can specify the requisite capabilities. The benefits are as follows:

— requirements for equipment can be shared between vendors and users;

— required equipment can be selected easily;

— new customized equipment can be quickly configured.

EBC also provides benefits for smart manufacturing technology. Annex C shows use cases in smart manufacturing.

7.2   Usage procedure for EBCs

A production system consists of multiple equipment. The adopted workflow of the production system is associated with the combined behaviour of multiple equipment to produce a product. Figure 4 shows the usage procedure for EBCs.
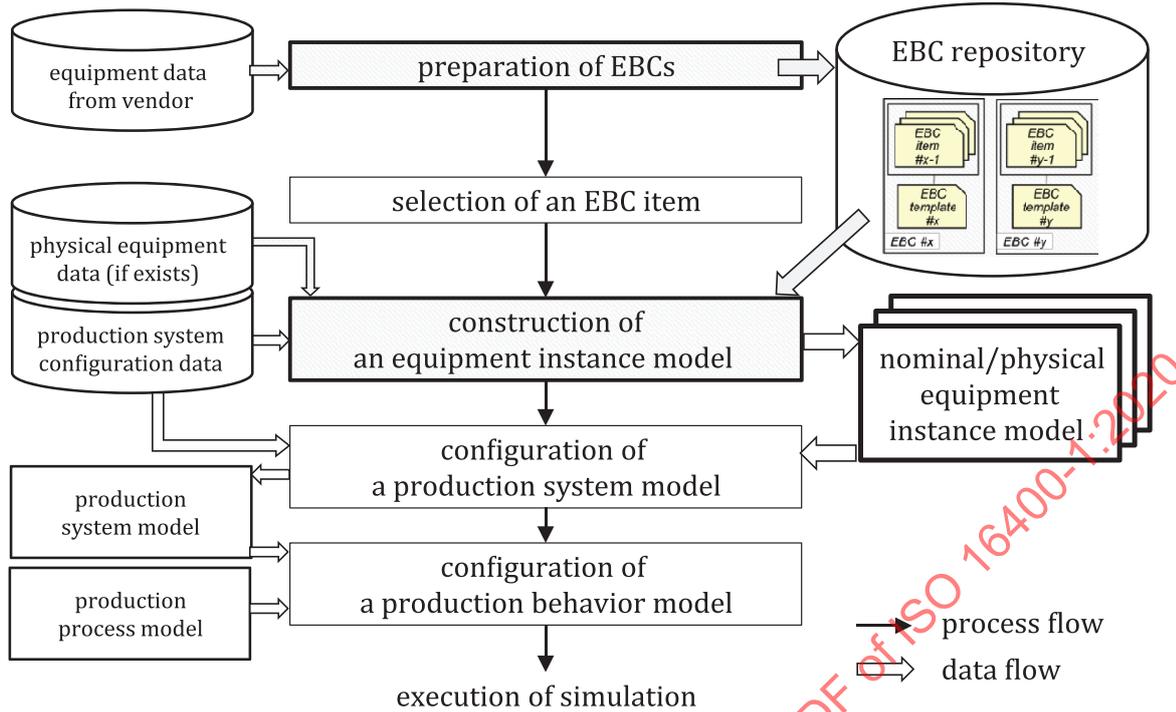
Figure 4 — Usage procedure for EBCs

NOTE   In Figure 4, grey shading shows the scope of the ISO 16400 series.

By following ISO 16400-3, an EBC user works out an equipment instance model from the selected EBC item, if corresponding physical equipment exists, by applying physical equipment data. Equipment instance models are made for all equipment which are components of a production system. A production system model is configured from these equipment instance models.

Figure 5 shows data flow in the usage procedure for EBC. A production system model contains specific configuration of a factory or a production line. Figure 5 shows a production system model consisting of equipment instance models with the production system configuration data applied.

