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Analysis of information interdependencies between product development and manufacturing system planning in early design phases

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Abstract

Manufacturing system planning (MSP) and product development (PD) are two highly interdependent domains of the product engineering process (PEP). Product design decisions impact on tasks and alternative solutions of the corresponding manufacturing system and vice versa. According to the "rule of 10" in quality management, especially within early design phases decisions highly impact on the accuracy of the overall result. Even today, PD and MSP are commonly processed sequentially without integration or interlinkage between the two domains. Existing integrative approaches aren't successfully implemented in most companies.
An innovative approach for integrating PD steps and tasks of MSP aims at an early conceptual design of the manufacturing system. While within PD, a conceptual view on the product exists, within MSP no early conceptual design is performed. Thus, a conceptual design for manufacturing systems is needed for a better integration of the two domains. In this context an integration of the process phases specification and concept design from PD together with preparation and structure planning from MSP is auspicious. For the integration of these early phases some preliminary analyses have to be performed.
This paper presents the results of the interdependencies and information exchange analysis between PD and MSP in the phases named above. The information content is outlined and an approach for the information classification is given. The information is distinguished by the way it is used within the two domains and conclusions from the analysis are drawn for the concept to develop.

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Keywords: Planning; Integration; Manufacturing; Product; Development.

1. Introduction

Manufacturing companies are permanently confronted with the challenge to reduce the duration of the product engineering process (PEP), aiming at a shorter time-to-market [1] for new products and an earlier start of production [2]. This persistent challenge exists almost as long as the manufacturing industry itself and is triggered by changing circumstances like technological progress and social evolutions. Recent examples are an intensifying market saturation and changing customer demands for individualized products manufactured at the same costs as mass products [3]. To meet the demands and maintain own competitiveness, companies have to handle increasing complexity [4, 5] and product variety [6], technologies and business models. Shortened product life cycles, caused by changing customer demands or by shortening technology life cycles, enforce according product changes. Consequently, the frequency of product developments increases. Therefore, even more flexibility in organization, planning and manufacturing is necessary [7]. To meet the challenge of the need for an even shorter PEP, product development (PD) and manufacturing system planning (MSP) have to be processed faster and process phases of the two domains have to be integrated and parallelized further. None of these objectives are truly new. Approaches like simultaneous engineering originating from the 1980s [8] or developments linked to the digital factory [9] already had the same objectives. But still, the processes of PD and MSP, defined as two sequent parts of the PEP, neither reached a considerable parallelization nor integration [10].

In this paper, an innovative approach to integrate the two domains is presented. It especially focuses the early phases of the development processes of PD and MSP (Fig.1) and aims at

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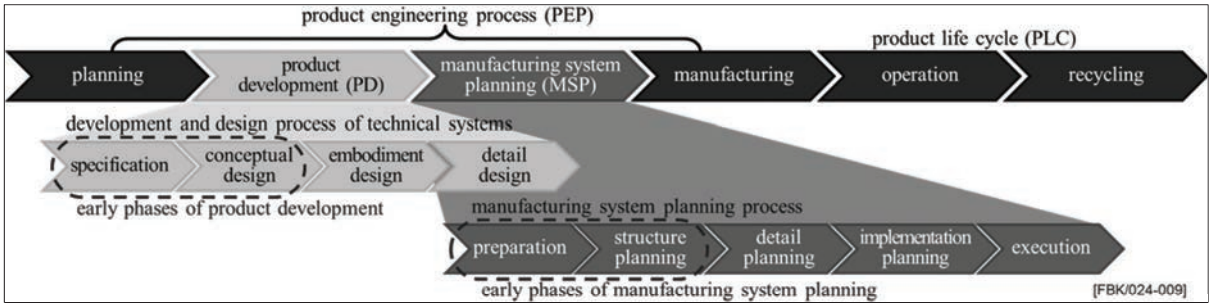

Fig. 1. Definition of early phases of product development and manufacturing systems planning within the product engineering process

integrating process steps and parallelizing process phases. Therefore, in the following, the PEP is elucidated. It is defined, which phases are considered "early" and their contents are outlined. Thereafter, the intended approach is described with objectives and development tasks. One of them is the analysis of information interdependencies between PD and MSP in early design phases. A classification of this information as well as an overview over the results of the analysis is given.

