Chapter 7
Description Means for Information Artifacts Throughout the Life Cycle of CPPS

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Abstract Recent research and development activities within the field of production system engineering and use focus on the increase of production system flexibility and adaptability. One common issue of those approaches is the consideration of hierarchical and modular production system architectures where the individual components of the system are equipped with certain functionalities and information. Up to now, there is no common understanding about what a component can constitute, i.e. which parts of a production system can be regarded as components within the hierarchy and which functionalities and information are assigned to it. This gap will be closed within this and the two the prior chapters.

They will at first discuss the relevant layers of components in a production system, then the types of information required to be assigned to a component on the different layers to establish a digital representation of the component, and at last the description means exploitable to represent the identified information in the different life cycle phases of a production system.

This chapter, in particular, will consider the artifacts and description means related to them in each of the three life cycle phases on each layer of the hierarchical production system structure as proposed in Chap. 5. Furthermore, the artifacts are clustered and generic artifact classes are derived from the fragmented information artifact landscape. Finally, description means are assigned to the artifact classes, paving the way for future research on this topic.

Keywords Model-based engineering • Description means • Information artifact classes • Life cycle phases • Production system hierarchy

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S. Biffl et al. (eds.), *Multi-Disciplinary Engineering for Cyber-Physical Production Systems*, DOI 10.1007/978-3-319-56345-9_7

7.1 Introduction

Due to the ever growing and accelerating trend towards industrialization and digitalization, the number of information artifacts, as well as the associated data formats and description means, are growing at an even higher speed (Vogel-Heuser 2015). However, as of today, there is no multi-disciplinary data modeling concept that is also consistent throughout the life cycle of a CPPS. The *Industrie 4.0* component addresses this topic, among others, by providing a structure for information elements to enable the implementation of functionalities of physical and virtual assets (Plattform Industrie 4.0 2016). Nevertheless, it is still unclear which overall requirements *Industrie 4.0* components will have to fulfill, considering the depiction of information artifacts and description means.

Therefore, the main research goal of Chaps. 5, 6, and 7 is to define the requirements on the capabilities of *Industrie 4.0* components in order to be able to create, manage, and use information along its complete life cycle. The two previous chapters already laid the groundwork to answer this question by providing a hierarchy and life cycle model to structure the emerging information (see Chap. 5) and by assigning information artifacts to the hierarchy layers and life cycle phases (see Chap. 6).

Against this background, in this chapter, the work of the previous two chapters is continued and the remaining research questions are answered, which are:

Which description means are exploited to represent the information types in the life cycle phases of a CPPS? Are there special description means related to the different layers?

These questions are closely linked to the research questions RQ M1 and M2 of Chap. 1, which state that it is of interest to identify requirements and architectures for *Industrie 4.0* component modeling considering their multi-disciplinary character and to have a look at the information creation and use related to it.

Therefore, in the course of this chapter, it will be shown which description means can be assigned to which generic types of engineering artifacts that are used throughout the life cycle of CPPS. In order to achieve this, the authors gathered and evaluated a characteristic set of information and the artifacts they are coded within. The first step was a literature review with focus on the work of (Foehr et al. 2012), where a Delphi-based expert survey was carried out. In a second step, the authors of this chapter complemented the data with further expert interviews and assigned a student work (Hell et al. 2016) to the topic in order to extend the representativeness of the work. The results are discussed here and, although the artifacts and description means in this work are not completely exhaustive, it is important to state that they are representative for a large part of the data types and formats used in the regarded setting.

In the foregoing, the focus is laid on interdependent information sets throughout the life cycle phases. For a detailed description on dealing with heterogenous information on project level using semantic web technologies, see Chap. 12.

Another important aspect in this context is data quality assurance, which deals with securing the faultlessness of (engineering) data throughout the life cycle. For further information on this topic, see Chap. 16.

To answer the described research questions, this chapter is structured as follows: first, a disambiguation is provided in order to delimit the topic of this chapter. In a second step, description means for the identified artifacts are identified, which are exploited to represent information coded within these artifacts. Thereby, it is possible to analyze whether there are special description means related to the different layers or not. In the process, description means are assigned to each layer of the hierarchy model and life cycle phases provided by Chaps. 5 and 6. This makes it possible to define classes of artifacts and corresponding generic description means in the next step. Finally, the contributions of this particular chapter as well as the overall contributions of Chaps. 5, 6, and 7 are discussed and an outlook to future research is given.