In Figure 5, the production process model is provided based on target product data and operation data. Finally, a production behaviour model is configured based on the production system model and the production process model. Simulation can be executed using this production behaviour model. As an output of the simulation, the dynamic performance of equipment and system can be monitored.
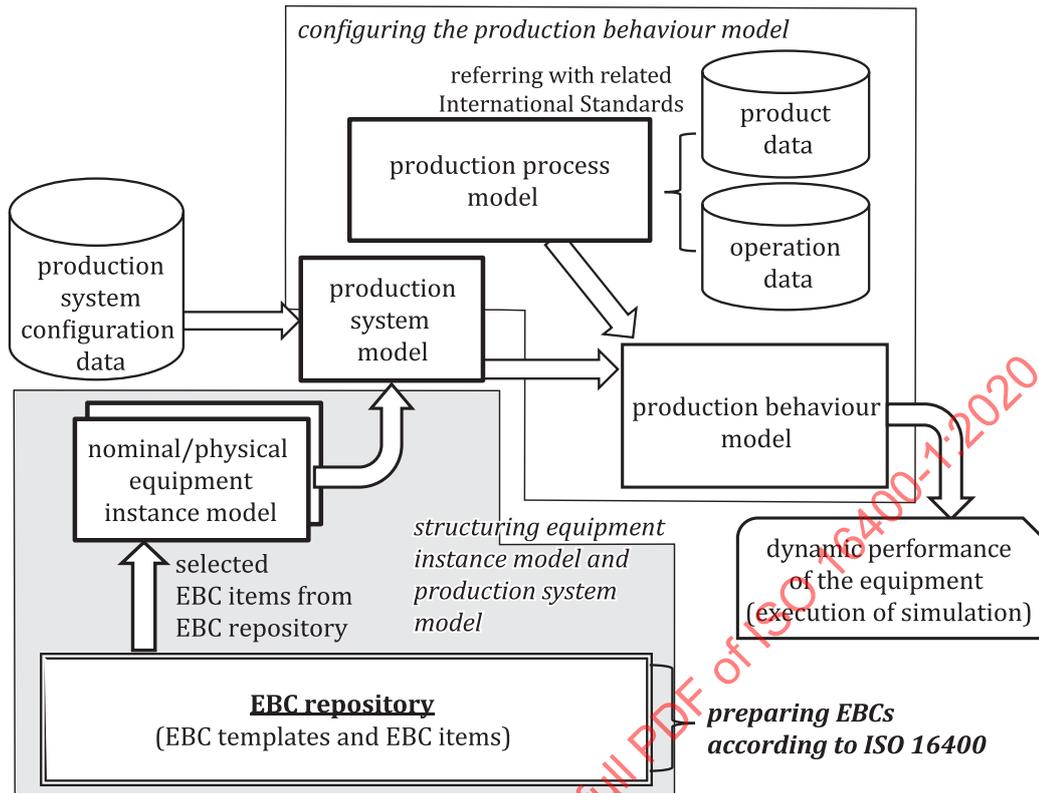
Figure 5 — Data flow in the usage procedure of EBC

