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VALUE CHAINS AND DIGITIZATION OF PRODUCT DEVELOPMENT PROCESSES

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Abstract

Currently, the digitization of value chains in the industrial context is intensively researched upon and discussed in engineering science. In the beginning, the scientific discourse was mainly technically driven. Soon, it became evident that the efforts for digitization may not only be economically justified by rationalization of processes, but that new business models, better products and types of services could benefit from these techniques. Consequently, research evolved into the direction of value chains and business models that could be improved by digitization. Possible improvements are individually designed products to better match customer requirements and new digitized types of services that go along with the use of cyber-physical systems (CPS) as products. Recent studies predict huge economical benefits, both for national economies and for businesses. An aspect of this development to be considered is the full digitization of the product development. This paper tries to give an practical approach how digitization of product development should take place.

Keywords: Product Lifecycle Management (PLM), Organisation of product development, Systems Engineering (SE)

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1 INTRODUCTION

Major trends in the development of physical products include globalization of customer driven markets with higher grades of product complexity and shorter times to market (i.e. see Feldhusen and Grote (2013), pp. 5-10). A major driver of product complexity is the individualization of products to better match customer needs (i.e. see Bauernhansl et al. (2014), p. 13). Numerous approaches, such as open innovation (Chesbrough (2003)), frugal innovation (Radjou and Prabhu (2013)) or disruptive innovations (Bower and Christensen (1995)) deal with the identification of customer requirements. The increasing complexity of the customer requirements leads to increasing complexity of products and production processes. Many approaches do exist that try to find an optimal inner complexity of products and processes to match the required outer complexity (Bauernhansl et al. (2014), p. 14).

Digitization of industrial production as part of industrial value chains aims at introducing the smart factory, where cyber-physical system (CPS) as smart products are manufactured by cyber-physical production system (CPPS). Soon, new individualized autonomous production techniques will be available (Plattform Industrie 4.0 (2015)). How may product development make the most out of this opportunity using digitization?

To answer that question, an approach presented by Ahrens based on systems engineering is used (Ahrens (2014), Haberfellner et al. (2012)). The situation analysis shows current research on the digitization of industrial processes and on customer individual product development processes. On that basis, research questions are derived. A setting for a product that might benefit from the digitization of industrial value chains is presented as an example to derive the requirements for the digitization of the product development process.

2 SITUATION ANALYSIS

2.1 Industrial Value Chains and Digitization

The most prominent aim of all product development activities is to provide customer benefits in order for a company to raise margins, usually ensured by a product planning cycle as described by Feldhusen and Grote (2013), p. 301, or Ehrlenspiel and Meerkamm (2013), p. 163. The product planning documents the types of technologies, products and services required to fulfil the business model. As digitization offers new types of products and services by the use of cyber physical systems (CPS), for details see Bauernhansl, ten Hompel and Vogel-Heuser (2014), researches have set up a framework for the design of business models that benefit from these new technologies.

The VDI/VDE Gesellschaft Mess- und Automatisierungstechnik (2014) defines industrial value chains that fit industrial digitization. These value chains are part of the product life cycle:

- the value chain “product development”, consisting of product development, product line planning, product line management and product discontinuation,
- the value chain “process development”, consisting of process development, production engineering, maintenance procedures and discontinuation,
- the value chain “production and after sales”, consisting of production, product use, after sales services and disposal and
- the value chain “technical equipment”, consisting of erection of equipment, industrial production (use of equipment), maintenance of equipment and disposal of equipment.

These value chains may connect to each other within a company and its customers or may connect different companies, businesses and services. The digitization of these value chains may lead to horizontal and vertical integration of processes (in the sense used by automation technology) and market places of production services (see Bauernhansl, ten Hompel and Vogel-Heuser (2014), p. 40).

Later on, the same organization (VDI/VDE Gesellschaft Mess- und Automatisierungstechnik (2016a)) uses this approach of value chains to identify requirements of engineering data to fulfil product development needs for digitization along certain value chains.

