Engineering Data Treasures, Their Collection and Use

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Abstract: “Data is the new oil” is a frequently pronounced statement. It is expected that intelligent utilization of information will change economies. With respect to production systems this fact can become reality by utilizing the Industry 4.0 Asset Administration Shell. This paper describes ways to fill and exploit the data treasure with respect to production system engineering data, by highlighting the importance of multi-modelling of production systems.

Keywords: production systems, multidisciplinary engineering, multidisciplinary improvement, integrated engineering data.

1. INTRODUCTION

Facing fast-changing market conditions related to supplier, technology and costumer markets, production systems all over the world have to cope with increasing challenges related to effective and efficient utilization of resources (Gehlhoff et al., 2019). An adequate reaction can be based on the application of ideas of smart factories integrating increased digitalization, flexibilization, modularization and networked automation (Kern, 2021). However, this reaction is likely to require re-thinking the life cycle of production systems (Ivanov et al., 2021; Xu et al., 2021).

In general, it is agreed that this rethinking will be based on the increasing utilization of information and their processing along the complete life cycle of the production system (Acatech, 2013). Following the European parliament, information will be the oil of this century (European parliament, 2020). Like in case of oil, information provision and processing can provide huge benefits such as increasing product quality, but also huge dangers from the increase of the attack surface of software-intensive production systems for hackers.

Production systems consist of physical assets, e.g., networks of manufacturing units utilizing robots, sensors, and motion drives, as well as non-physical assets, e.g., recipes, configurations, and control programs. Together, these resource assets execute production processes (process assets) to manufacture products (product assets) with required properties, e.g., quality and throughput. Thus, these assets together form a purposeful product-process-resource-asset-network (PAN) (Schleipen and Drath, 2009; Kathrein, 2019; Winkler 2021) that shall be designed in a way following relevant optimization criteria.

An open question to be answered is: what is the “right” amount and way of information use to reach an optimal (based on usual KPIs) solution for such a production system, resulting in an optimized information representation of the PAN? The answer to this question depends on the context and use case (Meudt et al., 2016). However, this paper can give directions by following the life cycle of information building blocks to be exploited along the complete life cycle of production systems.

Consequently, this paper will follow an axiomatic approach. It will start from the axiom that information processing within production systems will be based on the Industry 4.0 asset administration shell, further called *shell* in this paper, where a shell will represent a relevant asset of the production system, i.e., a PAN element. The paper will draw conclusions on ways (i) to collect the necessary data to fill a shell and (ii) to apply the collected information. Therefore, this paper will summarize results from two cooperating research groups at Otto-von-Guericke University Magdeburg and at TU Wien.

2. INDUSTRY 4.0 ASSET ADMINISTRATION SHELL

The Industry 4.0 Asset Administration Shell is under development as part of Industry 4.0 (I4.0) development process (acatech, 2013). Within this approach, the focus is on the Industry 4.0 component, the automation system component, and its capabilities (DIN, 2016). The I4.0 component is based on two main parts, the asset and the asset administration shells related to the asset. While the asset can be a physical object, such as drive, sensor, robot, or machine, or a logical object like a device configuration or a process step description, the shell is a virtual object enabling description of and access to the asset (Wagner et al., 2017). Recently, in Europe, the structure and use of the Industry 4.0 component have been discussed and agreed (Ministies, 2018), making it a good starting point for implementation approaches (Oztemel and Gursev, 2020).

The Industry 4.0 asset administration shell (I4.0 shell) is aims at representing and making accessible the asset along its complete life cycle following the ideas of IEC 62890 (International Electrotechnical Commission, 2017). Figure 1 shows the structure of an I4.0 shell (Plattform Industrie 4.0 2019).

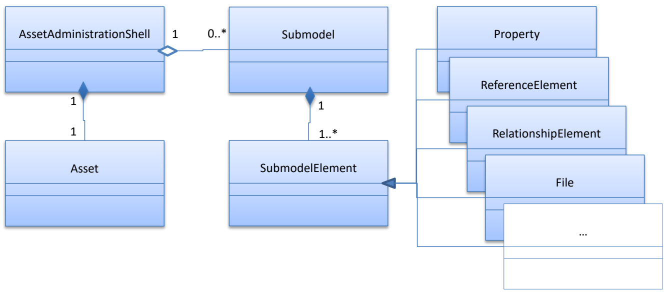

Figure 1. Asset administration shell meta model (excerpt from (Plattform Industrie 4.0 2019)).