7.2 Disambiguation: Description Means, Information Handling Methods, and Tools

An important point, here, is that the distinction between description means, information handling methods, and information handling applications and tools shall be considered (Schnieder 1999). The focus of this chapter is on the description means, neither on information handling methods nor tools. For further reading about methods and tools the reader can refer to Chap. 9.

Description means enable the expression of problems and their solutions in more or less formal ways. Usually, it can be distinguished between the information covered by description means (semantics) and their representation (syntax) (Diedrich et al. 2011). For example, the behavior of a production system component can be expressed on an information level by a Petri net where the places cover local states of the component while transitions express the state evolution. On the representation level, places are represented by circles with annotations and transitions by bars with annotations. Nevertheless, description means shall be independent from any methodology and any technical solution for their creation, management, and use.

Methodologies and any technical solutions for creation, management, and use of artifacts are represented by information handling methods (usually covering the Engineering, Operation and Maintenance, and End-of-Life phase activities as named in the previous chapter) and information handling applications and tools (used within the same phases). Usually, they are strongly correlated with the description means applied.

Within the following, the focus will be on the description means and not on the methodologies and applications/tools. The aim of this Chapter is to name and assign types of relevant description means to the artifacts identified in the previous

Chapter. As the number of artifacts and the number of applicable description means is apparently high, only representative examples will be considered.

7.3 Description Means for Artifacts

As it can be seen within the following figure, the artifacts named within Chap. 6 can be assigned to the three identified life cycle phases as well as to the different layers of the identified hierarchy of a production system in Chap. 5 (see Fig. 7.1). The description means within the three phases are described in the following.

7.3.1 Description Means During Engineering Phase

Initially, during engineering phase, the production system is designed in a kind of top-down approach starting with the requirement specifications leading to the details specification about how to install and commission the production system. Usually, engineering information is created here, which are stored and exchanged as files, database content, or paper documents in an appropriate way.

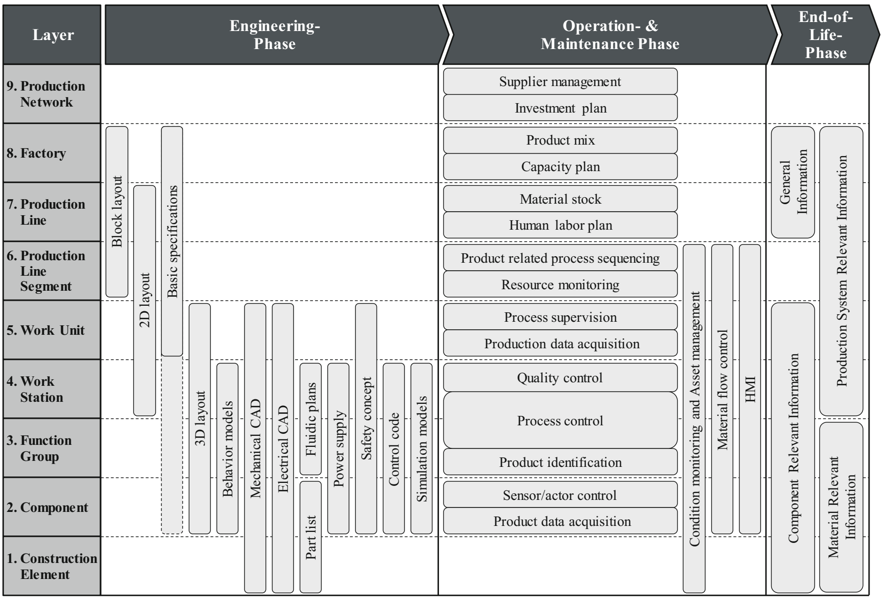

Fig. 7.1 Production system life cycle phases and phase-specific information

On the Factory and Production Network layers, requirements and legal, economic, and technical constraints (so-called propositions) are usually assigned. In most cases, these are text-based documents exchanged as PDF files. In some cases, companies have started to apply more formal ways within the requirement specification exploiting modeling tools like IBM DOORS or modeling languages like SysML. In this case, the exchanged documents are XML based (following XMI in the SysML case) or the information is stored in databases.

