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Adaptive and Dynamic Feedback Loops between Production System and Production Network based on the Asset Administration Shell

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Abstract

In production networks, production must run efficiently across company boundaries. Companies must be able to react quickly as a single unit. Two trends are influencing this situation: On the one hand, the progressing servitization leads to the increased offering of digital services in the field of manufacturing. From the literature, it is known that digital services let manufacturers, suppliers, and industrial customers interact more closely and frequently in a production network. On the other hand, the concept of the digital twin is trending. It promises the real-time prognosis and control of production systems. Although the concept of the digital twin itself can be vague there are some technologies trying to implement the digital twin of production. The asset administration shell (AAS) is an example of such a technology that draws growing attention.

Picking up the initial situation these two trends could be used to create a feedback loop between the production system and network and thus improve the overall efficiency in production networks. Based on this idea, the paper first presents an approach to model systematically a possibility for a feedback loop orienting to the business model concept. Second, a reference architecture is derived from the RAMI 4.0 standard. The specified reference architecture is the basis for the specific implementation. Third, a procedure is developed to implement a specific architecture. For implementing an architecture, the usage of the asset administration shell is assumed. Finally, the approach is validated in a use case from the high precision weight industry.

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Keywords: Dynamic Interaction; Asset Administration Shell; Servitization; IT Architecture; Production Network

1. Introduction

Classic value creation is currently transforming. While the focus had been on the manufacture of products in the past, today the importance of digital services related to value creation is growing [1,2]. This Transformation is called servitization [3]. It is well known that digital services lead to a close relationship between consumers, manufacturers, and suppliers in a production network [4,5]. This relationship improves the data basis which can be used for production planning and control. An example are insights from a predictive maintenance service allowing the prediction of spare part demand.

At the same time, concepts like the digital twin are trending [6]. The digital twin allows real-time prognosis and control of production system behavior [6]. This way tailored supply and quick responses to order volatility or disruptions are possible. For example, with an order request, the cycle time can be calculated precisely in a matter of seconds detecting bottlenecks before they strike. A promising technology in this context could be the BaSyx software development kit (SDK) which was created as part of the BaSys 4.0 initiative [7]. BaSyx implements the asset administration shell (AAS), a standard developed by Platform Industrie 4.0 [8]. The concept of the AAS is intended to make a wide variety of software systems and hardware (referred to as assets below) digitally available in the sense of a digital twin and to connect them with each other.

Now, the core idea of this paper is to integrate both trends closely creating a feedback loop between the production system and the production network. This feedback loop works as follows: Following the last two examples, the predictive maintenance data can be used to predict the demand for spare

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parts, but at the same time a bottleneck is predicted by the digital twin for the future. By connecting both streams an incentive can be provided, e.g. a discount, for buying spare parts earlier. Alternatively, spare parts can be made to stock as long as the production system has free capacity. Ultimately, this could improve the overall efficiency of production networks.

Now, the question arises of how a viable feedback loop can be created. To answer this question an approach is presented taking the perspective of a manufacturer utilizing AAS. To reduce the complexity of such a project it would be necessary to first limit the focus on a viable idea for harmonization, e.g. predictive maintenance and spare parts. Therefore a value proposition must be defined as a first step limiting the complexity of the project. Further, it would be necessary to identify the involved customers and stakeholders. It is then advisable to challenge the project cost against the value created for these customers and the resulting long-term profit. Within these boundaries the actual feedback loop architecture can be implemented. These thoughts match with the components of a business model (value proposition, customer, revenue model, and value chain) and are based on [9]. Therefore, these four components serve as an orientation for the approach later.

The further content is structured as follows: First, the basics of production systems, servitization, and the AAS are presented (chapter 2). Then, a reference architecture and an approach is developed to derive a necessary IT infrastructure including preliminary consideration of customers, value proposition, and revenue model (chapter 3). Further, the approach is evaluated within a use case in the field of high precision weight production (chapter 4). Finally, a summary and outlook are given (chapter 5).