Parallel to this research, the German consortium Plattform Industrie 4.0 (2015) published a framework for the standardization of industrial digitization, RAMI4.0 (Referenz Architekturmodell Industrie 4.0 or reference architecture for industry 4.0), see Figure 1. This standard is based on different approaches to communication (for example OPC UA), product description (for example eCl@ss) and integration. The aim of this effort is to identify existing standards, which may be used to digitize value chains, see where

new standards are required and to give a structure to the different aspect of digitization. The model uses three dimensions: layers, hierarchy levels and life value stream.
The dimension “layer” describes the business levels of a value chain. The top layer is the business layer, where the business models and legal restriction are defined. Beneath the business layer, the other layers are the functional layer (business processes), the information layer (rules and data), the communication layer (communication standards), the integration layer (the IT infrastructure) and the asset layer (the physical objects).
The life cycle of products (development of products, their production, use, maintenance and disposal) is modelled in the dimension “life cycle”. The dimension “hierarchy levels” describes the vertical integration in automation processes. It consists of the product itself, the field device, the control device, the station, the work units, the enterprise and on top the connected world. The idea of RAMI 4.0 is, that due to this three dimensional description, all aspects of digitization may be identified.

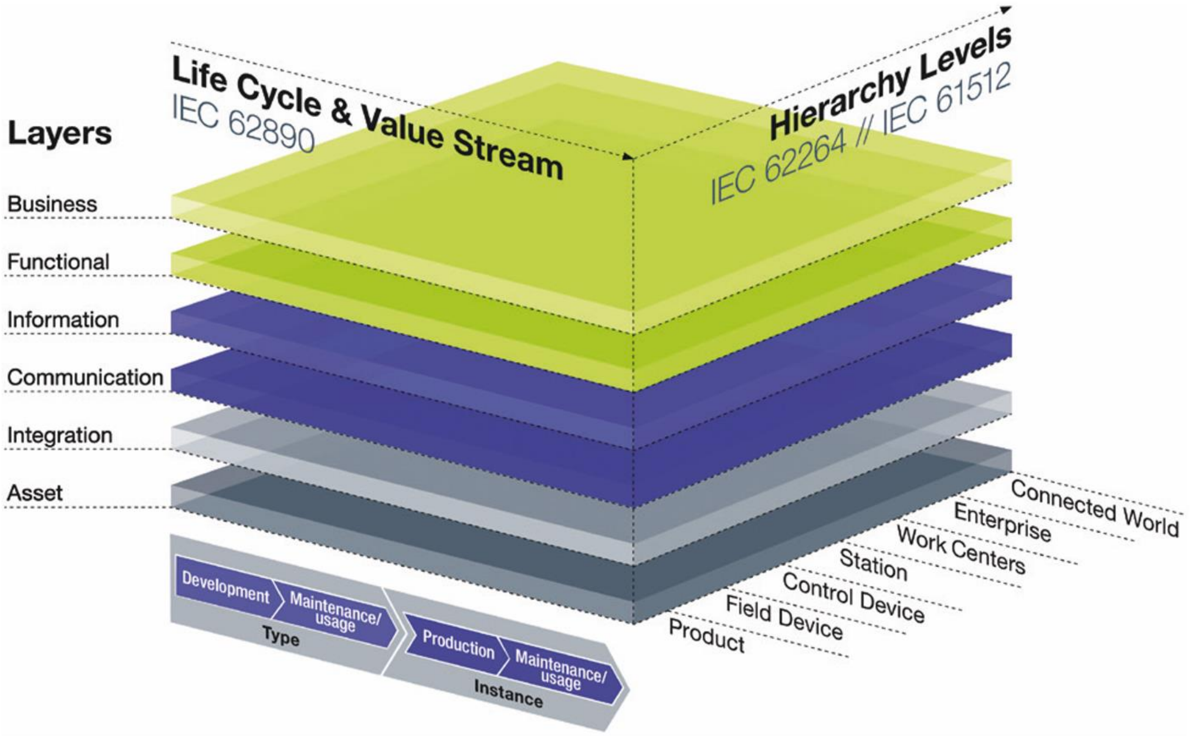

Figure 1. RAMI4.0 (Plattform Industrie 4.0 (2015), p. 43)

2.2 Business Models for Digitized Value Chains

Building on this approach, the VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (2016b) sets up a business model development canvas based on the business model canvas of Osterwalder (2010). The business model canvas is extended to the view of business eco systems such as the above mentioned value chains. In VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (2016b), the "VDI Industrie 4.0 Canvas" is described. This canvas consists of four major dimensions:

- the added value of each partner of the value chain,
- the relevant ability to provide this value for each partner,
- the reliability of each partner to provide the service and
- the ability to integrate into the value chain.

