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Model-based design process for the early phases of manufacturing system planning using SysML

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Abstract

This paper presents an approach for a model-based planning process for the early phases of manufacturing system planning (MSP). The goals are a better integration of MSP with product development (PD) in the early design phases and an improvement of the coordination of the MSP-related planning disciplines. The presented approach is based on model-based systems engineering (MBSE) and is supported by a modeling scheme which uses the systems modeling language (SysML). The approach consists of a process description of the MSP and of different so called SysML views which describe the information artifacts of each MSP step. It is divided into four different modeling levels that describe the manufacturing system's structure and behavior from different points of view. In order to validate the approach, an exemplary cylinder head production was modeled. Extractions from this example are shown as SysML-diagrams. To conclude the paper, the advantages and disadvantages of using a model-based planning approach with SysML for MSP are discussed.

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Keywords: Manufacturing; System; Planning; Design; Method; Modelling; MBSE

1. Introduction

The current demand for manufacturing companies is characterized by customer specific products with a large number of variants and shorter product lifecycles that require a shortening of the product engineering process in order to reach a shorter time-to-market [1]. Thus, companies are challenged to start the manufacturing system planning (MSP) at an earlier stage. In order to meet this challenge, one approach is the utilization of information from the early phases of product development (PD). This requires a consistent information base for all engineering processes that is not available so far. In order to reach this information base, within PD, new methods like model-based systems engineering (MBSE) are used [2]. MBSE is a method for designing complex systems using a central system model that enables an easy data exchange between all design disciplines. Yet, it is mainly used for PD and, so far, no approaches are known that use MBSE within MSP. Hence, this paper presents an MBSE-approach for the early phases of MSP that uses the Systems Modeling Language (SysML).

2. State of the art

In the following, the state of the art of current techniques for MSP is presented and an introduction to MBSE is given.

2.1. Manufacturing system planning

MSP is part of factory planning and characterized by strong interdependencies between the involved planning disciplines, like process-, layout-, or control-planning. For factory planning various approaches exist (e.g. [3]-[6]). Despite the large amount, most of them follow similar development patterns that can be divided into the five phases of preparation, structure planning, detail planning, implementation planning, and execution [7]. Within the preparation phase, preliminary work and objectives planning is done. Structure planning provides the design of conceptual solution variants of ideal and real layouts for the manufacturing system. After deciding on a variant, the detail planning finalizes the specification. Within

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the implementation planning, the implementation project itself is derived and during the execution it is coordinated until its finalization. [3] In this paper, especially the early phases like preparation and structure planning are focused, as during these the basic solution of the manufacturing system is derived.

Since for the MSP usually highly detailed information about the product to be produced is required [3], the development of products and the corresponding manufacturing system is commonly executed sequentially. That means that MSP only starts at a very late stage of the PD. In addition, the PD and the MSP are executed by separate departments that are often only poorly connected [8]. This results, e.g. in inefficiencies, costs for adjustments, media disruptions, and long development periods [7]. In order to overcome these problems, many different approaches were proposed like simultaneous engineering [9], Digital Factory [10], the design methodology for mechatronic systems by VDI guideline 2206 [11], the 3-cycle-model of product engineering [12], the double helix development of production systems and products [13] or the integrated product and manufacturing design by Britton et al. [14], to name but a few. However, so far, their industrial implementation is often limited to a strategic rather than detailed operational level, as they mostly address the mentioned problems on a high organizational level [15]. Furthermore, there is a lack of detailed domain-spanning procedures for the operational process level to properly integrate PD and MSP contents [15] during the early design phases. Moreover, no MBSE-approaches based on the usage of SysML are known, that target the domain-spanning design of products and manufacturing systems or the MSP itself.

2.2. Model-based systems engineering within the product engineering process

MBSE is an approach for the development of complex systems by iteratively connecting the development activities of all involved disciplines (e.g. mechanics, electronics, IT) with a formalized central system model, beginning in the conceptual design phase and continuing throughout development and later life cycle phases [16]. Thereby, the central system model is the basis for an interdisciplinary development and also substitutes the so far commonly used document-based information exchange [17]. Usually, MBSE-models describe a system by requirements as well as the system's behavior and structure [18]. For this purpose, modeling languages are used for a graphical, consistent, and formal description of the model [19], two examples for modeling languages are SysML or OPM [20].

In contrast to the MSP, within early phases of PD, model-based methods are already used more frequently. Some examples are the model-based system development [18], the model-based design of cybertronic systems [21], the geometrical constraints modeling for mechatronic design [22], the modeling and design of manufacturing machinery [23] or the software design for manufacturing execution systems (MES) [24]. In order to reach a better integration of PD and MSP, it is reasonable to use MBSE for the MSP, as well. Furthermore, since MSP necessarily requires information about the products to produce, synergies are to be expected by an integrated design, e.g. reusability of product information relevant for the manufacturing system, traceability of product changes during the development process, or an easier coordination between the disciplines based on similar models and common modeling language [25]. Therefore, especially in the context of MSP, the development of new planning methods using MBSE is required. For that reason, a model-based design process for the early phases of MSP is developed that uses the SysML for the modeling of manufacturing systems.

3. Model-based design process for the early phases of manufacturing system planning

The model-based design process for the early phases of MSP is developed as part of an integrated process framework for the design of products and manufacturing systems, targeting a better integration of PD and MSP within early design phases [26]. In the following, the MBSE-approach especially for MSP is described in detail.

3.1. Integrated process framework for the design of products and manufacturing systems

The MBSE-approach for MSP defines all required tasks for the product-integrated design of manufacturing systems. It has a two-part process structure, consisting of the cross-disciplinary early system design and the subsequent discipline-specific design, and is described with an iterative V-model that allows iterations within and between the two parts (Fig. 1).

The system design includes all tasks that are mainly executed during the early development phases of a system. These tasks usually relate to more than one design discipline of MSP but are coordinated by the systems engineer. The system design is subdivided into four design levels that describe the system from different points of view e.g. a behavioral or a structural perspective. The results of an iteration of the system design can either start another iteration or can be used within the subsequent discipline-specific design. The latter is usually coordinated by specialized engineers, e.g. the manufacturing process engineer or the logistics specialist. They build on results from the system design in order to develop a technically specific and implementable solution or several alternatives.

As products and manufacturing systems both represent technical systems, a mutually used description scheme based on the SysML is defined. It is used to build the formalized central system model that facilitates a non-redundant synchronization and cooperation between and within PD and MSP. The description scheme specifies a process model for the four levels of the system design. For most process steps, one so-called SysML view is defined, showing the result of each step in one or more SysML diagrams. For this purpose, the preferred diagram types and usable elements are defined in the SysML view. In the following, the model-based design process for MSP, including its four design levels, is described in detail.

3.2. Model-based manufacturing system planning in early design phases

The system design for MSP is divided into four levels: context level, manufacturing technique level, structure &