2. State of the Art

2.1. Production System and Network

A production system organizes the production [10]. It comprises all elements that are linked with the aim of working and processing materials or that are linked organizationally in this context to perform a production task efficiently [11]. The planning and organization of production are also carried out within a production system [10]. Typically, a production system is restricted to one physical location (a site) [5]. Nowadays, production takes place in production networks [12] and is therefore characterized by distributed sites connected by material, financial and informational channels which all have their own production system [12].

2.2. Servitization, the Role of Data Based Services, and the Business Model

As stated in the introduction, servitization changes the structure of cooperation between the manufacturers and their partners in a production network [1,2]. Through autonomous interaction and data exchange between all network participants, efficiency can increase significantly [2]. Digital services are the core concept of this transformation process. They are defined by the fact that they process data collected on physical assets or processes and deliver added value through the intelligent and customized provision of information via a digital channel. The provision of digital services leads to digital networking of the players in the production network [13].

From a research perspective, digital services bring together business management and information technology (IT). Therefore, when implementing digital services, both fields must be integrated. The IT defines a service as an artifact realized by software to provide functionality [14]. From a business management view, services are defined by different properties like intangibility and can be modeled by a business model [15]. A business model consists of four components: the value proposition describing what is offered to the customer and how that provides value, the customers who will be targeted and served, the revenue model defining how the company will generate revenue and financial profit, and the value chain providing information about the company's processes, resources, and capabilities which will build and distribute the value proposition [16].

From an IT point of view, service-oriented architectures are established for the implementation of industry 4.0 (I4.0) solutions in particular when coordinative or collaborative aspects are relevant [17–20]. The integration of a business management view at the same time is not common in the context of I4.0 solutions. Mostly, only one view is considered at a time. As a conclusion for the implementation of dynamic interactions, a consideration of both fields is crucial.

2.3. The Asset Administration Shell and BaSys 4.0

To address the requirements of I4.0, an infrastructure for bi-directional information flow via standardized communication interfaces is also mandatory [21]. The BaSys 4.0 initiative enables this information flow by providing an open-source SDK called BaSyx [22]. The BaSyx SDK supports the I4.0 requirements indicated by reference architecture models such as the Reference Architecture Model Industrie 4.0 (RAMI4.0). For example, requirements such as interoperability, flexibility, real- and non-real-time communication channels are covered [22].

AAS is the key technology and the common information model of BaSyx. Therefore, it plays an essential role in ensuring the data collection and standardized data transformation. The AAS provides a link between the cyber and the physical world by enabling users to create digital twins of their production systems and assets [22].

The AAS is defined by [23] and structured as follows: It consists of a header and a body. The header contains all relevant information about the identification and designation of the asset and its AAS. The body contains the core information about the assets and therefore takes the role of the data medium. There are various elements that the body can contain, the most important ones are sub models, sub model element collections, and properties. One AAS can contain multiple sub models and each sub model describes one aspect of an asset whereby one sub model can again contain many sub model element collections and also multiple properties. Properties are the lowest part of the hierarchy and can't contain further elements. Properties hold data like text or numbers.

Now, that the relevant state of the art is given, the approach is described next.

3. Concept for Creating a Feedback Loop between Production System and Network

From here on the perspective of a site is taken providing products and services to customers. The goal of the concept is to create a viable feedback loop between the production system of the site and the production network as described in the introduction. As described in the introduction, the business model components customer, value proposition, revenue model, and value chain serve as orientation.

3.1. Value Proposition and Revenue Model

The approach starts with the idea of a feedback loop between the production system and network. The feedback loop can be motivated by the production system (resource view) or the provision of value to partners in the production network (market view). Exemplary improvements can be a higher capacity usage (resource view) or a customer individual delivery time (market view). If the idea is the improvement of the production system, it is allocated in the revenue model. If the idea is market-based, it is allocated in the value proposition component. As a source of inspiration, the 55 business models from [24] can be used giving multiple options. So first, the models which are not suitable should be eliminated. Possible criteria are the applicability in the context of the business model, the suitability, and the practicability in terms of the necessary organizational and technological implications. For example, if the performance of an interaction is difficult to measure, the revenue model should not be based on the performance.

