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Integrating product characteristics into extended value stream modeling

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Abstract

Product characteristics, e.g. the amount of material used or the number of parts, can have great influence on processing times, setup times, and lead times, as well as costs in production. Unfortunately, detailed information about interdependencies between the product and its production is often not available within the product development phase. Developers are not fully supported in considering the impacts of different design options on manufacturing objectives. This paper addresses the linkage of product and process design by proposing a value stream based modeling approach for manufacturing information. The approach is exemplarily applied on the manufacturing of PCB.

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1. Introduction

Manufacturing companies face diverse challenges such as global procurement markets and international competition, individual customer demands, as well as rapid technological progress and shorter product life cycles. These challenges force companies to develop innovative and specialized products in order to stay competitive while the complexity of products and manufacturing processes, the required product variety and customization, quality requirements, as well as cost and time pressure have increased [1, 2]. This is in particular true for mechatronic products which combine the disciplines mechanical engineering, electrical engineering and information technology into one system. For these complex products it is essential to integrate domain specific expert knowledge in the development of products and manufacturing technologies [3].

Design decisions have a great influence on the product's life cycle performance, for example on manufacturability, assembly feasibility, energy consumptions, and costs [2, 4, 5]. Errors made in early product development can cause up to 70 % of manufacturing costs [5]. This indicates the importance of considering available manufacturing capabilities and constrains as early as possible during product development and motivates the integrated development of products, manufacturing systems, and processes [6, 7, 8].

Unfortunately, in the development phase detailed information about the interdependencies between product characteristics and manufacturing process is often not available. And although developers take diverse rules of design for manufacturing (DFM) into account, product characteristics are not necessarily oriented to meet optimal process parameters. Especially if suppliers are contracted with the manufacturing it becomes increasingly difficult for product developers to have sufficient knowledge about the required and available manufacturing capabilities and the restricting parameters of processes and resources.

Increasing complexity of products leads to the involvement of suppliers early in product development projects [9]. Several studies have shown that the utilization of expert knowledge could result in higher product quality, shorter time to market, and lower overall costs [9, 10]. However, collaboration of

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decentralized participants in value chains makes development processes even more complex [3, 11]. Moreover, various barriers related to information sharing between companies, such as differences in domain specific development processes or software, make collaborative product realization difficult and inefficient [12]. These barriers require product developers to use new methods and tools, enabling them to benefit from collaborations. What is required in particular is an approach for product–process integration into early stages of the product development process.

Current research aims at developing a methodology and software that supports the goal-oriented information exchange, communication, and project coordination in multi-domain value chains for mechatronic products [12, 13]. In this context, a modeling approach is required for the management and integration of knowledge from the domains product and manufacturing. This paper presents a formal modeling concept supporting product–process integration for the later implementation in a software solution.

2. Background

2.1. Product–process integration and knowledge modeling

The concurrent engineering (CE) approach aims at the parallelization of product and process development to enable an early consideration of requirements. CE can be supported by Design for manufacturing (DFM) techniques which help product developers to assess manufacturability, select the best suited processes and resources, estimate manufacturing costs, and to avoid over-engineering as well as unnecessary iterations in the product realization process [5, 7, 14]. In the context of collaborative product development the integration of product and process development becomes more difficult [2, 11, 15]. The extended 3D-CE approach includes the dimension of the supply chain considering level of partnership, lead time, logistics, and risk. However, specific tools are not available for 3D-CE and no information is given about how it can help to establish product–process integration in a multi-domain collaboration [14, 15].

Knowledge and information about products and manufacturing have to be modeled in order to be shared. Implicit knowledge of people has to be transformed into explicit information models [16]. Different forms of models are used in different domains, such as computer aided design (CAD) models for product geometry, Gerber files for layout of printed circuit boards, value stream maps or petri nets for production sequences, and specification sheets for capabilities of machines. A universal modeling approach is required for the integrated development of products and processes and information exchange between partners from different domains. Such approach has to be able to model information about a product and its components, manufacturing operations as well as relations between components and manufacturing operations [2].

Previous research provides a variety of different models and modeling methodologies for engineering knowledge. An example is provided by Demoly et al. who give a good overview over existing integrated engineering models and ontologies for different applications in the context of PLM [2]. Shady explained methods for knowledge representation for factory planning [17]. Chen presented methods for knowledge integration and sharing in the collaborative molding product and process development [18]. Elgueder et al. introduced a product–process interface model to link manufacturing information to product characteristics [7]. Bonvoisin and Thiede developed a framework for the prediction of processing times and energy consumptions of manufacturing operations related to specific product designs [19]. Umeda et al. developed a CAD tool for life cycle design which supports developers in considering the impacts of a product in all life cycle phases [20]. Datan et al. presented an information model for the causalities between product and manufacturing key characteristics represented in the Unified Modeling Language (UML) [5].

The UML, also used by many other authors, is a standard language for modeling physical systems and software. It provides a standardized syntax and different diagram types for modeling static structures and dynamic behaviors of systems. The UML is applicable to modeling information from all disciplines along a product life cycle [21].

2.2. Value stream mapping

Value Stream Mapping (VSM) is a well-established lean production tool, which supports the analysis of a static state of the value stream for one product or product family. It helps to identify improvement potentials regarding traditional KPI such as lead time or work in progress and the results are easy to understand even without having expert knowledge. During the last few years VSM was extended towards the consideration of energy demands of processes [22] or the entire production system [4, 23].

However, traditional VSM does not allow considering the impact of different product characteristics since a value stream map is created specifically for one product or one product family. Additionally, it does not include the constraints for parameters of processes and resources. The extended VSM concept proposed in [4] seems to be the first considering the impact of different product characteristics on the value streams under survey.

3. Concept

This paper addresses the integrated development of products and processes by proposing a value stream based information modeling approach. The well-known and easy to understand VSM concept is extended by the consideration of impacts from product design in order to describe product value streams and the relations between product characteristics and processes. The approach allows manufacturing experts from all disciplines to model their knowledge in a generic and familiar manner and to communicate with product developers. This is an advantage over many existing product–process models which offer rather specialized techniques and software tools. Moreover, no established tool was found for the linkage of the domains product, process, and coordination of projects with