Skill-Based Asset Management:
A PLM-Approach for Reconfigurable
Production Systems

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Abstract. To handle complexity in a modern reconfigurable production system from a strategic and tactical planning perspective as well as to enable operational decision making a skill-based asset management system is introduced. It provides a novel approach of managing assets in the context of the asset lifecycle based on their provided skills. It aims at the vertical integration of higher level management systems with production execution level systems of small and medium sized manufacturing enterprises, using a common skill-based abstraction. Thus the skill-based asset management system can effectively provide digital factory functionality to companies while integrating into their existing IT systems.

Keywords: asset management system, reconfigurable production system, skill-based model, vertical integration, digital factory.

1 Introduction

The increasing external complexity, such as changes in demand or the product, challenges production companies to raise their productivity while making use of the changeability within their asset park [1]. An evident need is recognized to plan the production organization and to utilize the production assets flexibly and efficiently in order to stay competitive in a rapidly changing market [2]. The production resources utilized in a modern production company are highly flexible and adaptable in their skills but there is still a lack in the IT infrastructure to appropriately allow them to use that high variety of operating alternatives in an economic reasonable way. The continuous research in the area of reconfigurable manufacturing systems (RMS) is highlighting the trend toward more flexible and adaptable production systems [1], [3-4]. However those types of production systems are associated not only with large capital investments [5], but rather with high lifecycle cost. They also increase the internal complexity and provide new challenges in terms of management and planning. They often stay underutilized because of the lack of appropriate tool support for overview, planning and reconfiguration. As a result production companies do not

optimally exploit their changeability provided by the available technical infrastructure. Furthermore on an operational level the production is planned by order-centric enterprise resource planning (ERP) software and its execution is controlled by technical shop-floor control systems such as manufacturing execution systems (MES) or production planning and control (PPC) systems. These systems operate on different levels in the enterprises' IT infrastructure and often lack technical as well as the conceptual integration [6].

This paper presents the ongoing work towards a skill-based asset management system (AMS) by the European project SkillPro [1] . The project aims at the development and utilization of a novel approach for skill-based resource controller architecture in the context of RMS. As one of the main components of the desired project framework the AMS in particular addresses the technological and conceptual gap between upper enterprise level applications and technical processes in the production. It provides a lifecycle approach that combines information both from a technical and a business point of view and via a common skill concept supports an appropriate frontloading towards product development as well as towards asset and factory planning.

Under the consideration of the product lifecycle management (PLM) for manufacturing companies this contribution reviews in paragraph 2 relevant works in the domains of digital factory, enterprise asset management, and skills in production and automation. An overview of the SkillPro framework and a brief introduction of the project's skill concept is presented in paragraph 3. Paragraph 4 describes the skill-based AMS, providing insights on its functionality, its utilization in the IT-landscape of a production company and its main benefits for a modern production enterprise. Finally, paragraph 5 concludes the paper and provides an outlook on future research.

2   Related Works

In the context of the *digital factory* (see [8]) there have been many findings regarding consistent mechatronic approaches to ensure integrated simulation models recently. The Hardware-in-the-Loop (HiL) approach derived from the embedded systems engineering is increasingly utilized within the digital factory [9]. Also aspects of interoperability between IT systems in the digital factory are often addressed besides the designation of virtual models [9]. Different formats for model exchange between computer-aided engineering (CAE) or simulation tools, such as the Functional Mock-Up Interface (FMI) [10] are now discussed regarding the improved simulation of production processes and resources.

Due to holistic simulation approaches as well as the consideration of the lifecycle of assets, the need for robust and consistent product-process-resources (PPR) models as a backbone system for the digital factory is identified. This gradually leads to further transmission of PLM approaches to the systems of the digital factory. Thus the aim is to combine the industrial value creation via a lifecycle-related PPR model [11] as depicted in Fig. 1.