Each I4.0 shell contains one asset data object and holds a set of sub-models. While the asset data object represents the identification information of the linked asset, the sub-models represent information items that are technically separated from each other but together form a consistent model of the asset of interest. Each sub-model may contain elements, which can be properties, references, files, and several more. The I4.0 shell structure shall reflect the different needs of the Industry 4.0 component life cycle.

The information set of a shell shall be stored within a so-called serialization. The guideline "Details of the Asset Administration Shell "(Plattform Industrie 4.0, 2019) recommends AutomationML for serialization during production system engineering, AASX for CPPS commissioning, and OPC UA for CPPS operation; and presents representations of the I4.0 shell meta model for these data formats.

As Industry 4.0 components can form hierarchies and networks, also shells can be interlinked and nested forming networks of shells (Ministies, 2018; Plattform Industrie 4.0, 2019). Therefore, appropriate *reference* and *relationship* elements will be utilized (see Figure 1).

3. AGGREGATING SHELL CONTENT

The first part of the life cycle of a shell is its creation by aggregating data (DIN, 2016). In the case of productions systems, these data may come from various engineering, reengineering, and maintaining activities, mostly at the beginning of the life cycle of the production system, i.e. within the engineering and ramp-up phases.

Production system (re-)engineering is a multi-model and multidisciplinary approach (Biffl et al., 2017). It is based on a network of engineering-discipline-specific design decisions like mechanical and electrical design that relate to each other. Appropriately skilled engineers take these design decisions by utilizing discipline-specific methodologies and tools like M-CAD and E-CAD tools creating engineering data (models) based on existing engineering data (models) (Biffl et al., 2017). The structure and level of detail of the engineering network depend on its application (Lüder et al., 2011). Nevertheless, the engineering network iteratively designs all necessary information required to commission, ramp-up, and run the production system. Hence, the engineering network is a first-class citizen source for all information to be covered by the shell (Lüder et al., 2020a).

Engineering networks of production systems apply a wide variety of data models, data formats, and modelling means (Lüder et al., 2017a). Bringing these engineering data models together into a consistent engineering network requires appropriate information modelling means that provide capabilities for the exchange of engineering information between engineering tools (Lüder et al., 2017b). A well-established technology for the required data integration is AutomationML (Drath, 2021a, b). Data integration can provide the foundation for AutomationML-based information logistics spanning the engineering network of production systems (Lüder et al., 2018).

Such a data logistics can build on the pipeline concept (Rinker et al., 2021) by integrating components for data transformation, integration, and consistency management. The data logistics shall be able to (a) transform engineering data created within an engineering-discipline-specific design decision and coded by discipline specific models and data formats into a data model, which covers the complete engineering network, in a neutral data format like AutomationML and (b) to integrate the engineering data in an engineering data base for further use (Behnert et al., 2021) as presented in Figure 2.

First prerequisite for the successful implementation of such an engineering data logistics is a common understanding of all information relevant within the engineering organisation and their relation to the assets of the PAN.

