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Comprehensive equipment behaviour description in production lifecycle using digital twin concepts and ISO standards of Equipment Behaviour Catalogues

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Abstract: A standardised description of machines and equipment as well as their behaviour is essential for the planning and operation of heterogeneous production environments. The article reviews standardisation approaches of Equipment Behaviour Catalogues from the ISO 16400 series as well as similar concepts for standardised asset and equipment description in context of creating, using and maintaining digital twins. In this context, an information model for the production life cycle is introduced to harmonise the required information and interfaces for their exchange in a manufacturing organisational context.

Keywords: Digital Twin, Manufacturing, Equipment, Assets, Industrie 4.0, Production Lifecycle.

1. INTRODUCTION

The collaborative planning and flexible operation of production systems represent a suitable approach to addressing shorter product life cycles as well as customization of demand in terms of quantity and variant diversity. Interoperability requirements result both in the planning phase, where production systems are collaboratively planned among multiple stakeholders and various simulation systems, and in the operational phase, where heterogeneous machine and heterogeneous machinery are operated (VDMA, 2021). This necessitates the joint utilization of product, process and resource (PPR) related information, extending to digital twin concepts. These requirements are not solely confined to static information derived from product and process engineering, but should also encompass dynamic information from current operations (prostep ivip, 2021). Due to highly heterogeneous data and operational system and process environments, the integration of PPR data is only conditionally feasible. The need for standards has been recognized by equipment manufacturers, users, system integrators, and software vendors (DIN & DKE, 2023).

This contribution focuses on a comparison of existing approaches of international standardisation activities for the unified interoperable description of plants and equipment as well as their behaviour, followed by the introduction of an information model for the production system lifecycle, unifying the perspective of planning information and integrating operational data using Industrie 4.0 standards (prostep ivip, 2019). Finally, potential applications and further action requirements are discussed.

2. STANDARDISATION OF ASSET AND EQUIPMENT DESCRIPTION IN MANUFACTURING

The standardisation of asset and equipment description provides a necessary pillar for the integration of data during development and operation of production systems. In general, there are a large number of standards for describing products, which can also provide an initial approximation for equipment. Geometric product data and metadata are often described using JT (ISO 14306:2012) and STEP AP 242 (ISO 10303) standards. In addition, ECLASS is a data standard for the classification of products and services using uniform characteristics, which has become established for product descriptions in the context of Industrie 4.0. It is based on the IEC Common Data Dictionary (CDD) standards that provide a metadata registry for product classification and formalized product descriptions (IEC 61360) as well as the ISO 13584-42. However, these standards do not contain any technical information on the use of equipment in production processes and systems and are therefore out of scope for the present analysis. In the following section, selected standards for describing machines, equipment and their behaviour within the production system lifecycle will be presented and evaluated.

2.1 Equipment Behaviour Catalogue

The EBC (Equipment Behaviour Catalogue) is a concept introduced in the ISO 16400 series, which provides a standardised way for equipment manufacturers to communicate the dynamic behaviour of their equipment. It is based on Japanese work on electronic catalogue libraries of machines to support the creation and usage of virtual production systems and supply chains (Matsuda, Matsumoto, Noyama, Sudo, & Kimura, 2016; Matsuda, Nishi, Hasegawa,

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& Matsumoto, 2019). The core framework consists of EBC templates and instantiates of it (EBC items), that are used to construct equipment instance models to be used in virtual production systems for e.g. supporting simulation, verification or monitoring of production processes. The EBC framework aims to facilitate the sharing of equipment behaviour descriptions, the selection of required equipment, and a fast configuration of customized equipment. The (ISO 16400-1:2020) provides an overview of the concept and structure of the framework, which includes the EBC template schema as a core element to represent an equipment type, including its behaviour. It contains descriptions that specify properties, behaviour (via possible states and state transitions) and external interactions. The (ISO 16400-2:2024) provides formal rules and standards for describing EBC templates in the form of an information model. It is embedded in the later shown Figure 2 as EBC package. The *behaviour* is a composition of *state transitions* as well as possible *states* that can be descripted using *state data*, *calculation formulas*, *mathematical models* or *programs*. *External interaction* describes the communication between the equipment with other/outside equipment. In addition, EBC templates contain a *property set* that includes static property data (e.g. operational limits such as cutting speed for a milling machine).