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[1] www.skillpro-project.eu

Digital factory systems are highly covered in research and even utilized in practice by large enterprises. However, despite their benefits, small and medium sized enterprises (SME) are currently hesitant to utilize them, due to the still poor integration in the preexisting fragmented IT landscape [12-13]. To address this issue, new systems are emerging that handle the data management for planning and operating of production plants similar to the well-known product data management (PDM) concepts. One standard, which is strongly considered for this type of systems, is AutomationML [2] as an open, XML-based interchange format. It can ensure the interconnectivity and interoperability of the systems, connecting especially MES with the digital factory [14].
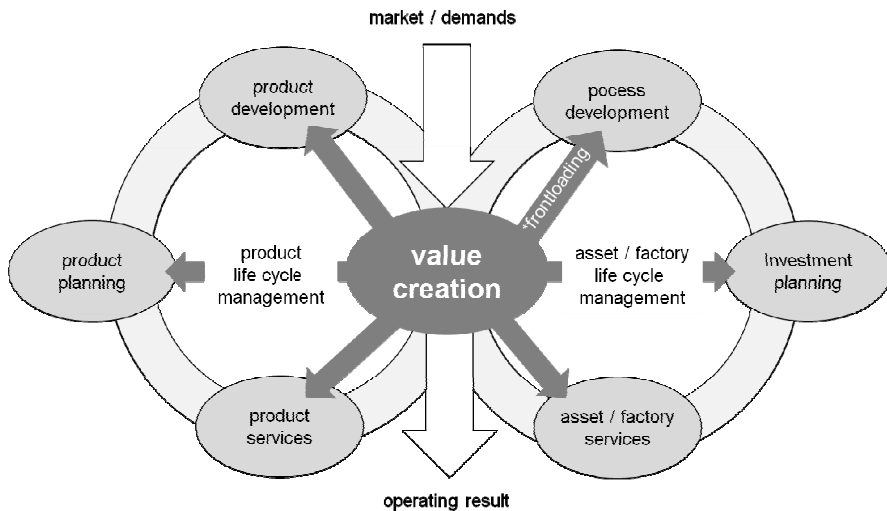

Fig. 1. The alignment of the product lifecycle and the asset/factory lifecycle managements in the value creation (according to [11])

The *enterprise asset management* (EAM) is gaining a lot of research interest in recent years. Initially regarding (technical) assets only from a financial point of view it now focus on different aspects of their lifecycle such as utilization, maintenance, effectiveness, etc. In his work Haider provides an extensive study of the asset management in the context of engineering and infrastructure [15]. Although this work is focused on the asset management of big infrastructure plants (water supply or roads) it summarizes an effective definition of an asset in the production domain as well. An asset is a component with economic life span of more than 12 months that has a value profile, and creates and maintains its value by providing services or certain skill sets [15]. Haider distinguishes between three types of asset management – strategic, tactical and operational – depending on the management horizon and the type of decisions, indicating that asset management is a lifecycle challenge. Cambel, Jardine and

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[2] www.automationml.org

McGlynn do extensive work on providing a framework for best practices and optimization of maintenance of plants, fleets, facilities or equipment from a lifecycle perspective [16]. They are addressing the complete asset management from a long up to a short-term perspective. Further multiple research projects engage the topics of enterprise assets and their lifecycle management. Kiritsis discusses the research activities of several European projects in the area of asset lifecycle management (ALM) via semantic technologies [17]. Tam and Price present an approach for optimizing the asset maintenance [18], which can be crucial if the given asset is a bottleneck in the production system. By using a generic model for the asset based on three decision dimensions (output cost, risk cost and resource cost), the authors provide a decision support framework for maintenance planning. In February 2014 a new ISO standard for asset management system (ISO 55000) [3] emerged focusing on the management of technical enterprise assets mainly in regards to the financial dimension and still incorporating lifecycle considerations. It defines the necessary activities for the asset management and the recommended features of an AMS. However it neither provides specification nor restricts the means of implementation of such systems. Additionally research efforts are directed towards the factory planning and managing of the factory lifecycle defining "factory as a product" and describing the interdependencies of the product and factory lifecycles [11].

Skill concepts in production and automation have been developed under different perspectives, using different approaches, implementations and naming conventions. Some research activities are focused on the function modelling in the production context. The Function Oriented Product Descriptions (FOPD) approach is used to formally model both product and factory functions [19] in order to conduct performance evaluation. Various works focus on the development and utilization of skill concepts for planning and executing tasks in robotics. Significant work is done in the field of service robotics, robot-human interaction and multi-robot coordination [20-23]. The research in those works is focused on autonomous execution of tasks by means of artificial intelligence. In an industrial context the skill concept is not that highly covered in the research, as the industrial robots are mainly limited in their autonomy [24] and controlled by a central system. Still, Malec et al. describe a skill-based approach for assembly and inspection in robotized work-cells [25]. They propose a dual approach for skill definition – top-down definition of production goals and bottom-up description of machine skills, called capabilities. A follow-up research activity is conducted in [24], [26-27] extending the skill concept of [25] focusing on the knowledge representation of the skill-enhanced PPR model (see [28]) via semantic web technologies. The presented approaches mainly concentrate on skill execution in various application fields. However, they do not consider the skills from a lifecycle perspective of the asset, such as utilization and maintenance profile of the skills, skill evaluation and comparison, asset wear, change possibilities, etc. Furthermore, skill modelling is focused mainly on robot operations and capabilities and although it provides a good common abstraction for the integration of different production-related domains such as manufacturing, logistic or assembly assets, this aspect is still

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[3] http://www.assetmanagementstandards.com/

not extensively explored. Also, the current research is mainly aimed at interoperability and interactions of technical resources (assets) and not on the high level integration towards ERP and PLM.