2. Early phases within product engineering process

In the following, the sequential PEP and the early phases of PD and MSP are defined and outlined. Furthermore, existing approaches for integrating PD and MSP are presented.

2.1. Sequential product engineering process

The product life begins with the first product idea. It initiates the product lifecycle (PLC), which contains the PEP. Most commonly, the PEP is defined by three sequential phases, but not invariably the same ones. As shown in Fig.1, in one case, planning is included but manufacturing is not [11] and vice versa [12]. However, PD and MSP are always part of the PEP.

The domains of PD and MSP both use process models with sequentially performed process phases to structure their tasks. Within PD four process phases are mostly agreed on (Fig.1). They are recorded by VDI guidelines 2221 [12] and 2222 [13] and based on, inter alia, methods of Pahl/Beitz [14], Hubka [15] and Rodenacker [16]. Apart from the sequential process models some other approaches for PD exist, e. g. the Munich Product Concretization Model [17] or the approach for PD of Ulrich and Eppinger [18]. MSP literature also defines a range of classical process models e. g. by Kettner [19], Grundig [20], Wiendahl & Nyhuis [21] Schenk [22] or Bellgran [23]. These classical process models differ with respect to the number of phases, to the level of detail, or the start and end point. But all models equal with regard to the contents and the analytical procedure. For harmonization, the contents of all classical models can be allocated to five reference phases (Fig.1) [24]. In addition, several newer ones exist like the manufacturing system design by Suh et al. [25], the counterflow method of factory planning [24] or Aachen's factory planning approach [26]. They can cope with some of the classical ones' disadvantages, but at the core, they are based upon them.

This paper focuses the early phases of PD and MSP. The definition of "early" is shown by Fig.1, including specification and conceptual design phase from PD and preparation as well as structure planning phase from MSP. In the following, the contents of these early phases are outlined in detail.

2.1.1. Early phases of product development

The process of PD begins with the specification phase. It aims at clarifying and specifying the development task, which is given either by the customer or the product planning. All available information on the product is collected, the design specification is formulated and documented in a requirements list. It serves as input to the conceptual design phase [12].

The conceptual design phase develops the product concept within several design stages [1]. It represents the principle solution of the product [14]. The first design stage investigates all collected information to determine the main purpose of the product, which defines the primary function of the product. Besides often additional purposes exist, which are represented by secondary functions. All functions are broken down into sub-functions and structured within a hierarchy of functions. Here, the connections between functions and their inputs and outputs are represented by flows of energy, material or signals. The first design stage results in the function structure of the product [12]. Based on this, the next design stage determines possible working principles for each sub function. Working principles are defined by a physical effect, material characteristics and geometric specifications or restrictions [15]. The gathered set of working principles is used to combine alternative variants of working structures. Each variant possesses other characteristics, advantages or disadvantages, depending on the degree of synergetic interaction of the working principles contained [16]. However, the combination of the best-fitting working principles of each sub-function does not inevitably lead to the best working structure. By using common selection and evaluation methods, different working structures have to be balanced against each other to achieve the ideal principle solution for the product [14]. Here, it is important to notice, that the same function structure can be fulfilled by many different working structures and the optimum choice of working structure is a multicriteria decision problem.

2.1.2. Early phases of manufacturing system planning

The first phase of MSP is the preparation and contains the tasks of objectives planning and preliminary work. Because MSP objectives are derived from strategic corporate objectives, the corporate management is responsible for objectives planning [19]. Beginning with the initiation of the planning