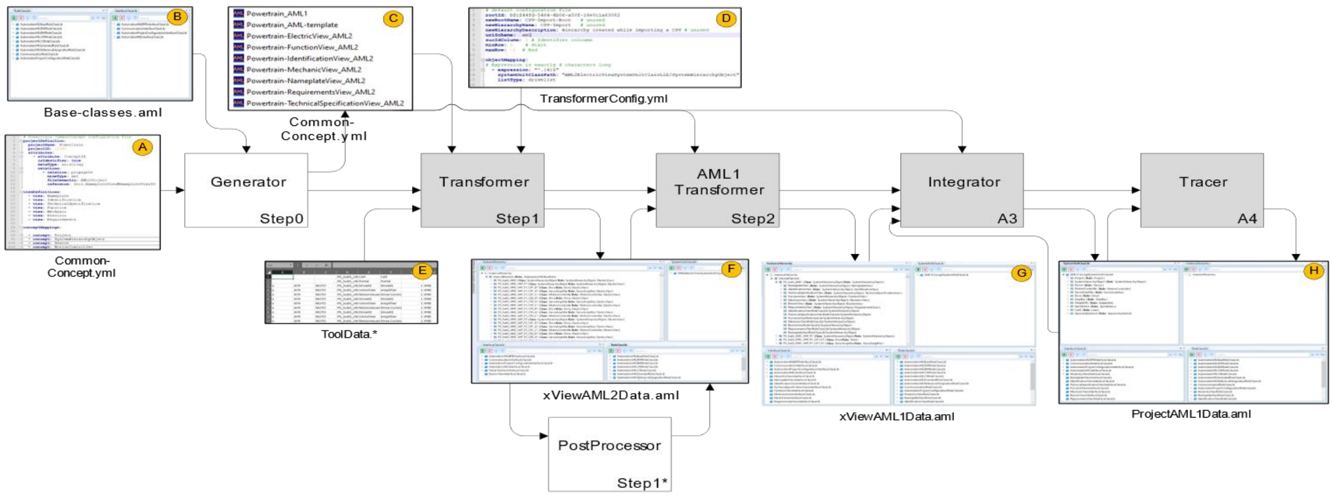

Figure 2: AutomationML based engineering data integration pipeline.

The engineering-discipline-specific design decisions forming an engineering network result in discipline-specific data models following local domain specific languages (DSL) of the involved engineering discipline and tools that are represented by so-called tool artefacts like M-CAD or E-CAD models. Each tool artefact contains information on a set of assets like the elements of a drive chain that represent a view on this asset. Combining all views for all relevant assets of an engineering network of an engineering organization will result in a global DSL being the representation of the complete relevant PAN of the engineering organization without developing a world model by focussing only on relevant information which will be always possible.

Based on this understanding of the relevant information space of an engineering network, the common concept approach (Lüder 2020b) will enable the identification and modelling of all relevant information and the generation of an AutomationML-based modelling framework to be used within the engineering data pipeline (see A, B, and C in Figure 2). The result of the *Generator* (step 0) will be a set of AutomationML role, interface, and system unit classes that represent the local and global DSLs in the engineering data logistics (see Figure 3).

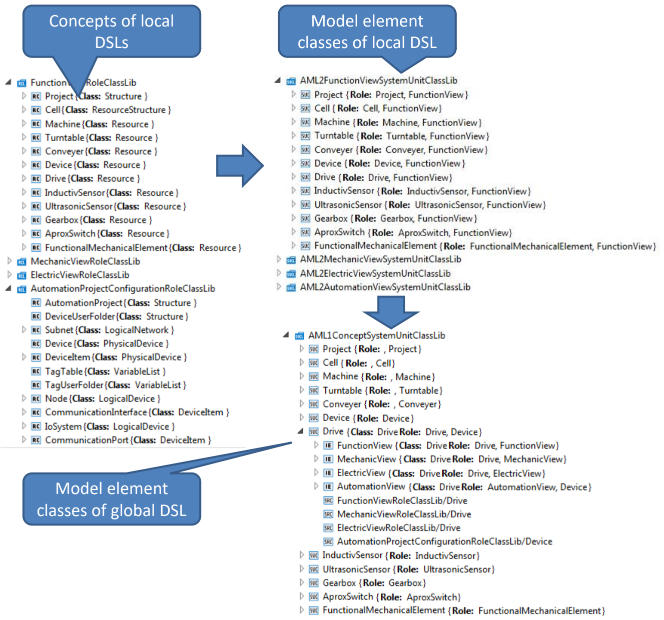

Figure 3: AutomationML-based local and global DSLs of an engineering data logistic for production system engineering.

Second prerequisite for the successful implementation of such an engineering data logistics is the implementation of a sequence of transformation steps (1) translating the tool artefacts coming from the individual engineering-discipline-specific design decisions (see tag E in Figure 2) to an AutomationML-based vendor neutral dialect following the discipline- respectively tool-related local DSL (see tag F in Figure 2), (2) translating these neutralized engineering data into the representation of the related global DSL (see tag G in Figure 2), and (3) integrating these engineering data representations into the existing AutomationML-based reached engineering data set of the engineering network following the related global DSL (see tag H in Figure 2) and ensuring consistency between the engineering-discipline-specific views.

Using these three steps iteratively on all tool artefacts, results in a complete AutomationML-based representation of the individual PAN assets. This representation will contain all relevant engineering data for an asset, structure them in discipline-specific views as depicted in Figure 4, and putting the asset in relation to the other PAN assets within the different views.