7.3 Construction of a virtual production system

A virtual production system is constructed on a production behaviour model which is configured by applying a production process model to a production system model as shown in Figure 6.
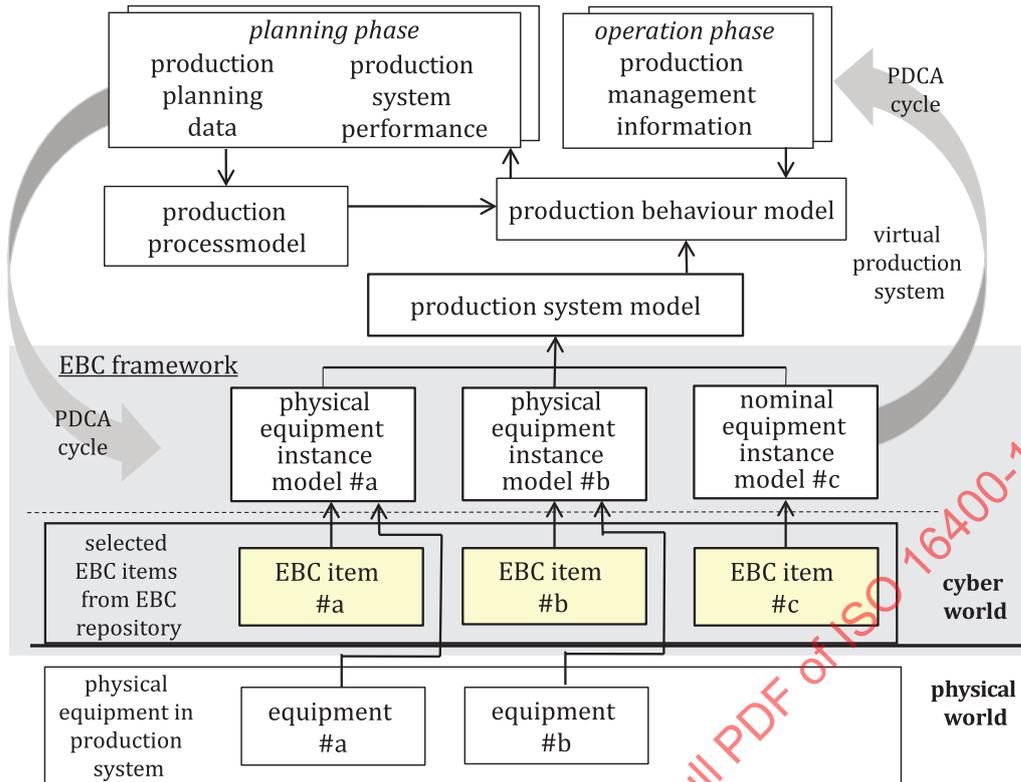
Figure 6 — Construction of a virtual production system

In Figure 6, a production system model is constructed using equipment instance models. A nominal equipment instance model is constructed from EBC items. A physical equipment instance model is constructed from EBC items and data from the physical equipment.

In Figure 6, a production process model which is provided from a planning system is a scenario to show how to operate equipment to produce the target product. A production behaviour model on which the equipment's activity is virtually executed is required. On the virtual production system, the examination can be executed by modifying models such as changing the equipment and/or operation. It is a Plan-Do-Check-Act (PDCA) cycle in the cyber world.

A manufacturing system simulation is run on a virtual production system, which is a simulation system of the corresponding manufacturing system. A virtual production system is constructed on a production behaviour model configured by applying a production process model to a production system model.

A virtual production system is constructed on a production system model which is modelled as a multi-agent system consisting of equipment agents. An equipment agent is an equipment instance model. It is difficult to write a software program of agents for the user of a manufacturing simulation system such as a production system designer and operator. Once an EBC repository is provided basing on ISO 16400, by using the construction system such as commercially available construction system, an equipment instance model is automatically constructed as a software agent from the selected EBC item. Furthermore, a production system model can be constructed as the combination of equipment instance models.

7.4   Use cases of equipment instance models

Use cases of a nominal equipment instance model and a physical equipment instance model are divided into four types as shown in Table 1. An equipment instance model can be worked out from the selected EBC item in the EBC repository. An EBC item provides nominal data about a specific type of equipment. In Table 1, Use Case 1 and Use Case 3 are the use case for a nominal equipment instance model corresponding to EBC item only, and Use Case 2 and Use Case 4 are the use case for a physical equipment instance model corresponding to EBC item for the physical equipment.

Table 1 — Use cases of equipment instance models

phase	nominal equipment instance model	physical equipment instance model
design & planning	use case 1	use case 2
operation	use case 3	use case 4