The review of the related works shows that a lot of research is dedicated to the topics of digital factory, asset management and skill-based task execution. However, a combined concept for skill-based asset management to support digital factory is not covered sufficiently.

3   The SkillPro Approach

The European project SkillPro aims at the design and realization of a skill-based framework for reconfigurable manufacturing systems. It can be considered as possible implementation of the plug and produce paradigm [29] concentrating not only on physical and asset level changes but also addressing logical and topological changes and long-term planning. Furthermore it provides a skill-centric view of the product-process-resource model [30] as one of its core research activities. The skill concept developed in SkillPro aims at extending the existing skill-based models and frameworks in two aspects. On the one hand it targets a wider scope of assets, focusing not only on industrial or service robotics, but including also logistic assets, CNC (computer numerical control) or DNC (distributed numerical control) machines, other production assets and even human workforce. On the other hand the skill concept is to be utilized not only during execution, but also for operative planning and mid-to-long term asset management.
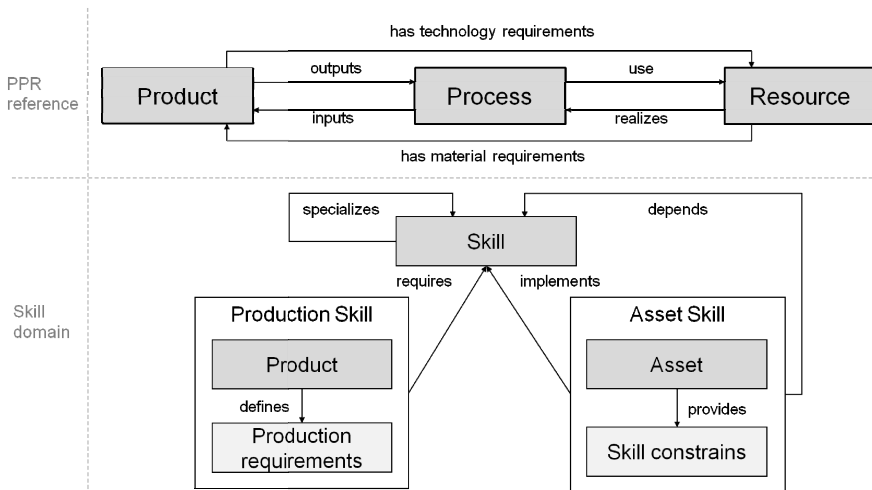

Fig. 2. The Skill concept according to [30] aligned to the classical PPR [31]

The Skill concept is a logical extension of the classical PPR concept in the production context (Fig. 2). Stanev summarizes the PPR dependencies having the asset (resource) as a central element of observation that requires specific properties of the product (such as material) and provides possibilities for its manipulation (via process). Furthermore, a product is an output of the process execution on a certain resource that transforms input products [31]. Another PPR approach that defines the different relations between the objects is the OZONE-model presented in [32]. There however, the product and the resource both provide constraints for the process (called activity) but don't have any direct relation to each other.

The skill concept developed in SkillPro extends the PPR model. It proposes a common abstraction that can be used for production system modeling, production planning and production execution and control, thus allowing a conceptual and technical integration among the production IT systems. Besides the product and the asset that retain their common meaning, the elements of the skill model are:

- *Skill*: A skill is a placeholder for a process providing metadata (parameters) needed for its specification. Skills can have hierarchical structure, thus building skill taxonomies. Thereby the lower skills are specializations, inheriting all parameters of the parent skills.
- *Production Skill*: A production skill is the assignment of specific production requirements for a product based on its properties. The production skill requires a skill with concrete values for all skill parameters in order to fulfill the production requirements.
- *Asset Skill*: An asset skill represents the possibility of an asset to provide a skill. The asset skill implements a certain skill, having restrictions for the skill parameters due to specific skill constraints that are defined by the asset. The asset skill can also have additional dependencies to other skills as pre- or post-conditions for its execution. Those types of relations are then used for different reasoning operations on skills such as skill matching, skill composition, etc.

Each skill type can have structure, thus defining sequential or parallel skill execution.