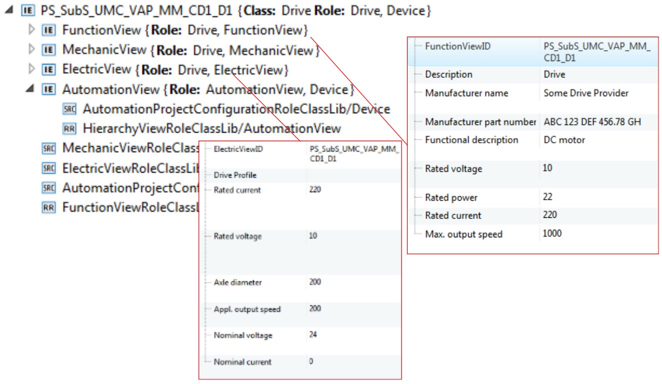

Figure 4: Model of a PAN asset based on common concepts.

The resulting Automation-ML based representation is structurally equivalent to the shell structure and can be easily transformed to a shell serialization as defined in (Plattform Industrie 4.0, 2019).

Prototypical implementations of such a data logistics leading to shell data representations have been presented in (Behnert et al., 2021), (Lüder et al., 2021) and (Lüder et al., 2020a).

4. UTILIZING shell CONTENT

The second part of the life cycle of a shell is its exploitation to control and optimize the production system. In this case, the aggregated and integrated engineering data reached by application of an engineering data logistics as presented in Section 3 shall be represented and exploited easily.

As each shell within this data set represents one asset of a PAN. Each shell is related to either a product asset, process asset or resource asset of a production system. Thus, a PPR-based approach for system representation as proposed in (Kathrein et al., 2019) can be exploited, leading to the representation of the PAN as presented in (Meixner et al., 2021) and (Winkler et al., 2021). Figure 5 depicts an excerpt from a PAN example representing a part of a car mounting line. It covers PPR assets of the placing and mounting step of the car dashboard indicating some relevant properties and relations between assets as well as tool assets that provide the related engineering information.

Such a PAN model can be handled and stored following a graph-based approach (Biffl, 2021a). The integrated AutomationML serialized shell based on PAN models can be stored in a Neo4J[1] graph data base by exploiting the meta modelling concepts named in Figure 6. It results in a knowledge graph that can be searched using *Cypher*[2] queries.

[1] https://neo4j.com/

[2] https://neo4j.com/developer/cypher/

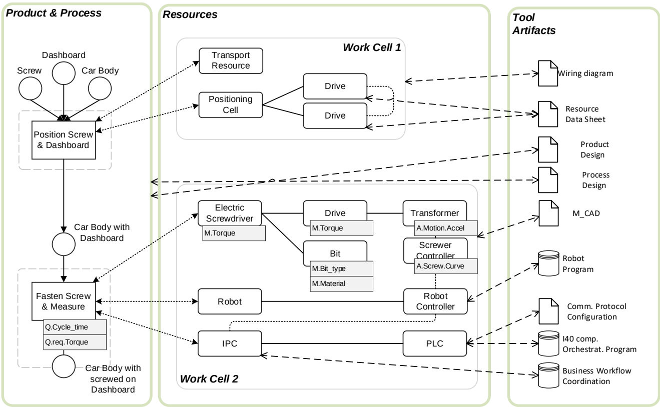

Figure 5: PAN model representation.

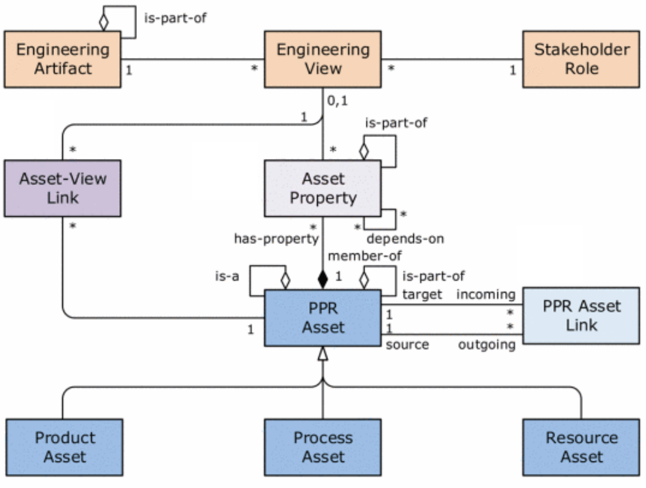

Figure 6:PAN modelling approach concepts (Biffl, 2021a).