3.2. Customer and Stakeholder

Parallel to forming the value proposition and revenue model, it is necessary to think about the customers or partners with whom to interact with. Typically, the partners originate from already existing business relationships, which can be the source of improvement. Historic data about orders can be used to analyze the customer segments and to create customer clusters. To evaluate the value proposition, we suggest integrating partners during the development regularly. For this purpose customers representing their cluster can be interviewed.

3.3. Value Chain pt. I: Introducing a Reference Architecture

After the first idea for value proposition, involved customers and revenue model is set, the value chain comes into focus. The best solution would be a general architecture fitting any feedback loop project. Although there is no universal architecture for such a purpose, it is possible to identify recurring components. This idea is already present in well-known reference architecture models like the RAMI4.0 [22,25]. RAMI4.0 is already specialized for the production context. Starting with the layer concept of RAMI4.0, an adapted reference architecture is developed using eight requirements, which are derived in the following: The central function of the targeted architecture is the mapping of interactions in the network. For this purpose, at least two entities marked by system borders must be displayable (I). In this context, the entities are equivalent to the production systems. Within the production systems, assets, as well as people, are relevant for the interaction (II). Although people and assets can belong to different production systems, they share a common environment (III). In order to interact with each other, people and assets need to be integrated into a common IT system consisting of a network, functions and a business logic (IV). The architecture must take care of data (information) separated into private and public (V). This requirement is already fulfilled by the RAMI4.0 layers. The goal of the architecture is to enable interactions by providing necessary functions like data preprocessing, decision support, automation and communication. These components must be integrated (VI). The core principle behind the interlinkage of production system and production network is identified as the incentive of the different actors to participate. On a production network level, business aspects jump in – another reason why using a business model previously as a framework is helpful. The different systems more often interact at eye level because they incorporate distinct companies with each other and have their own decision power. This aspect needs to be considered in the architecture as well. It should be located in the business layer (VII). The last but optional requirement is compatibility (VIII). In literature, it was shown that established architectures are compatible with RAMI4.0 [26]. By maintaining the core logic of RAMI4.0, the new architecture can fulfill this requirement as well. The resulting architecture model can be seen in figure 1.

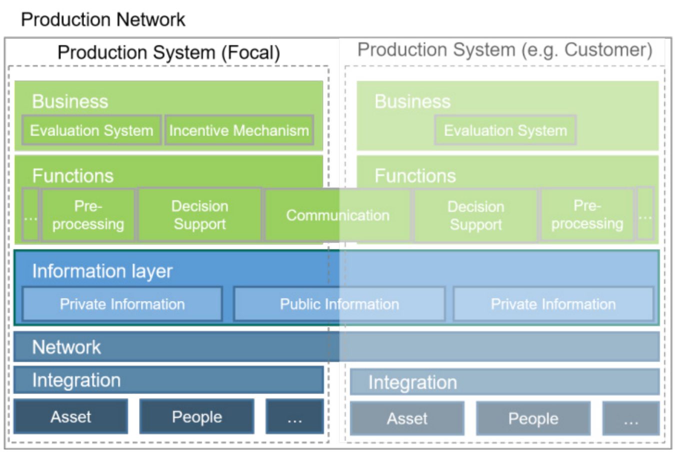

Figure 1 Adapted Architecture for Interactions between Production Systems

3.4. Value Chain pt. II: Derive a Specific Architecture

Now, the next step is to derive a specific architecture based on this reference architecture. For this purpose, all involved assets for the proposition of value must be listed. This list will not be finished directly but grow over time during further detailing. Assets can for example be machines, software or computers - Anything that can be named.

This list helps to deviate process and architecture models. The process and architecture models help to get a clear vision of how the project can be implemented. The process and architecture models can be generated in two ways. Either the model of the solution is designed or the model of the status quo is captured first. The models are interdependent: Normally, it is not possible to create the value chain from scratch. Rather, the value chain is created by adapting already existing processes and assets. On the other hand, it can be important to break away from existing structures.

For the modeling itself, we recommend the usage of a standard model library like the Unified Modeling Language (UML) suitable for the task [27].

The resulting models give us two insights. First, it is recognizable which functionality and which information the assets need to provide to whom by checking the solution process model. Second, the change needed to accomplish functionalities and information provision is clear by comparing the solution process model with the status quo process model. These new change requirements should be listed for each asset. The asset requirements list is the foundation for the design of the asset administration shells in the next section.