Each partner in the value chain may now check for the value of his contribution to the new business model and his ability to provide the service.
All these approaches are rather theoretical. Few practical applications exist (see i.e. Meussen (2015)): academic examples often cover rather simple products and do not consider business models, industrial examples are often funded by companies from the automation industry to promote digitization of processes and are restricted to production needs. Recent studies, as, for example, presented in Manzei et al. (2016), show that companies are reluctant to invest into the necessary infrastructure for digitization

as the outcome seems uncertain. However, many studies, such as Aharon et al. (2015), clearly show the expected benefits of digitization for modern businesses.

2.3 Product Development Processes for Individualized Products

The classical product development process for mass production finishes the design activities with the release of the product for series production (Feldhusen and Grote (2013); Ehrlenspiel and Meerkamm (2013)). Baumberger (2007) gives an overview of the possible customer individual product development processes. Lindemann proposes that customer interaction is required if customer individual design processes are to be incorporated into the process of ordering and production (Lindemann et al. (2006), p. 13).

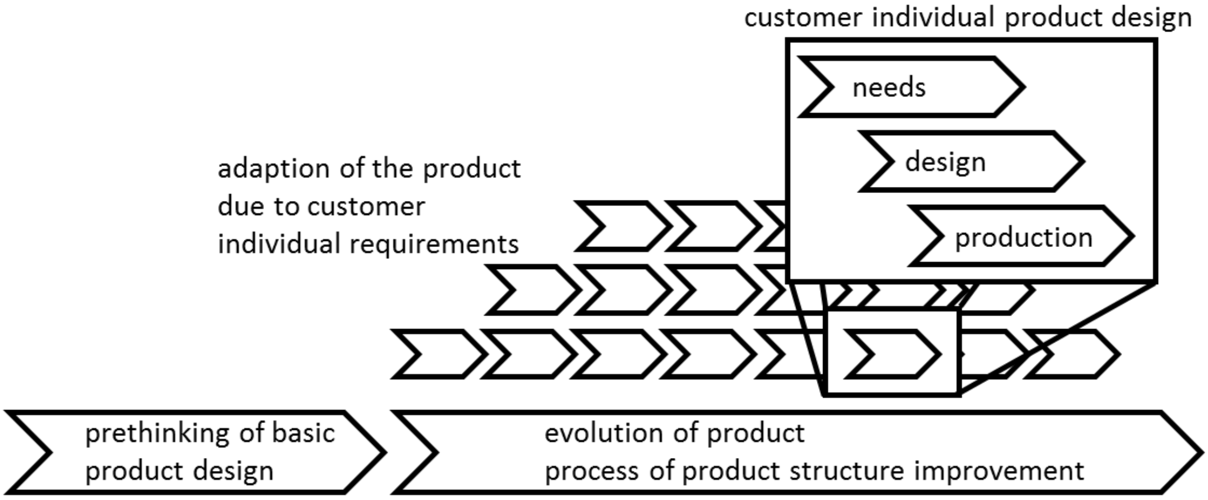

Figure 2. Individualized product development (Lindemann et al., 2006, p. 13)

3 RESEARCH QUESTION

As stated in brief situation analysis above, the most prominent task of product development lies in the ability to provide a product that satisfies the business model. Thus, the business model has an enormous impact on the product development process. Furthermore, the combination of mechanical and electrical engineering and IT has an influence, as well as normative requirements. A weakness of the theoretical framework, for example the RAMI4.0, might be the broadness of the approach. From the investigations of the complex development of customer individual products, it is well known, see for example Baumberger (2007), that feasible solutions for the appropriate definition of product development processes may successfully be achieved by generalization of practical examples. In order to set up a framework for the examination of the requirements for the successful digitization of the product development, the following research questions are derived:

- Which business model and what type of product may benefit from a fully digitized value chain?
- What processes, models and data are required to describe this type of value chain?
- Which means are necessary to digitize the product development?