The PAN model can be exploited for configuration management of production systems (Biffl, 2021a). As the interlinked shells within a PAN model represent all relevant assets with their properties, consistency rules can be applied on them (Winkler et al., 2020) ensuring a configuration to be valid and applicable.

In a similar way, the PAN model can be exploited within production system engineering process management. Each PPR asset can be regarded as coordination artefact, i.e., as an engineering project related entity requiring coordination actions among different engineering disciplines. Extending the shell representation by required coordination information, the coordination of engineering-discipline-specific design decisions can be supported.

Beyond the single use of the PAN there are further potential applications based on an extended PAN model. This extension exploits the integration of additional assets representing additional information either on the elements of the PAN or on additional assets. By this an extended PAN model structure as presented in Figure 7 can be reached.

At the moment different application cases of such extended PAN models are under investigation containing for example business models, quality models, safety related models, or data security related models as analysis models.

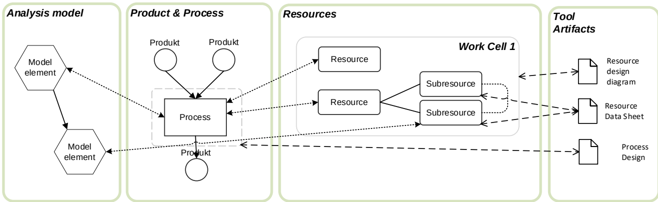

Figure 7: Extended PAN.

Kropatschek et al. (Kropatschek et al., 2021) introduce a PAN extension named Quality Dependency Graph (QDG) that represents cross-domain knowledge dependencies for efficiently prioritizing data sources for quality management within production systems.

Biffl et al. (2021c) extend a PAN with FMEA-related PAN assets is applied for shell for multi-view risk assessment. It enables the simplification of cause-effect (re-)analysis within production system (re-)engineering and maintenance by exploiting the graph-based structure to facilitate the semi-automated evaluation of hypotheses based on data, even across discipline boundaries and allows validating cause-effect pathways, i.e., to what extent a PAN element linked to a cause is connected to a PAN element linked to an effect.

(Kropatschek et al., 2021) details the use of FMEA as analysis model for safety and quality management issues.

The main advantages of the development and utilization of the extended PAN models can be seen in the increase of engineering activity effectiveness and efficiency by explicitly combining the different but related knowledge fields that are relevant for this engineering activities. The involved engineer can safe time and effort for information acquisition and reduce engineering failures by improved scoping.

5. OPEN RESEARCH ISSUES

Currently several further applications of the shell based PAN networks are under discussion. They cover for example identification of critical assets by extending the PAN by value stream analysis assets and executing an impact analysis of PAN assets on relevant Key Performance Indicators (KPIs) and identification of security risks by combination of attack models with PAN to identify the most critical resources for improving production system security.

All named application cases of shell-based PANs require automatic analysis of the network. Currently, the analysis is more or less “handmade” tailored to the application case. To open up the approach for general cases requires a PAN analysis language that supports engineers in defining requests to the PAN network. This language shall be based on the shell meta model and shall enable to reflect the individual engineering discipline related knowledge.

In addition, a software technical integration of the engineering data logistics presented in Section 3 and the Neo4J based PAN analysis framework is required to support their combined application within engineering organizations.

Finally, the current research is based on exploiting the AutomationML serialization of a shell covering the engineering data of an asset. Within the Industry 4.0 approach, there are further serializations covering life cycle phases, like AASX covering the ramp-up phase and OPC UA covering the runtime phase. Therefore, these serializations shall be considered to be integrated in the presented approaches like for example the Quality Dependency Graph or the FMEA-related PAN.

6. CONCLUSIONS

One facet of the Industry 4.0 approach is the optimal utilization of information on the individual assets of the production system to improve production system performance in various directions (Acatech, 2013). However, open questions are the identification, collection and utilization of the “right” amount of information to reach optimal solutions.

Within the presented paper reached results coming from the close cooperation of two research groups in Magdeburg and Vienna have been presented, highlighting aspects of information collection and utilization in engineering organizations executing engineering networks. An engineering data logistics and some engineering data exploitation approaches have been sketched that are based on the idea of an asset administration shell and enables an optimized information application as shown in Section 4.

The current research is yet not able to solve all problems upcoming within the Industry 4.0 like optimal AI methodology utilization or Plug-and-Play of production system resources. But it shows huge potentials to be widely applicable within industrial practice as discussions with industrial partners about improved engineering data integration for example within the AutomationML association suggest.

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