2.2 Digital Factory Framework

The digital factory framework (DFF) focusses on providing semantic information for engineering data, that is e.g. used in heterogeneous modelling and simulation tools to design and optimize production systems. The core is based on the IEC CDD and aims for providing a common reference for the digitization of data related to production systems. The framework aims to integrate design, operation and improvement of production systems by addressing underlying IT and data structures. Additionally, explainable modelling is proposed to enable collaboration and interaction between modelers and stakeholders, increasing communication efficiency and building trust. The underlying IEC 62832 series of the DFF provides rules and data models for the description of the information used to represent the assets in a digital factory. The dictionary and library concept can be used to describe the possible behaviour of assets (e.g. if a variable changes over time or is constant). Specific rules to manage the DFF with the lifecycle of a production system are also provided. Furthermore, a description of PPR is explicitly considered and information models for a feasible integration in this standard are provided (IEC 62832-1:2020).

2.3 Asset Administration Shell

The Asset Administration Shell (AAS) is a concept for digital representation of various assets, such as machines or products. As German driven initiative by the Plattform Industrie 4.0, the aim is to establish the AAS as key concept for implementing interoperable digital twins. It is supposed to administer all relevant asset information, which can include equipment characteristics, parameters and documentation. The AAS standardisation is on the one hand coordinated by the Standardisation Council Industrie 4.0 and mainly focusses on the IEC 63278 series (IEC 63278-1:2023). On the other hand, the Industrial Digital Twin Association (IDTA) manages and provides applicable submodel templates for various scenarios in an agile structure, that provide the possibility of applying the structure related to the different equipment description options within the production system lifecycle (e.g templates for technical data for industrial equipment in manufacturing, handover documentation, asset interfaces description, plant asset management, capability description,…). Many of these templates are under development and warrants further investigation. The AAS was adapted by CESMII in form of Smart Manufacturing Profiles, resulting in high application and potential market orientation. However, the inclusion of PPR data provides challenges in the applicational contexts. It is possible, and the relationship between each element can be described, but a holistic linkage needs to be drawn. A standardised way of describing dynamic behaviour of asset and equipment (such as a submodel) is currently not available.

2.4 Automation ML

Automation Markup Language (AML) is a neutral data format for the exchange of industrial automation engineering information. It aims to facilitate data exchange between engineering tools and manage multiple semantics in a heterogeneous engineering tool landscape. AML is designed to standardise and unify data to enable consistent data exchange, information flows and data reuse across the product, production system (IEC 62714-1:2018; Schmidt & Lueder, 2018). It is often used in combination with industrial communication standards to enable secure and confidential information exchange in industrial environments. Regarding asset and equipment behaviour, AML provides the possibility to model some but not all information. The limitation is mainly regarding the model possibility inside the XML meta model. Additionally, the lifecycle of a production system can be described and related to PPR information (prostep ivip, 2021)

2.5 OPC UA

The Open Platform Communications Unified Architecture (OPC UA) is a machine-to-machine communication protocol for industrial automation and is standardised in the IEC 62541 series (IEC TR 62541-1:2020). It is often associated as an Industrie 4.0 protocol to enable secure and reliable data exchange between machines from different manufacturers. The protocol offers features such as security, platform independence, and robustness, making it suitable for a wide range of industrial applications (VDMA, 2021). OPC UA companion specifications provide a standardised way to integrate domain-specific information and requirements, e.g. in robotics, packaging and filling machines in food and beverage industry, or pumps and valves, by defining the data models, communication protocols, and behaviour for the information exchange. Similar to AAS submodels managed by IDTA, the umati initiative manages companion specifications for machines and equipment. They are mainly used in the operational phase of the production system lifecycle.

2.6 Digital Twin Framework for Manufacturing

The ISO 23247 series defines a Digital Twin Framework for Manufacturing (DTFM), aimed at guiding the implementation of digital twins in smart manufacturing environments (ISO 23247-1:2021). The standard consists of four parts, detailing general principles, reference architecture, digital representation, and information exchange protocols. It serves to standardize approaches for creating and managing digital twins, ensuring interoperability, consistency, and efficacy across various manufacturing systems and applications. Potential digital twin implementations are discussed in the NIST testbed. A further integration with the product lifecycle is currently under development in ISO/AWI 23247-5.