4 EXAMPLE BUSINESS MODEL

One of the strengths of the new business models using digitization of product life cycles are, according to Bauernhansl et al. (2014) and VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (2016b), individualized products. The most obvious reasons for customer individual products in a B2C business surely are individualization due to biometric features, personal taste and individual functionality.
Using appropriate creativity tools, a business model has been identified which could cover all three of the abovementioned aspects (for details: see Böttcher et al., 2016). The products used are electrical components like light switches or power sockets for the home use. These products cover typical aspects of customer individual products. They are subject to biometric features, are chosen by customers according to their personal taste, also consist of standardized components (i.e. the mechanical and electrical parts that are not visible) and are subject to individualized functions in the context of smart

homes, thus giving the possibility to extend in the direction of smart products. The business model proposed is set up in do-it-yourself stores (DIY-stores), similar to equipment to choose individualized painting colour, see Figure 2 using the VDI 4.0 canvas according to VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (2016b).

In this setting, the customer wishes to buy an individual light switch with an individual frame and an individual switch pad, for example to symbolize the floor plan and the position of the lights or to match the architecture of the building. The customer accesses the DIY-store using the shop (or the internet) and either describes his idea to a trained sales person who sketches the individual design in a CAD application or the customer uploads his design. The DIY-store processes the order and orders the electrical parts, which are standardized, at the manufacturer's site. The manufacturer is responsible for the design of the product, he is the owner of the product development process to be digitized. The DIY-store furthermore sends the STL-file to an additive manufacturer who produces the individualized parts according to the customer's ideas and the adoption made by the sales person in the DIY-store according to the specifications of the switch manufacturer. As soon as all parts are produced and send to the DIY-store, the customer may pick up the switch, make the payment and mount the switch in his home.

The Industrie 4.0 canvas serves to describe the business model and the value created by each member of the model. This model is then, according to VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (2016a), to translated to the value chains and their network depicted in Figure 3. The value chain network now gives all the chain links that are necessary to fulfil the business model. Here, the complete product life cycle may be found and all links in the chain network are subject to digitization, for details see VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (2014) and (2016a).

Specific features of this value chain network are the bidirectional interaction of the customer with the DIY-store (a), the bidirectional connection of the DIY-store with the switch manufacturer (b) and the additive manufacturer (c) and the link between the switch manufacturer and the additive manufacturer (d). In this setup, the relevant product development process lies in the responsibility of the switch manufacturer, as stated in the business model.

5 REQUIRED DATA TO DESCRIBE VALUE CHAIN LINKS

With the value chain links identified, it is now possible to define the required data to digitize the complete product life cycle. As the switch manufacturer is the responsible entity in this value chain network concerning product safety, his product development process, due to common legal restraints (see for example the European Machinery Directive, European Parliament (2006)), should also be responsible for setting up the data of the complete value chain network.

In VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (2016a), the required engineering data for several value chain links are described. Furthermore, it is obvious, that due to the level of detail, the thoughts presented here are restricted to the top "hierarchy levels" of the RAMI4.0 presented above, especially the hierarchy levels "work centers", "enterprise" and "connected world". The dimensions "life cycle and value stream" and "layers" are covered for these hierarchy levels.

Table 1 shows a brief overview of value chain links and examples of typical data used. For the sake of briefness, only the specific data requirements according to the new features of the business model will be further discussed here.

