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Developing products for changeable learning factories

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ABSTRACT

Experiential teaching and research facilities such as learning factories provide a favorable environment and tools to develop, test and implement new products and manufacturing systems concepts and solutions. Learning factories that are geared towards the capabilities and requirements of changeable manufacturing systems (CMS) are used for validating new products, their variants and changeable production systems design, planning and control methods. Existing approaches of developing new products are reviewed, and a new approach to develop products for changeable learning factories is presented and validated by a case study. The new development approach is dedicated to changeable learning manufacturing systems by choosing a product line among many candidates to suite the learning system capabilities and desired learning outcomes. Designs for product variants that suite the learning factory and planned learning scenarios and training experience. This paper focuses on learning factories for changeable manufacturing systems, which are constructed to possess the necessary changeability enablers such as mobility, modularity, scalability, universality and compatibility. It is challenging to associate learning and research to a changeable manufacturing system.

Introduction

Proliferation of product variety, dynamic customer requirements and reduced time-to-market are common challenges in industry. Learning factories provide the needed experience to educate engineers and practitioners about facing those challenges in manufacturing [1,2]. A learning factory consists of physical didactic and digital environments to realistically simulate production processes. Physical and digital environments should be integrated to support adaptation and improvement of the digital solutions [1,2].

Changeable manufacturing systems (CMS) are becoming crucial for variant-oriented industries, to introduce the needed change when it is needed [3–5]. This paper focuses on learning factories for changeable manufacturing systems, which are constructed to possess the necessary changeability enablers such as mobility, modularity, scalability, universality and compatibility. It is challenging to associate learning and research to a changeable manufacturing systems [6,7]. This challenge involves the development of the appropriate products that allow experimenting with and demonstrating the full extent of system changeability to gain maximum learning experience and increase the educational impact and research productivity, as well as the utilization of physical and digital capabilities of the system [8,9]. On the contrary, the common approach for a new product development is to fulfill the functional needs of customer and market demands not to exploit the capabilities of the manufacturing system. Having the ability to react to all possible product variants and production scenarios enables the actual factory to react to specific market demands, by only selecting the targeted product variants and its processes.

In real factories, the objective of new product development is to fulfill the customers functional requirements and market demands. The design of those factories follows the process requirements for the planned products and their variants. Changeable manufacturing systems have additional physical and logical characteristics, such as mobility, reconfigurations and flexibility, to enable effective and faster response to changes in requirements and markets. In educational environment, physical learning factories are used to demonstrate and illustrate using hardware and software many concepts and technologies related to the scope and purpose of the leaning factory. Unlike real factories, learning factories naturally have special limitations including physical size, space and work envelopes of machines, type and

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number of included productions stations and material handling systems. It is important, therefore, to select or design products to be manufactured and/or assembled using a specific learning factory which best utilize its capabilities, respect its restrictions and allow demonstrating as many learning objectives as possible for undergraduate and graduate education as well as research. Hence, this presents an interesting design challenge to those educators who utilize a given learning factory to find real products or design/modify product that meet these requirement, limitations and objectives and offer variety to enhance the learning experiences. This challenge is the motivation and objective of the product design procedure presented in this paper. Learning factories can also be used for developing and testing prototypes of real products and their manufacturing processes within the capabilities of the given learning factory.

Based on the survey of learning factories requirements by Wagner et al. [9], there is a set of development activities that should exist in a product development approach, such that it illustrates the full changeability extent of a changeable learning system. These are as follows:

1. Investigating current system learning and research capabilities (physical and digital environment), e.g. if the system is for machining or assembly, degree of automation/robotization and integration, used digital manufacturing software and their change capabilities, etc.
2. Determining objectives of the studied learning factory based on its capabilities with comparison to similar changeable learning systems. This is an activity that is decided by the system manager. Objectives may include: learning about change propagation in manufacturing, lean oriented thinking, operation planning, industry based projects, etc.
3. Defining system components, configuration and layout needed for product development and corresponding processes. This includes equipment selection and determining the relative locations of system equipment and their control system.
4. Systematic development of product variants, their structure and design, and corresponding manufacturing processes and layout configurations variants.
5. Development, planning, manufacturing activities and testing of the new product.