On Production Line and Production Line Segment layers, the production system structure is designed in general. Thus, 2D layouts are relevant which are exchanged as CAD drawings using files like TIFF, JPG, and PDF which are accompanied by text-based documents like PDF.

On Work Unit layer, there are basic behavior models, 2D layouts, mechanical and electrical specifications, 3D layouts, and safety concepts. For modeling basic behaviors usually Gantt Charts or similar high-level models are applied given in spreadsheet based documents like Microsoft Excel. Mechanical and electrical specifications are stored in a textual way or based on dedicated MCAD and ECAD tools with its appropriate data formats like JT or STEP. 3D layouts are given, in general, as CAD files. Safety concepts are described by text and/or in structures defined by legal regulation organizations exploiting XML.

On Work Station layer, behavior models, 3D geometry models, mechanical and electrical specifications, control programs, fluidic plans, powers supply concepts, safety concept, electrical construction, and simulation models are applied. Again related to 3D modeling as well as mechanical, electrical and fluidic constructions CAD data are created using special CAD files like JT and STP or dedicated XML structures. Comments and additions to these documents are given in text-based documents like PDF. Behavior models and simulation models usually cover more detailed behavior descriptions given by timing diagrams, SysML diagrams, or automatons as well as by dedicated models for simulation tools like automatons and Petri nets stored as legacy files or XML. Finally, control programs are given in appropriate control code following e.g. IEC 61131 stored as PLCopen XML.

On Function Group layer, the engineering information is more detailed covering basic behavior models, 3D layouts, mechanical and electrical specifications, control programs, fluidic plans, power supply concepts, safety concepts, electrical construction, detailed behavior models, and simulation models. The 3D data and construction specifications are again given as CAD files. Behavior and simulation models are usually given as detailed timing diagrams (in the specification case), automatons, or dedicated simulation models like Simulink or Modelica. For the other named information types XML-based or text based documents are often applied to represent the information.

Again, on Component Layer, the level of detail increases, especially related to the structure and behavior specifications like 3D layouts and constructions, control programs, power supply concepts, safety concepts, electrical construction, detailed behavior models, and simulation models. In addition, detailed part lists will be relevant defining the purchase parts of the production system. CAD based construction models are usually given as CAD files also used for mechanical and electrical constructions. Control programs are based on the relevant control programming languages, which are component type and vendor dependent, or they are stored as more or less user organization based XML formats like PLCopen XML. Behavior and simulation models are either given as dedicated simulation models like Simulink or Modelica or specified by automation based models like state charts. Especially for part lists Excel based CSV documents are relevant.

On the lowest layer, the Construction Element layer, the most detailed engineering information is relevant. This include part lists and mechanical and electrical specifications which are given as text-based documents, CSV files or XML-based files, and CAD-based construction given as CAD specific files like JT and STP.

An overview of layer specific artifacts and description means during Engineering Phase is given in Table 7.1.

7.3.2 Description Means During Operation and Maintenance Phase

Within the use phase, the identification of description means is a bit more complicated as here the time of validity and the way of artifact collection/transmission are relevant for the description means definition. Artifacts on the higher hierarchy layers have a validity period of hours and days while the artifacts on the lowest hierarchy layers are real-time control data with a validity period of minutes, seconds, and below. Thus, in contrast to engineering data, there is a drastic shift within the description means.

On the Production Network Layer, there is volume and cost planning information, economical Key Performance Indicators (KPIs) as well as technical and sales rules which usually are coded within text documents like PDF and XML-based documents.

On the Factory Layer, the relevant artifacts are very similar containing long-term production program and manufacturing planning, as well as technical and sales restrictions which mostly are given as text-based documents like PDF, economic, manufacturing, and logistics related KPIs given as XML structures like KPI XML, and material stock/availability, and order data coded as database content.

On Production Line Layer, the use related data mostly cover KPIs for staff, material, and resource allocation possibly coded by XML structures like KPI XML as well as resource planning, order data, supplier orders modeled as text-based documents like PDF, spreadsheet-based documents like CSV and database content like SAP systems.