Typical examples for each use case and details of the examples are shown in Annex D.
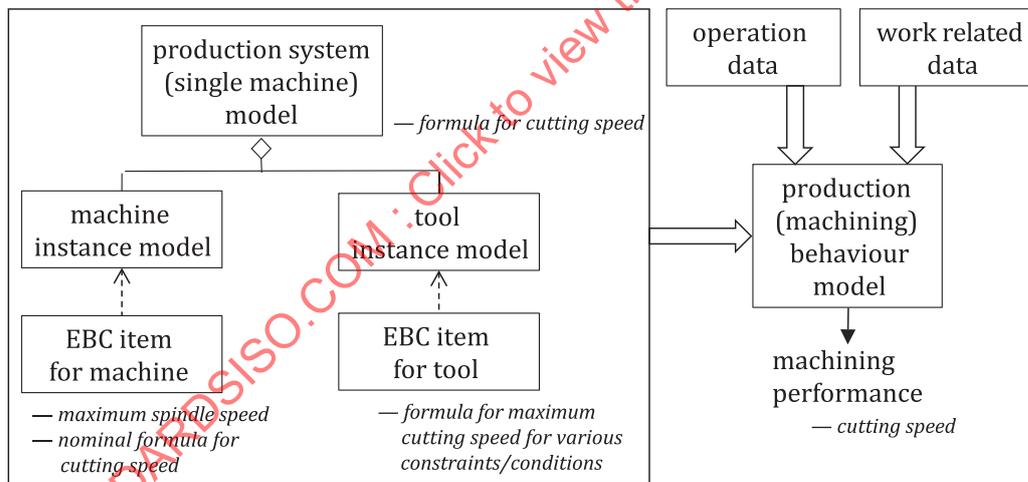
Annex A
(informative)

Simple use case for deriving requirements for an EBC

The simple example of using EBC items is introduced in [Figure A.1](#). This example shows the case for presentation of cutting speed of the selected tool for a machine tool. The EBC item for the machine tool includes description about maximum spindle speed and formula for calculating the cutting speed of target product. The EBC item for the tool includes a formula for calculating the maximum cutting speed for various constraints and/or conditions. A formula can include variables which would be provided as operation data, work related data and/or product data. In this example, the model description of the production system which is constructed by one machine tool is generated from the machine tool instance model and tool instance model. The production behaviour model is prepared based on the production system model by adding operation data and work related data. The best fitted tool for planned operation and the product is selected by simulating and comparing performance of candidate tools through the production behaviour model.

This example provides following requirements for the EBC:

— the EBC is bound by the names based on the common taxonomy (e.g. CDD)

— the EBC supplies required behaviour functions and/or parameters to a given production system model.

Figure A.1 — Selection of a tool for the machine by using EBC items

Annex B
(informative)

Examples of EBC templates

B.1   Example of a behaviour model

The machine tool's behaviour in Figure A.1 is modelled using the UML state chart as shown in Figure B.1. There are four normal states: idling, workpiece fixing, turning operation and workpiece release. Furthermore, in the turning operation state, there are three sub states: tool selection, tool change and turning. In B.2 and B.3, EBC templates for this machine are provided using XML and JSON as example. These EBC template include the description of nominal formula for cutting speed in the turning state. This nominal formula description for cutting speed could be used to construct a production-system model which includes formula for calculation of cutting speed. The description of the formula for cutting speed includes the following variables; spindle speed and workpiece diameter. Values of these variables would be provided when constructing a production system model and when constructing a production behaviour model.
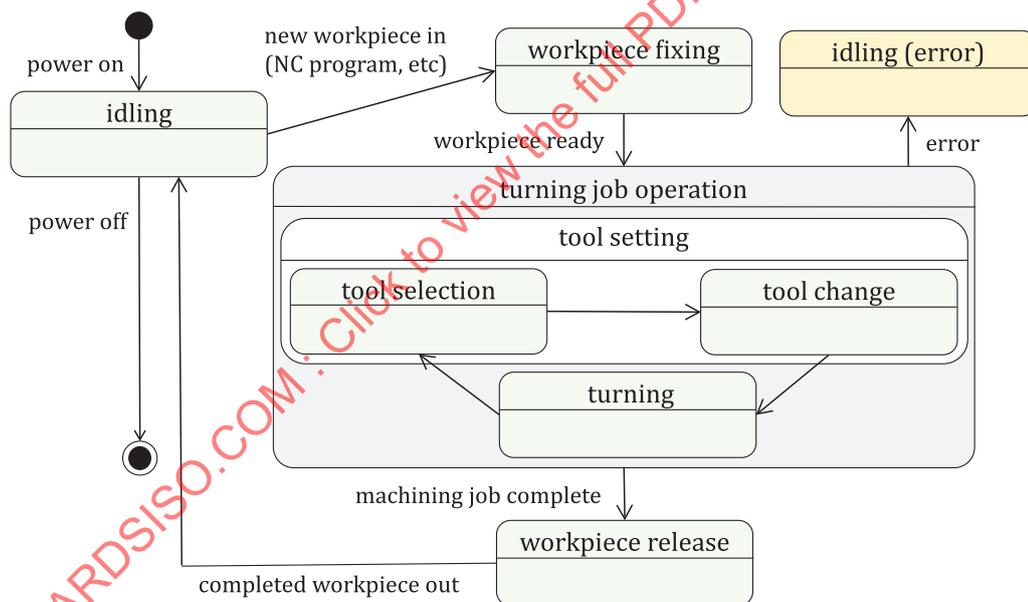
Figure B.1 — UML State Chart for Machine type X