2.7 Summary of current standards

The current standards provide different advantages for the implementation of a unified representation of equipment behaviour. There are also consortium standards for digital twins such as a reference architecture by the Industry IoT Consortium (currently migrating with Digital Twin Consortium), which also reference ISO and IEC standards during implementation (IIC 2023). Each standard uses different approaches to standardise practical problems encountered. For an evaluation, criteria to support the holistic lifecycle, modelling of equipment behaviour, extensibility, integration degree of PPR information and communication capabilities have been selected and rated by the authors in Table 1. As a result of the evaluation, no standard provides a holistic overview over the whole lifecycle yet. Therefore, in the following chapters, this contribution introduces a production lifecycle information model and – in this case study – embeds the EBC in the information flows.

3. PRODUCTION LIFECYCLE INFORMATION

Generally, a distinction has to be made between knowledge, information, and data models. Knowledge refers to the understanding and expertise gained through study and experience. It involves the assimilation and interpretation of information and data to form meaningful insights and conclusions. Information represents processed and organized data that conveys meaning and context. It is the result of data being analysed, structured, and presented in a format that is useful for creating a common cross-domain understanding, thus enabling decision-making or facilitate further research. Lastly, data models are conceptual frameworks that represent the structure, relationships, and constraints of data (Halpin & Morgan, 2010). In order to promote an overview of operational information flows in the production lifecycle, the PLIM project group has developed an information model within the prostep ivip association (prostep ivip, 2021). The information model is used to create a reasonable understanding between domain experts and software developers and follows a structure of five packages that are summarized in the following section und interface with EBC information (cp. Figure 1).

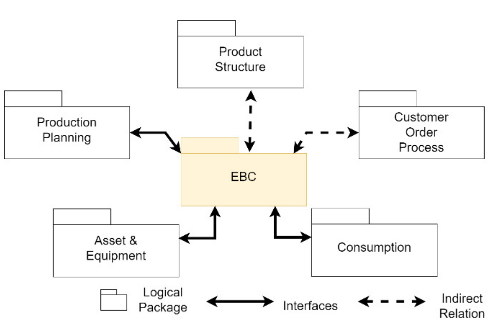

Figure 1. Overview of production lifecycle information packages

Table 1 Evaluation of existing standards for asset and equipment description in manufacturing

	Lifecycle orientation	Equipment behaviour	Extensibility	Holistic PPR integration	Communication capabilities
EBC	◕	●	◕	◑	◕
DFF	◔	◑	◑	●	◑
AAS & SMP	◕	◕	●	◔	◕
AML	◑	◔	◕	◕	○
OPC-UA	◔	◔	●	◔	●
DTFM	○	◔	◔	◑	◑

They include the main information objects and convey the context for digital equipment representations - in this case study the EBC It catalogues information about equipment properties, interactions and their behaviour, following the formal standard for describing EBC templates (ISO 16400-2:2024). It interfaces and links to almost all packages presented in the following, most notably the Asset & Equipment package. Multiple standards are satisfactory in each category, but the behaviour of equipment during the lifecycle was identified as a gap.

3.1 Asset & Equipment

This package is concerned with the structure and utilization of physical assets and equipment. It includes the physical structure of plants and specifies the interconnection between hall, production units, workplaces, equipment and the controller level. Based in this, it also includes functionalities like Manufacturing Execution System (MES) aggregation and data storage about operations. This package connects rather seamlessly to the production planning package.

3.2 Production Planning

The production planning package deals with the strategic planning and operative scheduling of production activities. It encompasses most basic information objects such as process plans and operations, which can be used to support planning tasks like capacity planning and production scheduling. The package captures the relationships between the engineering of production systems as well as production orders, resource availability, material availability, and production timelines.

3.3 Product

The general information flow and in particular product planning, assets and equipment for production as well as the customer order process depend on the product. The product package represents the hierarchical arrangement and composition of products using the part and assembly information object types as well as functions, which are implemented by process steps. Functions, which belong to a part or an assembly, can be used to connect to the production planning package.

