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Knowledge-based design for assembly in agile manufacturing by using Data Mining methods

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ABSTRACT

Decision making in early production planning phases is typically based on a rough estimation due to lack of a comprehensive, reliable knowledge base. Virtual planning has been prevailed as a method used to evaluate risks and costs before the concrete realization of production processes. The process of product assembly, which yields a high share in total production costs, gets its particular importance. This paper introduces a new approach and its initial implementation for knowledge-based design for assembly in agile manufacturing by using data mining (DM) methods in the field of series production with high variance. The approach adopts the usage of bulk data with old, successful designs in order to extrapolate its scope for assembly processes. Especially linked product and process data allow the innovative usage of DM methods in order to facilitate the front loading in the product development. The concept presents an affordable assistance potential for development of new products variants along the product emergence process (PEP). With this approach an early cost estimation of assembly processes in series production can be conducted using advanced DM methods as shown in an industrial use case. Furthermore, design and planning processes can be supported effectively.

1. Introduction

Today globally operating companies face additional challenges due to turbulent fluctuations in market demand, increasing variability of products, shortened product lifecycles and corresponding complexity of processes [1]. It results in higher flexibility expectance in production system and economically reasonable dispatch of new products in an existing production line. The pivotal link between design and manufacturing lies in process planning. Process planning deals with the selection of necessary manufacturing processes and determination of their sequences to 'transform' a designer's creation (namely the shaped part) into a physical component economically and competitively. In the modern product emergence process (PEP), production planning gains in importance and has to be executed as parallel as possible to the product development according to concurrent engineering principles [10]. In this early product creation phase, a first step for planning processes is a cost calculation for the industrialization of the product in existing production lines regarding basic conditions [5]. The cost-effective feasibility of series production must be assured with vague information on product and given general conditions, e.g. shift model [6]. This is a great challenge especially to planning cost-intensive assembly of a product [41,53].

Front loading has been seen as an appropriate means to tackle such challenges [43] and must be supported by adequate processes, methods and tools. Subsequently, production planning should start as early as possible in phase with product development. The research and development project "Prospective Determination of Assembly Work Content in Digital Manufacturing (Pro Mondi)" was initiated to link the early product design with the early production planning using methods of data modeling and data mining (DM) to generate information with focus on the product assembly planning for new products in early production planning phases. Aim of this project is to achieve accurate estimation of expected assembly work and resulting costs in an early stage of the product development. This should be realized in sync with design through provision of additional support with assembly knowledge for an underlying design. The approach, thus, contains reuse of existing planning data in order to extrapolate assembly processes. Especially linked product and process data allow the innovative usage of Data Mining methods. As proof of concept this

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approach has been evaluated with different manufacturing companies.

2. Related work

2.1. Design for X

The literature offers besides "Design for X" also the term "Design to X", both of which are often grouped under the concept "Design for X", but have different meanings. Many definitions highlight the fact that there are different objectives that come into consideration in this work as well. The terms are interpreted according to the definition of Vielhaber [62]:

1. According to Chen [14], "Design for X" describes the reactive, methodological assistance in development of a product to a property – determined by a set of features – which is necessary, to make a follow-up process in the product lifecycle successful (e.g., adaptability to manufacture).
2. "Design to X" describes the proactive, methodical assistance in development of a product for a target property (e.g., cost-effective products).
3. "X-Oriented Design" refers to the collection of all "Design for X" and "Design to X" criteria.
4. The terms "features" and "characteristics" are understood according to the view of the "Characteristics-Properties Modeling" (CPM)/"Property-Driven Development" (PDP) approaches by Weber [66] in the definitions.

The main objectives (whether Design for X or Design to X) are often repeatedly considered during the development process and therefore decisions have to be brought about at a time. For example, the criteria are taken into account in early stages of product development, but may need to be focused again later during the elaboration of the product shape and have to be adjusted [50]. Therefore, it can be stated in principle that the application of methods and tools of Design for X is a way to consider the numerous restrictions in the development process [65]. Both analysis and synthesis steps must be included. Weber explains the poor integration of Design for X-methods and tools in the design methodology with the required characteristic by Design for X (e.g., material strength or assemblability), which cannot be easily described by terms such as "functional structure" or "solution principle" [67].