3.5. Value Chain pt. III: Develop the Necessary AAS and Software

The development process should be structured by the value proposition of the assets to get an implementation roadmap as it becomes clearer what assets and functionalities are needed during implementation. Otherwise, unnecessary effort is created. Based on the asset list from 3.1.2, the assets can be evaluated and the most important assets can be chosen to start with.

The development of the AAS should be done iteratively. It is recommended to use a tool like the AutomationML Editor to model the AAS as it will support the implementation using the BaSyx SDK later on [28]. AutomationML creates aml files but can also export to XML. In the standard edition, templates for the modeling of AAS are missing. But a library called 'Asset Administration Shell Representation Library' provides a template for content modeling of the AAS, containing the required attributes for each sub model element [29]. The focus should be to develop an MVP AAS that represents the most important functions and data of the most important asset. In further iterations, more assets can be added and the model of each asset can be enhanced and improved.

After the first initial development and deployment of the asset, the whole system architecture can be tested and evaluated. Once there is a working system architecture and a solid ground structure, it is less complicated to enrich the AAS with further sub models or properties.

4. Application of the Model in the High Precision Weight Industry

To evaluate the presented approach, a use case from industry is raised: In the production of high-precision products, it is necessary to calibrate weights and provide a corresponding calibration certificate. Up to now, this calibration certificate has been issued and sent in paper form. In addition to the physical administrative burden of the calibration certificate, the weights must be recalibrated from time to time to ensure that the tolerance of their class is maintained. Past calibration certificates are used for the extrapolation of the weight drift and, thus, the next recalibration date. In the context of the use case, the complete interaction between manufacturer and customer regarding weights and calibration shall be digitalized. This is the basis for further services, e.g. an automated calibration planning service.

4.1. Applying the Business Model Logic

First of all the value proposition is defined: In the future, a platform should provide the data and offer a way for the customer to easily check all his previous calibrations and print them out on demand. This way, the management of calibrations is simplified for the customer. Additionally, the customer can plan the recalibration of weights and receives discounts if he sticks to proposed calibration schedules. Last but not least, the customer will also be reminded about upcoming calibrations. As a result, the customer doesn't need to worry about missing a necessary calibration.

The revenue model is as follows: Based on the insights from the calibration management and planning system, calibration scheduling shall be optimized to utilize capacity in an optimal manner. This way, the capacity utilization increases, the delivery time decreases and more customers can be handled.

Using the historic order data, the customer groups were analyzed. The most important customer groups based on the number of orders and the revenue for the re-calibration of weights are the three branches 'calibration laboratories', 'automotive' and 'packaging industry'. Typical representatives of the three branches were chosen for validation during

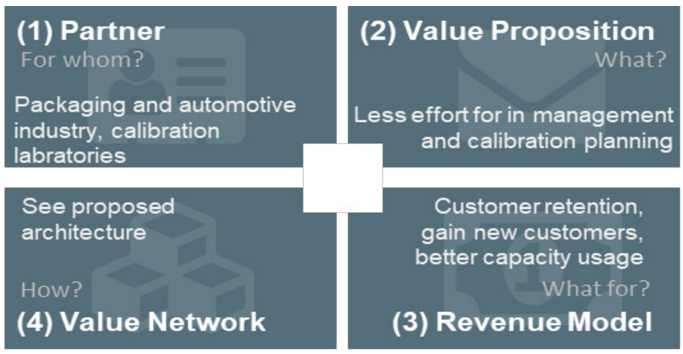

Figure 2: Overview of Initiative Structured by the Business Model Logic

implementation. For an overview of the resulting business model representing chapter 3.1 to e.2 of the approach see Fig. 2.

4.2. Derive a Specific Architecture

After having defined the value proposition and revenue model, it was possible to derive the process model and architecture.