This paper proposes a design approach for products than can be processed using changeable learning factories to show their full capabilities. This procedure is also useful for other learning factories that may not be changeable/ reconfigurable.

Product development approaches

Many approaches for developing a new product exist in literature. The suitability of the existing product development approaches for the specific development activities in changeable learning systems are examined in this section. They can be classified as procedural with a serial development process, concurrent/parallel development through multiple fields, directed development for a specific target, and finally methodologies targeting product variety and changeability in manufacturing systems.

One example of a procedural approach for product development and design is presented by Hubka and Eder [10], which consists of six phases. (1) Clarify the assigned specification, (2) establish the function structure, (3) establish the concept structure, (4) establish the preliminary layout of the product, (5) establish the dimensional layout of the product, and finally (6) detail the selected design.

A different product development approach is "Concurrent engineering" which considers the product life cycle processes (e.g. product planning, design) and treats them in parallel partly to minimize development time as well as cost, and to maximize quality. For example, "Concurrent Engineering" comprises the simultaneous establishment of products and processes of phases such as manufacturing or assembly. In this context steps like "Idea generation", "Screening", "Concept development, testing and evaluation", "Prototype development testing and evaluation", "Pre-launch", "Launch" and "Project evaluation" are partly processed in parallel [11,12].

A group of methodologies is referred to by the name "Design for X", where "X" stands for a particular property like, e.g. cost, quality, lead time, efficiency or flexibility, or it stands for a life-cycle phase, such as parts manufacturing, assembly or distribution. One example is "Design for Manufacturability" (DFM) that includes the determination of the sequence of the manufacturing processes and the optimization of design the parts for these processes. Another example is "Design for Assembly" (DFA) to reduce the amount of assembly processes and equipment, and to ensure the suitability of the design for assembly. The main goal of DFA is to enhance manufacturing, assembly and testing, and to optimize costs, quality and time [13]. A third example is "Design for Disassembly" which is related to the reduction of time and costs for disassembling the product to maintain, recycle or reuse the whole product or parts of it. This is done by taking into account economic and environmental aspects. The principles of Design for Disassembly are "the selection and use of materials", "the design of components and product architecture" and "the selection and use of fasteners" [14].

ElMaraghy et al. [15] surveyed a large number of Design-for-variety (DFV) methodologies in literature and pointed out that most well-known design methodologies are still usable for product families and variants with more focus on capturing customer needs, concept generation and evaluation, product structure modularization and platforms, since a family of product variants should be optimized to reduce engineering costs and time to market, extend product portfolios and expand market share, maximize customer satisfaction and at the same time increase components commonality and cost.

"Adaptable design" approach adjusts existing products for the changing requirements by adding or substituting components, while the product architecture may not necessarily be modular [16,17]. "Reconfigurable design" is a part of "Adaptable design". In contrast, "Modular design" is frequently employed to minimize development and manufacturing efforts but it is not necessarily adaptable for changing requirements [18,19]. An enhancement of "Modular design" is "Product Platform design" realized by means of shared modules in a product family [20], which is the basis for designing products for mass customization satisfying customer's requirements with an efficiency that corresponds to production in bulk [21].

Although there is a large number of product development approaches, their use should be adapted for developing products that support both learning and changeability in changeable learning factories, since product development is usually based on market demands, needs, problems, trends, business objectives or business potentials. Developing products for changeable learning factories focuses on investigating new concepts and solutions for the enhancement of changeable manufacturing systems. Products and product variants have to be developed in correspondence with the existing equipment, capabilities, processes and operations of learning factories. The proposed product development approach in Section "Product development method for changeable learning factories" is based on a combination of activities and tools taken from existing product development approaches.