The only difference between Production Line Segment Layer and Production Line Layer is the more detailed focus on resources. Thus, there are resource related KPIs, resource alarming, order data, and material logistics data which can be represented by spreadsheet based documents like CSV, XML structures like KPI XML, database content, and, as new means especially for alarming, PLC data.

Table 7.1 Layer-specific artifacts and description means during engineering phase

	Layer	Artifacts	Usable description means
9	Production network	Requirement specifications, legal, economic, and technical constraints	Text-based documents like PDF, XML structures
8	Factory	Requirement specifications, legal, economic, and technical constraints	Text-based documents like PDF, XML structures, database content
7	Production line	2D-layouts	CAD drawings using files like TIFF, JPG, PDF, text-based documents like PDF
6	Production line segment	2D-layouts	CAD drawings using files like TIFF, JPG, PDF, text-based documents like PDF
5	Work unit	Basic behavior models, 2D-layouts, mechanical and electrical specifications, 3D-layouts, and safety concepts	Gantt Charts or similar high-level behavior models in Excel, text-based documents, CAD files like JT or STP, XML-based files
4	Work station	Behavior models, 3D-geome-try-models, mechanical and elec-trical specifications, control programs, fluidic plans, powers supply concepts, safety concepts, electrical construc-tion, simulation models	CAD files like JT and STP, XML structures, text-based documents like PDF. Impulse diagrams, SysML diagrams, automatons, and Petri nets as legacy or XML files, IEC 61131 code as PLCopen XML
3	Function group	Behavior models, 3D-layouts, mechanical and electrical specifications, control pro-grams, fluidic plans, powers supply concepts, safety con-cepts, electrical construction, detailed behavior models, and simulation models	CAD files like JT and STP, XML structures, text-based documents like PDF. Impulse diagrams, SysML diagrams, automatons, and Petri nets as legacy or XML files, simula-tion models like Simulink or Modelica, IEC 61131 code as PLCopen XML
2	Component	Behavior models, 3D-layouts, part lists, mechanical and elec-trical specification, CAD con-struction, control programs, powers supply concepts, safety concepts, electrical construc-tion, detailed behavior models, simulation models	CAD files like JT and STP, XML structures, text-based vendor dependent documents, simulation models like Simulink or Modelica State charts, IEC 61131 code as PLCopen XML, CSV files
1	Construction element	Part lists, mechanical and electrical specifications, CAD-based construction	Text-based documents, CSV files, XML-based files, CAD specific files like JT and STP

On Work Unit Layer, the real-time control impact drastically increases and the importance of KPIs decreases. The relevant data on this layer contains especially maintenance related resource KPIs, resource state information and resource alarming, order related data, and production process control data. Thus, here are with spreadsheet-based documents like CSV, XML structures like KPI XML, database content, and PLC data the same description means as on Production Line Segment Layer.

On Work Station Layer, there are the same artifacts and description means relevant as on Work Unit Layer.

The most relevant shift within the used description means can be found between Work Station Layer and Function Group Layer. On Function Group Layer as well as on Component Layer, the use data are related to field control. They subsume resource and component state and alarming information as well as production process control data which are modeled as PLC, RND, CNC, etc. data.

Finally, on the Construction Element Layer, there are no direct use phase related data. Nevertheless, it can be assumed that there might be construction element related data relevant for maintenance activities like durability of materials. But they are collected on Work Station Layer as resource KPIs. An overview of layer specific artifacts and description means during Operation and Maintenance Phase is given in Table 7.2.

7.3.3 Description Means During End-of-Life Phase

The identification of artifacts for the End-of-Life phase of production systems is still an open field of research. However, with general information (relevant on layers 8 and 7), production system related information (relevant on layers 8–4), component-specific information (relevant on layers 5–2), and material-specific information (relevant on layers 3–1), four general information- types are known.

General information is mostly related to guidelines and regulations defined/developed by legal advisors, standardization organizations, or vendor organizations. They are usually provided as text-based documents like PDF, sometimes including more formal representations like UML diagrams and XML structures.