B.2   Example of an EBC template using XML

Example of XML codes for an EBC template of a machine in Figure B.1 is as follows:

```xml
<?xml version="1.0" encoding="utf-8" ?>
<EBC
      xmlns:production-system="production-system-operation.xml"
      xmlns:machining-performance="machining-performance.xml"
      xmlns:tool="cuttiog-tool.xml">
  <organization>XYZ Corporation</organization>
  <model>HPQ-100mxy</model>
  <description>multi-tasking turning center</description>
   <ability>
      <maximum-spindle-speed>1500</maximum-spindle-speed>
   </ability>
```

```
   <behaviours>
     <state id="1" name="idling">
       <transition name="new workpiece in (NC program, etc)">
         <state-ref id="2" />
       </transition>
     </state>
     <state id="2" name="workpiece fixing">
       <transition name="workpiece ready">
         <state-ref id="3" />
       </transition>
     </state>
     <state id="3" name="turning job operation">
       <transition name="machining job complete">
         <state-ref id="8" />
       </transition>
       <transition name="error">
         <state-ref id="9" />
       </transition>
     </state>
     <state id="4" name="tool setting" />
     <state id="5" name="tool selection" />
     <state id="6" name="tool change" />
     <state id="7" name="turning">
       <seq>
        <!--
        Spindle-speed is decided at the upper limit or less from the tool and the material
to be cut
          -->
        <machining-performance:cutting-speed
          select="(pi*tool:material-diameter*production-system:spindle-speed)/1000" />
       </seq>
     </state>
     <state id="8" name="workpiece release">
       <transition name="complete workpiece out">
         <state-ref id="1" />
       </transition>
     </state>
     <state id="9" name="idling(error)" />
   </behaviours>
</EBC>
```

B.3   Example of an EBC template using JSON

Example of JSON codes for an EBC template of a machine in Figure B.1 is as follows:

```
{
   "EBC":
   {
      "organization":"XYZ Corporation",
   "model":"HPQ-100mxy",
      "description":"multi-tasking turning center",
      "maximum-spindle-speed":1500,
      "behaviours":
      {
         "idling":
         {
            "state id":1,
            "state name":"idling",
            "transition":
            {
               "new workpiece in(NC program, etc)":
               {
                  "transition name":"new workpiece in(NC program, etc)",
                  "next state id":2
               }
            }
         },
         "workpiece fixing":
         {
            "state id":2,
```

```
          "state name":"workpiece fixing",
          "transition":
          {
             "workpiece ready":
             {
                "transition name":"workpiece ready",
                "next state id":3
             }
          }
       },
       "turning job operation":
       {
          "state id":3,
          "state name":"turning job operation",
          "transition":
          {
             "machining job complate":
             {
                "transition name":"machining job complate",
                "next state id":8
             },
             "idling(error)":
             {
                "transition name":"idling(error)",
                "next state id":9
             }
          }
       },
       "tool setting":{},
       "tool selection":{},
       "tool change":{},
       "turning":
       {
          "state id":7,
          "seq":
          {
             "cutting-speed":"(pi*tool:material-diameter*production-system:spindle-
speed)/1000"
          }
       },
       "workpiece release":
       {
          "state id":8,
          "state name":"workpiece release",
          "transition":
          {
             "completed workpiece out":
             {
                "transition name":"completed workpiece out",
                "next state id":1
             }
          }
       },
       "idling(error)":{}
    }
}
```