3.4 Customer Order Process

The customer order process package focuses on the steps involved in processing customer orders. It includes activities, which stem from the order and its fulfilment. A customer order includes specific parts and has to be transformed to a manufacturing order. By including a manufacturing order information object the relationships between process plan, resources availability and logistics can be drawn.

3.5 Consumption

Lastly, the consumption package focuses on tracking and analysing resource usage. It has been included as a placeholder for many other packages, which serve specific data for various use cases. In addition to energy, this point also includes, for example, personnel and, ultimately, costs.

4. EBC INTERFACES IN PRODUCTION LIFECYCLE

Based on the logical packages and their contents, further described in (prostep ivip, 2021), the standardisation work of ISO TC184 SC5 WG13 addresses the EBC embedding in the production system lifecycle by standardizing EBC interfaces using the information model. The following section presents the extension of the model and focuses in particular on the interfaces. For bridging the gap between domain experts and software developers the chosen notation for depicting the model is closely related to known UML notation with slight differences in interpretation of the meaning of some symbols. A focused drill-down of the information model is given in Figure 2. The entire information model is attached in Figure 4.

The production lifecycle begins virtually after product planning with the planning of production processes. Various assets in equipment information including their behaviour, needs to be integrated. The EBC concept envisions machine manufacturers providing this information in the structure of EBC templates. In a first interface between EBC and Asset & Equipment, desired or existing equipment information as objects of consideration in planning and operating are related to EBC templates. The information of EBC templates include behaviour, the property set as well as external interaction information of equipment and can be used the enrich equipment descriptions in planning processes, for simulation tools and other IT systems. Also, the result of planning and operating processes can be integrated in EBC information.

The external interactions are connected to the communication bus that represents the network infrastructure or communication channels. It is used to enable the exchange of information between different components of the system like MES and PLC information and is unique due to its infrastructural nature. For example, an EBC can store information on possible communication protocols and channels to a real equipment, that can be used for further integration in IT and automation structures – both virtual in the planning phase and physical in operation.

The state is supposed to harmonize its information with physical or virtual controllers of existing or planned equipment. The information defining the state, such as programs, calculation formulas or state data, also has interfaces to the real world of information in the lifecycle of production systems. In a concrete utilisation, calculation formulas or mathematical models provided by the EBC can be used to feed consumption calculations for energy, but also for raw materials, consumables and supplies, and thus also to support cost accounting. Also, new contexts, e.g. from simulation models, data analysis or other methods of knowledge acquisition, can be integrated into EBC via calculation formulas and/or mathematical models. A data set definition object type provides any structural data information and thus can be used to represent data such as mathematical formulas, scalars, vectors, matrices etc. This information can be used from the concrete realisation and operation of assets and equipment to keep the EBC representation updated. In concrete terms, there are overlaps in the attributes both for shop floor automation in corresponding IT systems such as MES or within controller level at the interface to physical asset und equipment. Also for the execution of production program planning and operating state information as part of the behaviour represent important input variables.