Production system related information is mostly based on the re-use of engineering information as well as engineering-like information describing the current state of the structure and behavior of the production system. This may include 2D- and 3D-plans and -layouts, behavior models, and part lists, which are modeled by CAD-drawings using files like TIFF, JPG, PDF, text-based documents like PDF, XML-based structures, Gantt and timing diagrams, as well as spreadsheet-based documents like CSV.

The component-specific information is very similar to the production system related information, but usually contains a higher level of detail. They subsume mechanical and electrical specifications and constructions, behavior models, safety concepts, and part lists, which are modeled by CAD-drawings using files like

Table 7.2 Layer-specific artifacts and description means during operation and maintenance phase

	Layer	Artifacts	Usable description means
9	Production network	Volume and cost planning, economical KPIs, technical and sales rules	Text-based documents like PDF, XML structures like KPI XML, database content
8	Factory	Program and manufacturing planning, economic, manufacturing and logistics related KPIs, technical and sales restrictions, manufacturability, parts stock/ availability, order data	Text-based documents like PDF, XML structures like KPI XML, database content
7	Production line	Staff, material and resource allocation KPIs, resource planning, order data, supplier orders	Text-based documents like PDF, table-based documents like CSV, XML structures like KPI XML, database content
6	Production line segment	Resource KPIs, resource alarming, order data, logistics data	Table-based documents like CSV, XML structures like KPI XML, database content, PLC data
5	Work unit	Resource KPIs, resource state and alarming, order data, production process control data	Table-based documents like CSV, XML structures like KPI XML, database content, PLC data
4	Work station	Resource KPIs, resource state and alarming, order data (like quality), production process control data	Table-based documents like CSV, XML structures like KPI XML, database content, PLC data
3	Function group	Resource state and alarming, production process control data	PLC, RND, CNC, etc. data
2	Component	Component state and alarming, production process control data	PLC, RND, CNC, etc. data
1	Construction element	–	–

TIFF, JPG, PDF, text-based documents like PDF, XML-based structures, timing or automaton diagrams, as well as spreadsheet-based documents like CSV. The focus of this information is on the modular and hierarchical structure of the production system and the way it is assembled during installation. Thereby, the way of disassembling can be defined. In addition, the component-specific information covers use-phase related information, describing the way of the utilization of components. This is necessary to estimate the current economic value of a component and its capability to be reused in other production systems. The named information mostly covers resource related KPIs, which are modeled as text-based documents like PDF, XML structures like KPI XML, spreadsheet-based documents like CSV, database content, or even as PLC data.

Finally, the material specific information focuses on the material identification within the used production system elements as well as on the description of the deterioration of the used material during use time. This is based on the use of device, material, and other documentations which are given as text files for example as PDF and on resource/component related KPIs which are modeled as XML structures like KPI XML, spreadsheet-based documents like CSV, database content, or again as PLC data.

The named mappings of useable description means are summarized in Table 7.3. As can be seen, the number of currently applied description means is high. It changes with the considered layer being more formal and can be automatically evaluated better on the lower hierarchy layers. In the future, it is advisable to reduce the number of applied description means.

7.4 Artifact Classification

In order to identify description means potentially usable for the artifacts in a future scenario, the artifacts need to be classified and the description means need to be assigned to each artifact class. By this, a potential unification of artifacts can be reached. It might enable the representation of all identified information types within/of *Industrie 4.0* components by a uniform representation.

One possible classification of the identified artifacts is given in Fig. 7.2. It represents the three main life cycle phases of the production system, indicates artifact classes applicable, and maps the artifacts named above to the artifact classes.

Considering the available description means named in the sections above, generalized XML-based data formats like AutomationML (Drath 2010) and (AutomationML 2009) can be identified as possible candidates for a data format covering all artifacts. Nevertheless, following (Schmidt and Lüder 2015) AutomationML will not cover all relevant information sets. Therefore, it needs to be extended by text files like PDF, CAD drawings using files like TIFF or JPG, and control information represented in databases like OPC UA or in control devices like PLC, RND, or CNC. (Lüder et al. 2014) presents a possible integration approach.

Table 7.4 summarizes the combination of the five named information description means to represent all artifact classes.

7.5 Summary and Outlook

The goal of this Chapter was to define description means that can be exploited to represent the information types in the three life cycle phases and whether they are related to the different hierarchy layers as described in Chap. 5.