Figure 3 shows the developed process model and architecture with its assets. It shows how data is retrieved from the asset database and transferred to the Web Portal using the AAS as a standardized format for the data transfer. The necessary components can be seen in the figure. The main component is the "Program". Based on a date contained in the temporary memory, it can check for and request new calibration certificates through a SQL request (1.-4.). It then uses the returned data to generate multiple AAS. After that, the AAS will be serialized as a JSON to send them via HTTP/REST to the database of the web portal (5.). If and only if the database returns a success message to all HTTP pushes (6.), the date will be updated in the temporary memory (7.). After saving the date, this cycle repeats.

On the web portal site, the AAS are deserialized and the data is saved in a SQL database. The web portal can access and display the data stored in this database. This allows customers to access and manage their calibration certificates online.

4.3. Develop the AAS and Software for the Use Case

From the list of all assets in the context of the described value proposition, the following were identified as the most important and implemented so far:

- Administrative Data: contains all information about the identification of a weight set, such as the identification number, descriptions of the weight set or information about the manufacturer
- Customer Order: contains information about the order, such as the order number or information about the customer.
- Calibration Plan: contains all relevant calibration information such as information about the calibration method, the calibration date, the calibration number or administrative metadata, e.g. information about the calibration laboratory.
- Calibration Certificate: contains the calibration certificate in standardized formats as PDF, JSON and XML files. These file formats can be integrated into the AAS as a BLOB.
- Weight: contains the relevant data and specifications of a single weight. It is the most comprehensive model of this AAS. The other AAS consist of data from a weight set, while this AAS provides weight-specific data. It covers all information about product description and measurement results.

  The resulting aml files can be found here: [30].

5. Summary & Outlook

In this paper, an approach was shown to create a feedback loop between the production system and network from the perspective of a manufacturer utilizing the concept of the asset administration shell. The approach is based on the business model components value proposition, customer, revenue model and value chain. These components provide a boundary for implementing the value chain The value chain is forming the main part of the approach handled as being identical with the IT architecture. Here, a specification of RAMI4.0 was created to provide a reference architecture in the context of this work. Further, necessary steps to derive a specific architecture and AAS were described. The whole approach was applied to a use case in the high precision weight industry.

Although the approach works for the use case shown so far, not all parts could be validated. For the full validation, a dynamic planning and discounting system is planned to interact with customers of high precision weights – compare chapter 4.1. This system has not been implemented, yet. Therefore the full potential of the approach was not assessable and will be part of future work.

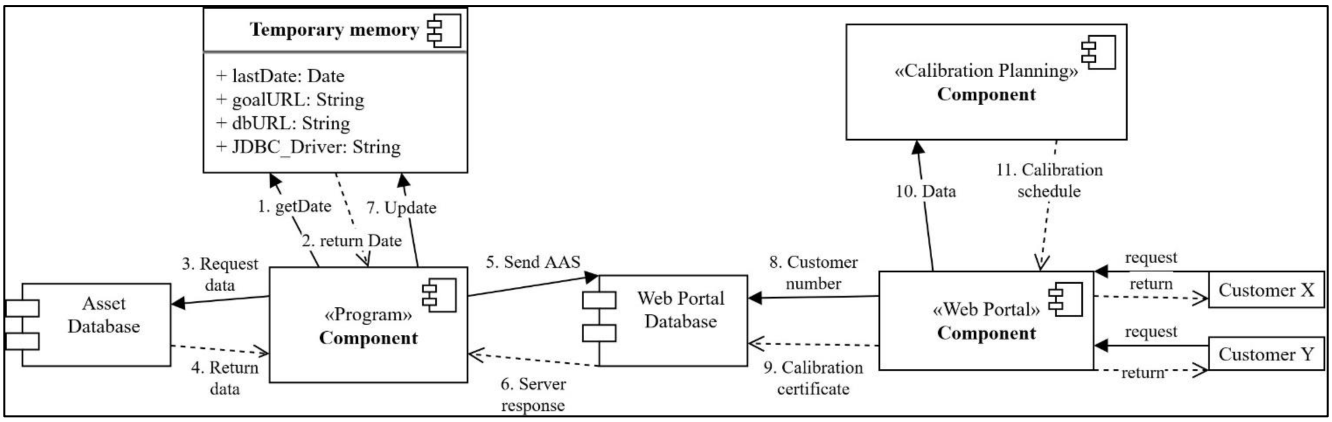

Figure 3 Architecture of the Use Case

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