According to Bossmann [9], DfX methods can be subdivided in five main groups (user, environment, functional reliability, costs, and production). The latter is composed of the following subgroups: Machining, Reshaping, Primary forming, Component manufacturing, and Assembly.

In the ideal case all guidelines are considered in designing a new product, but that case is improbable. Therefore, the design department has to be supported by other departments which provide their expertise in order to meet the "Design for X" requirements.

There are several "design for" or "design to" criteria, which are summarized with "Design for X". Design for Disassembly and Design for Recycling, for example, are covered by the same group, which is headlined with Design for Environment. Boothroyd and Alting concentrated on design for assembly [7]. In their concept the reduction of the number of components is particularly addressed to reduce assembly costs. A consistent implementation in Swedish companies led to convincing results [61]. In 50% of these companies a reduction of development time and development costs by 33% was established. The assembly costs could be reduced by up to 85% with the DFA approach by Boothryd and Alting [61]. Design for assembly and Design for Manufacturing are often summarized by the concept Design for Manufacturing and Assembly (DFMA) [7]. The normal result of DFMA, as an integral part of the design process, is simpler and more reliable products that are less expensive to manufacture and assemble [37]. However, products designed in this way tend to have a smaller number of complex components, making maintenance and upgrading difficult and expensive. The emphasis on reducing manufacturing costs has, therefore, been at the detriment of in-service costs. This may not be a particular problem for mass-produced (typically minimal maintenance, low priced, short life span) products such as the majority of domestic appliances [22]. Meeting manufacture criteria, not only anticipated the manufacturing engineering autobody design activities reducing the time to market, but reduces investments and structural cost of the plant are the findings of the industrial study [36] [39]. These strategies have generated resources with the mechanical presses selling and create a new platform with fewer operations, on average, comparing similar parts with previous designs [57]. Other approaches focus on the complexity of design rules, especially in semantic assembly decision [15]. A major challenge of the complexity is a computational issue associated with a very sophisticated and time-consuming task with respect to semantic reasoning for ontology-based product design. By using disparate attributes algorithm, computer-aided systems become more easily able to understand and to discern joining types.

An excerpt of typical DFMA guidelines is provided in Fig. 1 [9].

An updated version comprises the broad, long-term experience in DfMA by a set of generic guidelines [6].

2.2. Assembly planning

Assembly is the installation of geometrically defined objects by joining, handling, calibration and control operations. The task of assembly planning refers to the creation of necessary precondition for economic installation procedure. This includes identification of needs, targeted and efficient use of staff as well as resources. Assembly is defined as joining or assembling manufactured items into a functional unit. Within the installation planning, a distinction is made between operations and detailed planning. Function of operations planning is to develop an assembly system and to create a rough schedule [41,53].

The detailed planning is divided in concretization of the assembly system and preparation of a detailed schedule. Table 1 shows functions and planning phases of assembly planning as well as its required input information and results to be achieved [9,11]. As product geometrical shape is main, but not only criterion for assembly process, many relevant product properties are defined in CAD systems [3,8].

In "classic" Assembly Planning the assembly sequence has to be determined by a product analysis. Thereby, geometric relationships between product structure components are examined in particular. For this purpose the product is dismantled into separate parts. In some cases, the assembly sequence can be sufficiently characterized by the joining sequence of the components [51].

For the determination of the assembly sequence Lotter and Wiendahl evince that 40% of the time is to be invested in order to determine the order of the components in the assembly while performing the planning activities [41]. In recent years, some expenditure shift could be registered due to an increased use of computers. The largest effort is still located in determining the assembly sequence, which is why this aspect focused in research activities [18]. There are numerous approaches which can be based, for example, on the disassembly sequence to determine an appropriate assembly sequence [25,38,47].

One result of the assembly planning is the assembly graph, which represents the possible assembly sequences in a network