In order to achieve this, in a first step usable description means were assigned to the artifacts on each layer of the underlying hierarchy structure. Since the

Table 7.3 Layer-specific artifacts and description means during EOL-Phase

	Layer	Artifacts	Usable description means
9	Production network	–	–
8	Factory	General information, production system related information	Text-based documents like PDF, UML diagrams, CAD drawings using files like TIFF, JPG, PDF, XML-based structures, Gantt and Impulse diagrams, table-based documents like CSV
7	Production line	General information, production system related information	Text-based documents like PDF, UML diagrams, CAD drawings using files like TIFF, JPG, PDF, XML-based structures, Gantt and Impulse diagrams, table-based documents like CSV
6	Production line segment	Production system related information	Text-based documents like PDF, CAD drawings using files like TIFF, JPG, PDF, XML-based structures, Gantt and Impulse diagrams, table-based documents like CSV
5	Work unit	Production system related, component-specific information	Text-based documents like PDF, CAD files like TIFF, JPG, PDF, XML-based structures, Gantt, Impulse, or automaton diagrams, table-based documents like CSV, database content, PLC data
4	Work station	Production system related, component-specific information	Text-based documents like PDF, CAD files like TIFF, JPG, PDF, XML-based structures, Gantt, Impulse, or automaton diagrams, table-based documents like CSV, database content, PLC data
3	Function group	Component-specific information, material specific information	CAD drawings using files like TIFF, JPG, PDF, text-based documents like PDF, XML-based structures like KPI XML, Impulse or automaton diagrams, table-based documents like CSV. database content, PLC data
2	Component	Component-specific information, material specific information	CAD drawings using files like TIFF, JPG, PDF, text-based documents like PDF, XML-based structures like KPI XML, Impulse or automaton diagrams, table-based documents like CSV. database content, PLC data
1	Construction element	Material-specific information	Text files like PDF, XML structures like KPI XML, table-based documents like CSV, database content, PLC data