With the bidirectional connection between the customer and the DIY-store (link (a) in Figure 3), the customer and the DIY-store exchange information on the electrical type of the switch, its price and the customer's individual shape of the switch. In the DIY-store, a trained employee digitizes the design in the framework of the specifications of the switch manufacturer. He then orders the standardized parts according the type of switch chosen at the switch manufacturer's site (link (b) in Figure 3) or takes them from the store's stock. He furthermore sends the STL-file he derived from the design model to the additive manufacturer (link (c) in Figure 3) and orders the individualized parts. As soon as all parts are in stock of the DIY-store, the customer is notified to pick up the parts or the parts are send to him. Technical requirements for the individualized parts are specified by the switch manufacturer and are input to the process development of the additive manufacturer, for example concerning the type of material to be used in additive manufacturing.

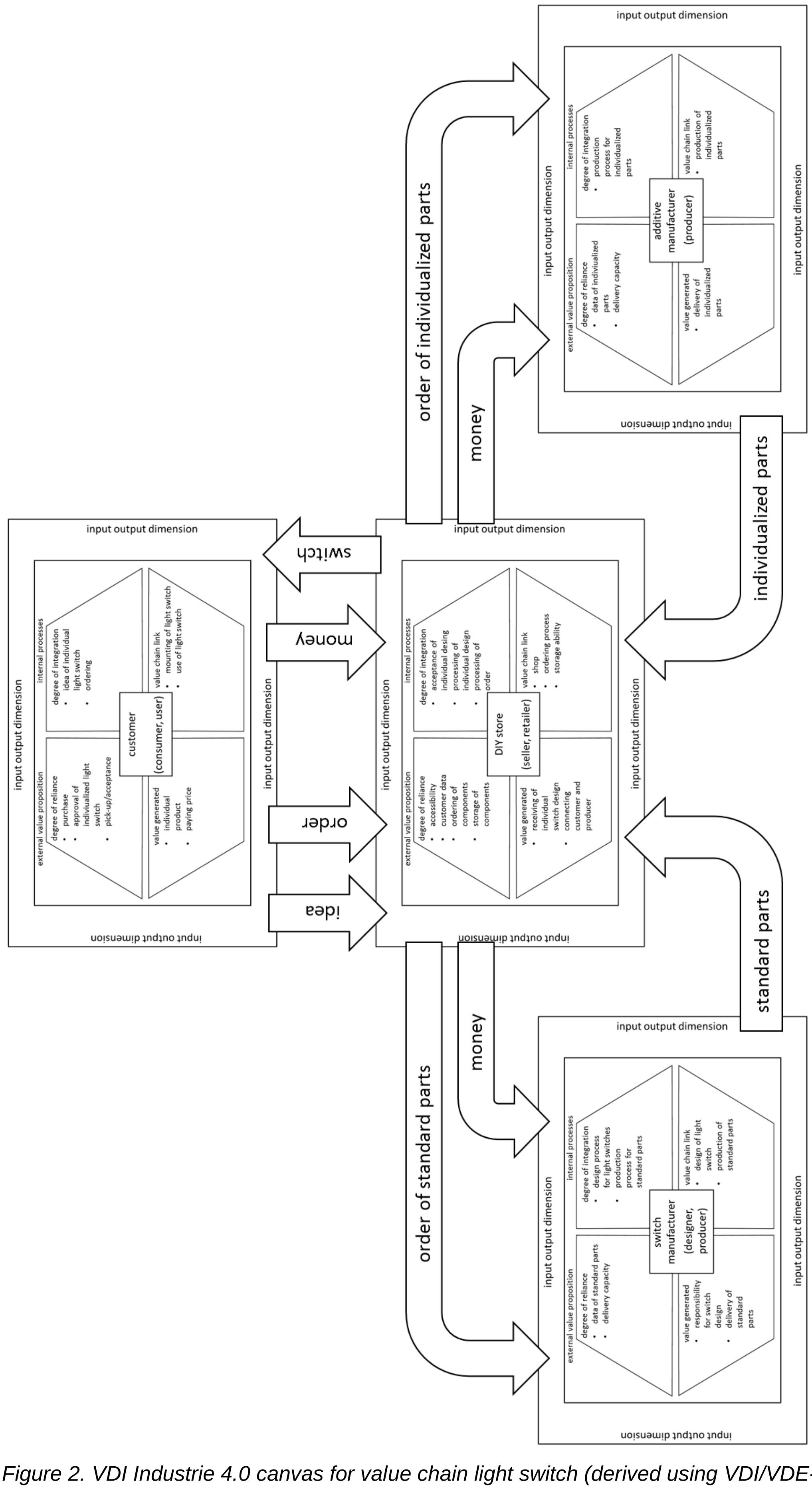

Figure 2. VDI Industrie 4.0 canvas for value chain light switch (derived using VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (2016b))