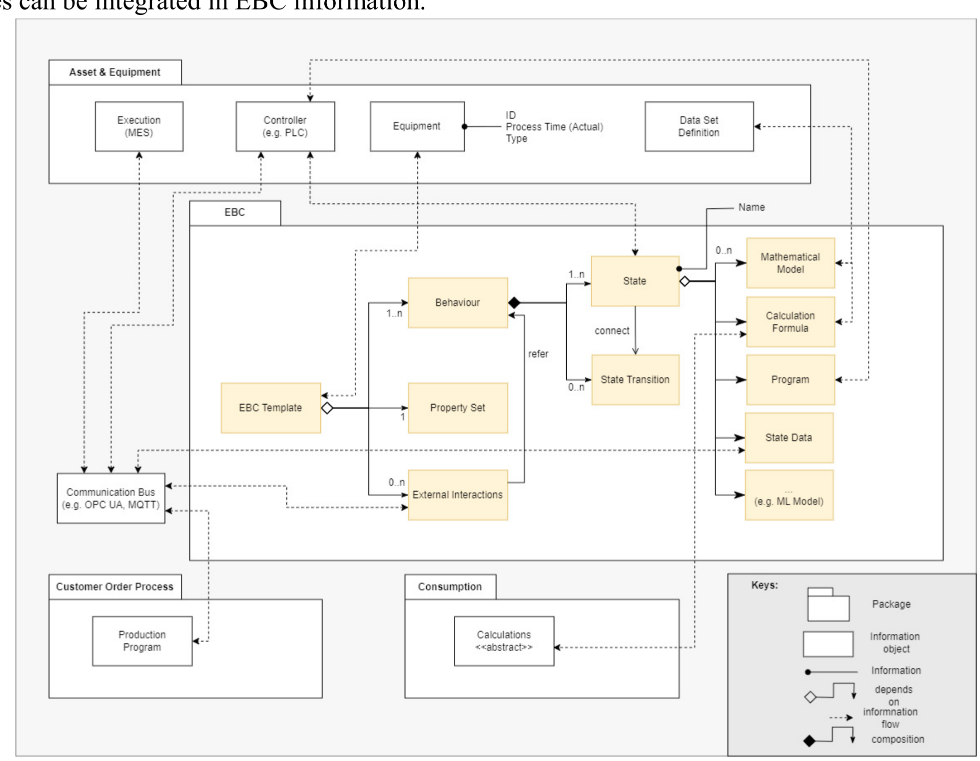

Figure 2. Interfaces for overarching equipment behavior description in production lifecycle utilizing the EBC (ISO/WD 16400-5)

5. APPLICATIONS

The use of standards for describing machines and equipment such as EBC or AAS enables heterogeneous applications in smart manufacturing. Parts of these applications are characterized in (ISO 16400-1:2020), in which fundamental use cases are presented. In the planning phase, they include, for example, the selection of the most suitable equipment in simulation studies with nominal equipment instance models or the derivation of optimized operation plans with physical instance models. In the operations phase, performance estimates can be made, actual performance can be evaluated and factory-as-a-service concepts can be enabled. Further applications in the energy-optimized factory are shown in the work of (Matsuda et al., 2021), in addition (ISO 16400-2:2024) and (ISO 16400-3:2024) contain application examples for EBC templates and items as well as the building procedures. Part 4 was initiated to further detail the application methods in the interaction of standards such as EBC, AAS and DFF (cf. Figure 3). In addition, the role of AI for the description of complex multivariate cause-and-effect relationships of equipment behaviour in the context of standardisation and standardisation is of great interest.

6. CONCLUSIONS AND OUTLOOK

In times of increasingly digital planning and operation of production systems, heterogeneous plant, machine and equipment environments require interoperable standards for the exchange of data and information. This article provides an overview of existing standards on the path to creating digital asset and equipment twins. Information within the life cycle of production systems is often not consistent and requires interfaces between IT systems and the real world. In the presented work, an information model for the production life cycle and the interfaces with the EBC standard were presented. The main goal of creating such a model lies in increasing the common understanding and thus enabling the various experts, vendors and consultants to create meaningful and ubiquitous software that bridges the current gaps, as well as data and information losses in different production life cycle stages. The decisive factor for the future will be how plant manufacturers and equipment suppliers as well as software service providers and users adopt unified standards. The AAS in particular offers flexibility through submodels as well as OPC UA via companion specifications in order to provide semantic about asset and equipment information in a unified manner. This also enables interfaces between the standards (e.g. an AAS submodel for EBC), which, however, characterize the need for further action. Other future topics include the sovereign exchange of data in the context of collaborative development of products and production systems as well as the harmonization of platform ecosystems in the operations phase (prostep ivip, 2023).

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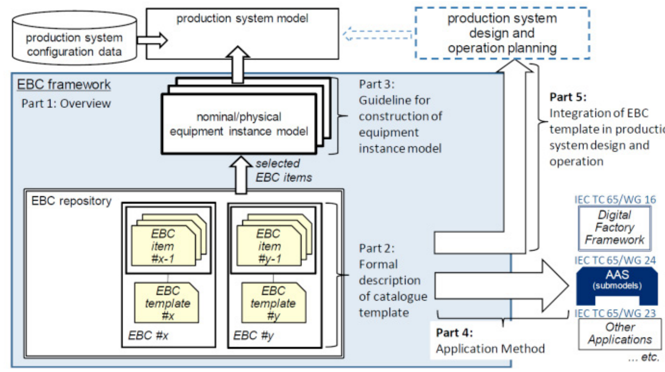