Annex C
(informative)

Use case in smart manufacturing

C.1 Digital twin

A digital twin is a digital replica of a living or non-living physical entity such as a virtual equipment. By bridging the physical and the virtual world, data is transmitted seamlessly allowing the virtual entity to exist simultaneously with the physical entity. An EBC item is digital descriptions of properties and behaviour of a physical equipment. A virtual equipment could be constructed by referring a corresponding EBC item. EBC item works as a bridge between physical equipment and virtual equipment in digital twin.
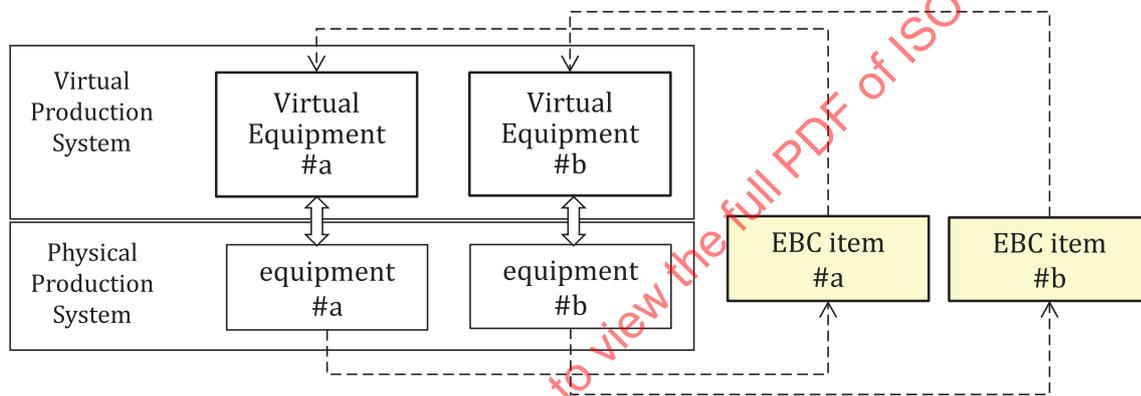
Figure C.1 — EBC and digital twin

C.2 AAS (Asset Administration Shell)

An AAS is one main concept of Industrie 4.0 for providing information hiding and higher levels of abstraction for assets. An equipment is one type of asset. An AAS has a unique identifier and contains sub-models. Sub-models define properties and services, and implement a reflexive interface. They provide high-level information such as regarding offered services of assets, asset status models, or plant topology models. An EBC could support to derive sub-models of the asset.
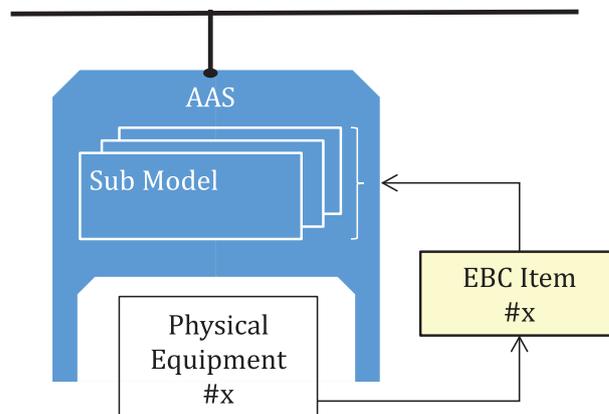
Figure C.2 — EBC and AAS