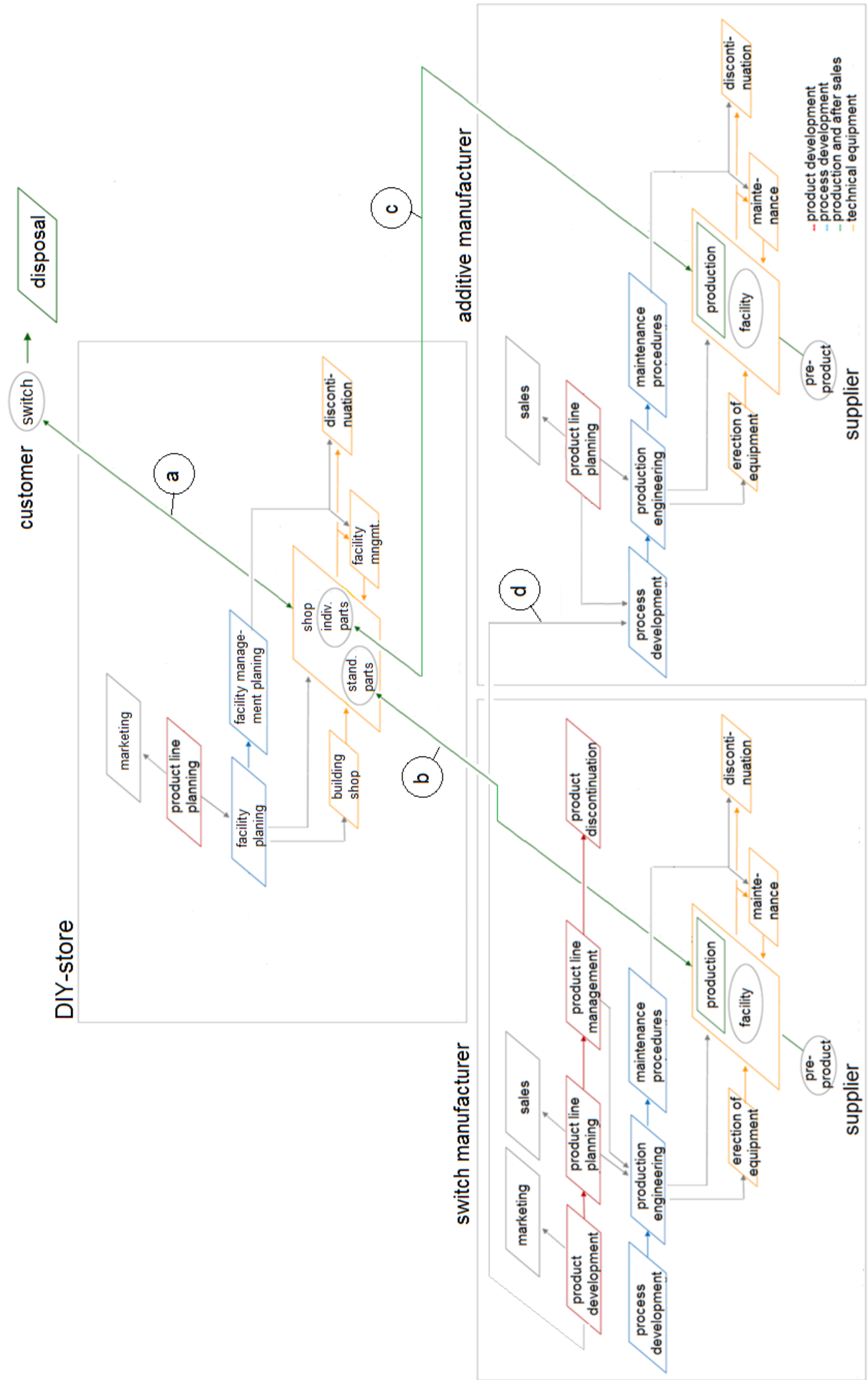

Figure 3. Value chain network of example business model (derived using VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (2014))