Figure 3. EBC application context (ISO TC 184 SC5 WG13)

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Appendix A. INTERFACES BETWEEN EBC AND PRODUCTION LIFECYCLE INFORMATION MODEL

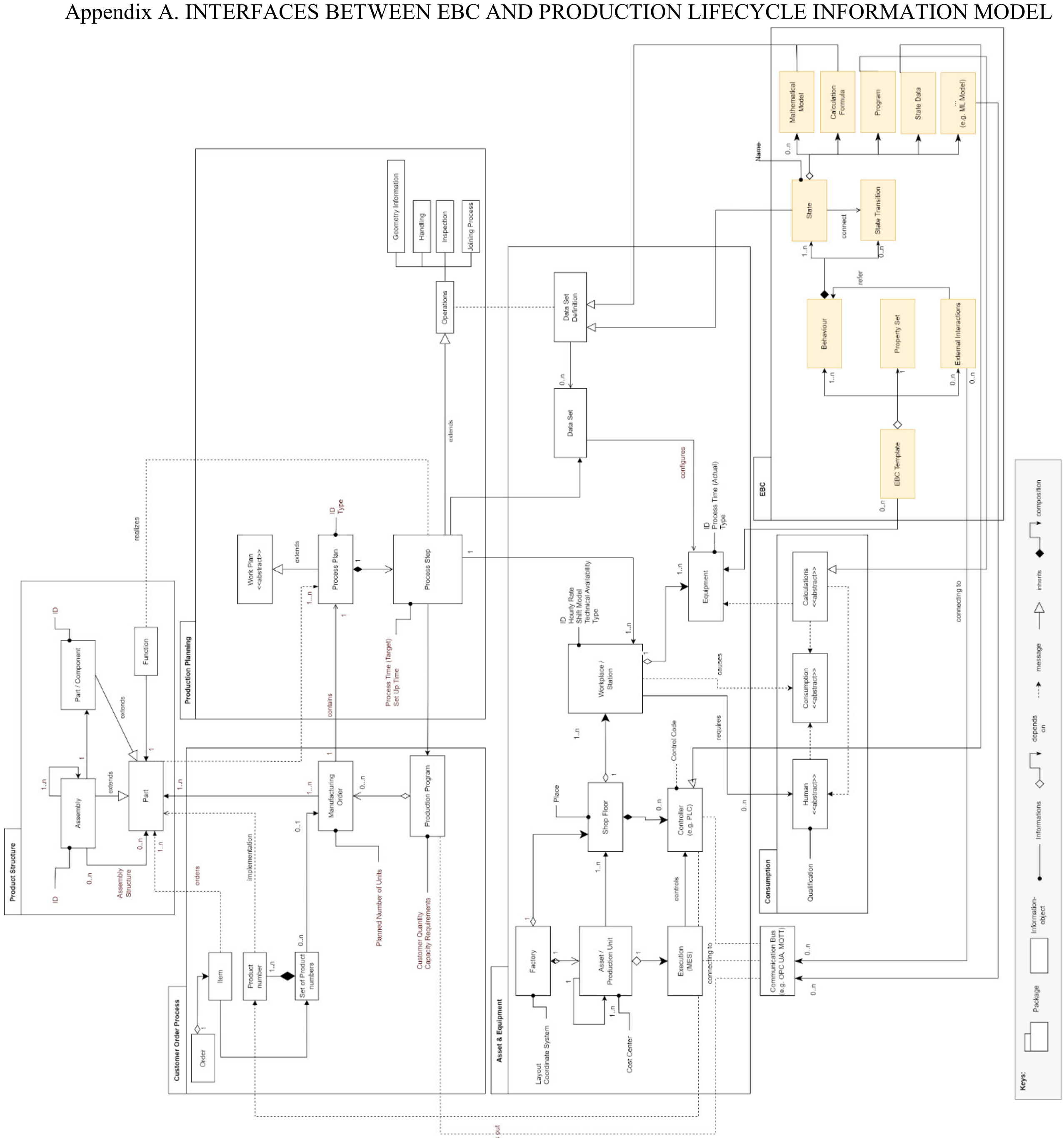

Figure 4. Overview of the PLIM model and interfaces to the EBC based on (ISO/WD 16400-5; prostep ivip, 2021)