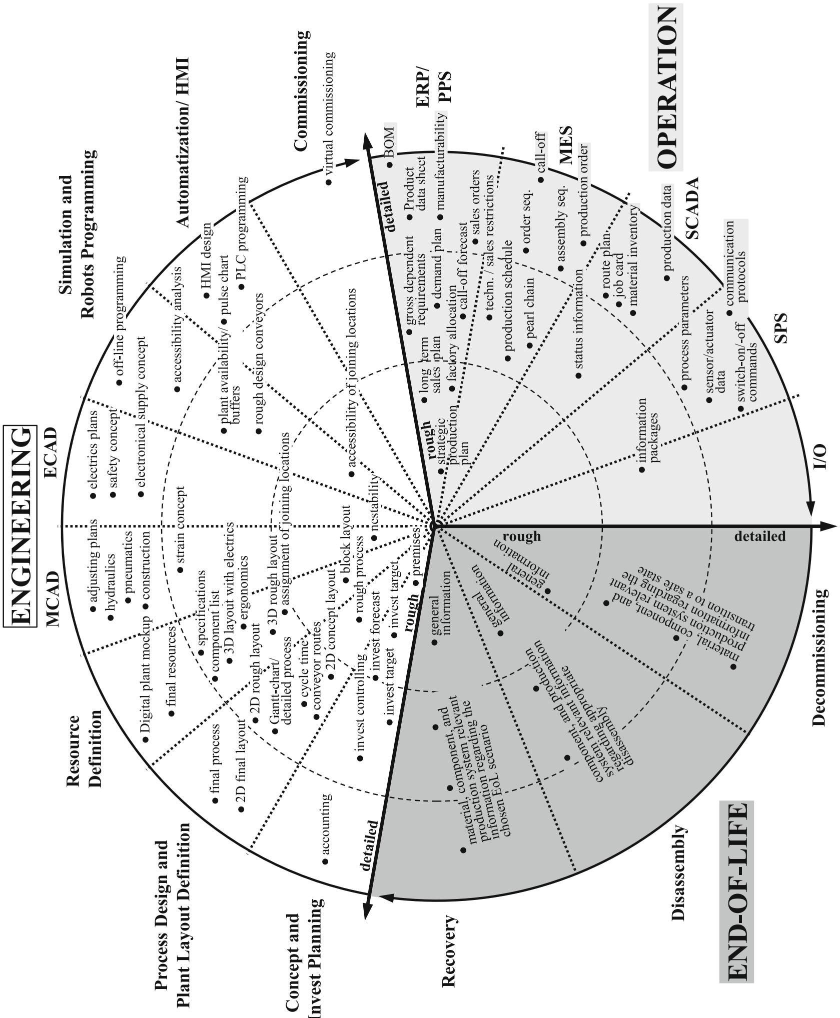

Fig. 7.2 Examples of relevant artifacts in the three life cycle phases

Table 7.4 Description means assignment to artifact classes

Artifact classes	Description means				
	XML-based structures like AutomationML	Text files like PDF	CAD drawings using files like TIFF, JPG	Database content like OPC UA	PLC, RND, CNC, etc. data
Concept and invest planning	X	X			
Process design and plant layout definition	X		X		
Resource definition	X		X		
MCAD	X		X		
ECAD	X		X		
Simulation and robots programming	X		X		
Automation/HMI	X			X	X
Commissioning	X	X	X	X	X
ERP/PPS	X	X			
MES	X			X	
SCADA	X			X	
PLC				X	X
Field-I/O					X
Decommissioning	X	X	X	X	X
Disassembly	X	X	X	X	X
Recovery	X	X	X	X	

information and description means can vary greatly between the three specified life cycle phases of CPPS, it was necessary to match artifacts and description means for engineering, operation, and EoL-Phase. Thereby, it was shown that both, the assignment of description means to hierarchy layers as well as to life cycle phases is possible.

However, since the information used in the various scenarios can be interdependent, incompatibility of description means used throughout the life cycle is a possible outcome. Therefore, in order to make description means compatible in the future, in this Chapter possible artifact classes were defined and assigned to description means, making them more consistent.

What are the requirements on the capabilities of *Industrie 4.0* components to create, manage, and use information along its complete life cycle?

Considering the main research question of the Chaps. 5, 6, and 7 the intention of this work was to provide assistance for engineers to decide about the right information set to be covered by an *Industrie 4.0* component and to decide about applicable implementation technologies. Therefore, the main research question of this work has been the identification of requirements on the capabilities of *Industrie 4.0* components to create, manage, and use information along their complete life cycle.

To answer this question three underlying research questions have been addressed beforehand. At first, nine different layers of *Industrie 4.0* components in a production system have been presented in Chap. 5. For each layer, the relevant functionalities of an *Industrie 4.0* component were used as criteria for identification.

At second, the different types of information to be assigned to an *Industrie 4.0* component on the different layers have been discovered establishing a kind of virtual representation of the component. Therefore, the main life cycle phases of a production system have been reviewed in Chap. 6.

Finally, description means applicable to represent the identified information types in these life cycle phases are given in Chap. 7.

As a result, the named three Chapters together are able to provide

- Candidates for *Industrie 4.0* components,
- Candidates for meaningful information sets relevant for these *Industrie 4.0* component candidates following the different layers of components in a production system, and finally
- Candidate technologies for representing these information sets in the administration shell of the *Industrie 4.0* component.

The three Chapters failed to provide information-based identification characteristics for *Industrie 4.0* components. Figure 7.2 depicts this problem. Here it gets visible, that for example the Layers Work Station, Function Group, and Component contain similar engineering information just with a different granularity. Also, the runtime information are very similar. Thus, these information set relevant for an *Industrie 4.0* component is not necessarily layer characterizing. Here, further research can provide a more detailed view on the problem.

In addition, this work still leaves another essential question open. Especially Tables 7.1, 7.2, and 7.3 indicate that there are various information sets relevant for an *Industrie 4.0* component. But these information sets are not independent from each other. In contrast, they are strongly dependent, requiring on the one hand consistency between the information sets as well as sometimes enabling the generation of some information exploiting other information sets.

The representation of these dependencies and generation processes are beyond the scope of this paper but need to be considered in detail in future work.

Furthermore, the requirements of model-based engineering make it necessary to integrate proper methods and tools throughout the engineering processes. Since this is also a workflow-management topic, Chap. 11 discusses the adoption of this model-driven systems engineering approach considering the requirements for CPPS.

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