Table 1. Value chain links of example business model

value chain link	required by customer	DIY-store	switch manu.	add. Manu.	typical data
switch (product)	X	X			identification number user manual
disposal	X				recycling data
marketing		X	X		pricing product features, USPs
facility planing		X			shop requirements storage size
facility management planning		X			shop requirements
building shop		X			shop requirements storage size
shop					shop requirements storage size
standard parts		X	X		identification number pricing lead time
individual parts		X		X	identification number STL-Data pricing lead time
sales			X	X	pricing
product development		X	X	X	standardized feature individual features product specification

value chain link (cont.)	required by customer	DIY-store	switch manu.	add. Manu.	typical data
product line planning		X	X	X	business data
product line management			X		business data
product discontinuation			X		business data
process development			X	X	technology data machinery data
production engineering			X	X	production data work plans quality data
maintenance procedures			X	X	machinery data production data
erection of equipment			X	X	technology data machinery data
production			X	X	production data work plans quality data
maintenance			X	X	machinery data production data
discontinuation			X	X	technology data machinery data
supplier			X	X	product specification commercial specification

From the point of view of the customer, the trained sales person at the DIY-store has all the knowledge to judge if the customer's individual design may be realized and may check if the final product still fulfils the specifications set up by the switch manufacturer and may safely be operated when mounted at the customer's home. Basically, the product development for the individual product is distributed between three partners (customer/employee - switch manufacturer - additive manufacturer) and does not take place within the framework of the classical product development process as described by Ehrlenspiel and Meerkamm (2013) or Feldhusen and Grote (2013) of the switch manufacturer.

6 DIGITIZATION OF PRODUCT DEVELOPMENT PROCESSES

According to Alt (2012), pp. 1 ff, model based systems engineering is a suitable tool for complex, distributed development processes. Product safety for the individualized product also requires a modelling approach (see Bauernhansl et al. (2014), pp. 433 ff.). Expanding the example business model to more complex products, for example by considering a smart switch (see above) by adding an embedded system to the switch, makes it even more feasible to consider model based systems engineering by using SysML (System Modelling Language) as defined by the Object Management Group (2015). SysML provides appropriate means to define the specifications of a product, its structure and its behaviour on the basis of models.

Based on the system model provided by the switch manufacturer, the employee of the DIY-store who is setting up the design idea of the customer is now able to provide a ST-file leading to a safe and customer satisfying product (value chain link (a) in Figure 3). The switch manufacturer has ensured that his specification to cover his product liability are followed (part of value chain link (b)). The additive manufacturer can act independently from the switch manufacturer as long as he satisfies the system model (value chain link (d)). Changes of the product by the switch manufacturer are safely transferred to the other partner of the business model without transferring all data, because SysML provides views on the model. The switch manufacturer only allows the view of his partners on the model that are necessary to serve the business model. Thus, basic security requirements for data transfer may be satisfied.

With the procedure presented here, changes in the business model and the value chain network may more easily be applied. Figure 4 give s sketch of the example business model presented here and a variation of the value chain link. The customer now not only may change the design of the switch, but by using embedded systems within the switch (developed by the switch manufacturer), now may also define individual functionality. In that sense, the switch promotes to be a CPS. Now, an additional partner, the function programmer, uses a new view on the system model (grey boxes in Figure 4) to provide a software that again is covered by the specifications of the switch manufacturer.

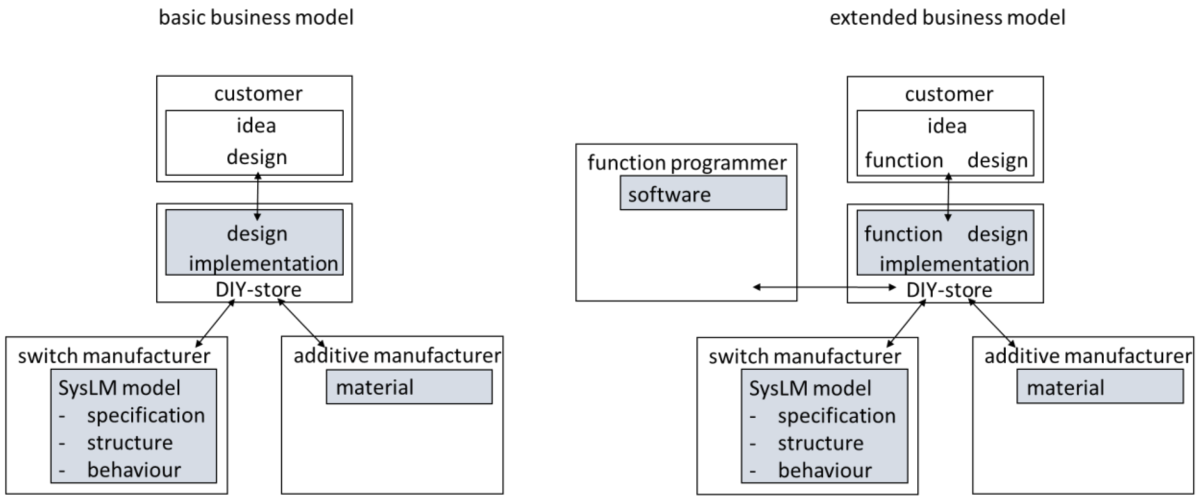

Figure 4. System model used in value chain network

Other changes in the business model and the network may provide direct access of the customer to the system model via internet to provide the implementation of the design and functionality himself. Also, the supply chain might vary if the DIY-store has the standard parts in stock and runs an additive manufacturing device in his store.

7 CONCLUSION

The digitization of industrial processes is still in the very beginning, at least if digitization is understood not only as automation technology with computers but as an opportunity for new business models and new products. It is expected that huge benefits might arise for businesses (see for example Aharon et al. (2015). However, the efforts to digitize a business model and consequently the product development to provide the basis of that digitization are high. This also holds for the complexity of the task. As theoretical approaches to solve the problem on a general basis are often not applicable for complex problems in product development management, an example business model to simplify the problem was chosen as a means to approach the problem: which information should be digitized in what way?

From recent research in the field of standardization of industrial processes and digitization of value chain networks and business models, this paper proposes the following procedure for the digitization of product development and the product life cycle:

- identification of the business model that determine the product (i.e. using VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (2016b))
- setting up the value chain networks which represent the business model (i.e. using VDI/VDE-Gesellschaft Mess- und Automatisierungstechnik (2014))
- identification of the value chain links which require parts of the digital representation
- derivation of the data required by the value chain links
- description of the product with all the required data using model based systems engineering (i. e. using SysML (Object Management Group (2015)))
- setting up the required views for the value chain links

Using this approach, businesses may find a path to more successful business models and improved products with better products and higher productivity. Because of the use of a business model canvas, business plans may be derived to check if digitization of the product development which extends current grades of digitization are economical feasible or not. After the analysis of the value chain links, missing grades of digitization may be identified. The use of model based systems engineering makes an effort to digitize a good basis for the future development of the business model and the product itself.

Currently, this procedure is adopted to the example business model presented here. First approaches in industry, for example the companies Schunk GmbH & Co. KG and Harting Technology Group as exhibited on the Hannover Fair in 2015 and 2016, show that the integration of the individual requirements of the customer needs in industrial production are increasing. Until now, the digitization of a value chain is restricted to products which might easily be adopted to customers needs from the point of view of the production and the product development. If products get more complex, the efforts and the benefits of digitization might increase rapidly. This paper tries to sketch an approach to manage the decision to digitize and the way how to do it from a need driven perspective rather than from a technology driven perspective.

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