4   Skill-Based Asset Management System

The goal of this skill concept is to provide a common model that can be used by the three main components of SkillPro. As depicted in the figure (Fig. 3) these are the skill-based AMS managing the enterprise assets, the skill-based MES scheduling and controlling the execution and the skill-based control system (called skill execution engine – SEE) executing skills on the assets. The AMS system conducts high level feasibility check for production orders, creates coarse production plans and plans reconfigurations. The same model shall also be used on the lower control and execution level for exchanging and interpreting instructions. The three components integrate with each other, based on the common skill model, exchanging skill information and conducting certain operations in their level of concerns. These are based on three different time horizons. During the long-to-mid-term planning the AMS is involved by evaluating the production system, managing the lifecycle aspects

of the assets and their skills and preparing the production system for new products and product orders. This includes also the "teaching" of previously unknown skills to the execution controller (SEE). The AMS also provides some services (to the MES) during the short-term-planning (operative) such as retooling/reconfiguration instructions and additional feasibility checks. During execution it provides (to the MES or the SEE) the needed models (regarding product and skill), usually before the first execution of a batch as it acts as a central repository for all skill and object models. Via the SkillPro-Framework the AMS gets product and order information from the PLM and ERP systems and persists it in the SkillPro format.
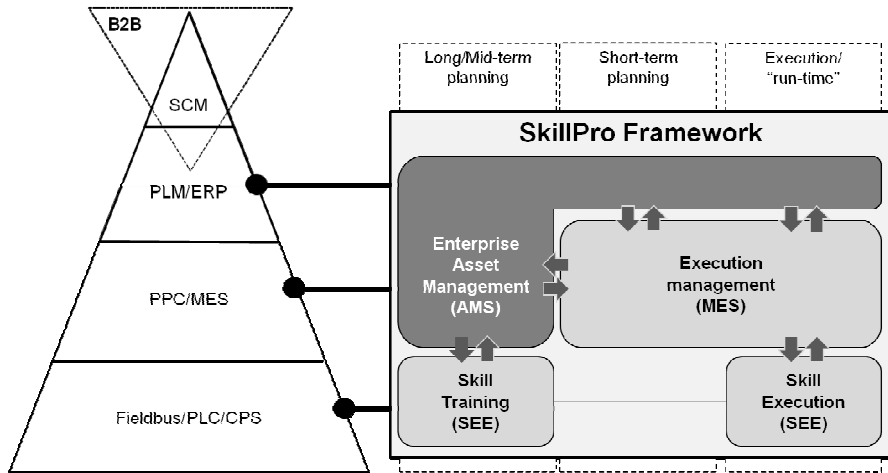

Fig. 3. A bird eye perspective on the SkillPro framework architecture aligned to the different IT-levels in a production company (pyramid on the left) and the different planning horizons (on the top).

The skill-based AMS constitutes an in-house company-specific knowledge base. During production, it gains content by storing correlations between products and resources via the skill abstraction. It is thus further augmented by new skill definitions and skill properties. Hence the previous experiences can be used for production re-planning, estimation of delivery time and strategic planning. In particular the functions of the skill-based AMS are:

- Long-term scope: Manage assets in context of their lifecycle and in context of their skills lifecycle. Each Asset Skill is provided by a certain asset configuration, for example a tool state of a machine, or specific adjustment in an industrial robot. Assets can provide additional Asset Skills in combination with other assets that are otherwise not available if used independently. The skill-based AMS system can manage both asset and skill lifecycle maintaining lifecycle models for both types of entities and evaluating performance indicators such as time, quality, energy consumption, flexibility or responsiveness, etc. to secure a high lifecycle value and minimize the total cost of ownership (TCO).

- The skill-based AMS performs skills matching followed by evaluation for production skills and asset skills. Thereby it identifies different production possibilities for a given asset park and allows for a dynamic assignment of production orders and dynamic generation of the skill-based bill of processes (BoP). By searching for corresponding asset skills to the required production skill (skill matching) the skill-based AMS can perform feasibility checks for new or changed products. Thus it can identify asset bottlenecks, missing assets or outdated assets. It can identify necessity for changes on asset configurations (retooling), topology (changing workflow or communication flow) and topography (layout), based on the currently available and potentially provided skills.
- Short-term scope: When the execution planning and control system (MES) is re-planning due to failure, the skill-based AMS supports the process by providing other production alternatives for the current production system configuration or withdraws order if production is not possible. Also it serves as model repository providing product and skill models to the other components in the framework. This is especially important for embedded SEE that cannot afford to store multiple models of skills and other data simultaneously. In this way it provides necessary manufacturing information on the shop-floor securing the reconfiguration of assets.

The skill-based AMS shall be a central system for a production company. Depending on the type and size of the enterprise the AMS shall be able to support multiple production facilities on different locations. Hence it is intended that the AMS acts as a cloud-based service provider for the other systems in the framework that are installed on-site for each location or for external components such as ERP or supply chain management systems. In this way it serves the purpose of an operating system for the digital factory and bridges the planning and manufacturing layer. The AMS shall store information about skills and assets for each location and consider them while creating coarse production plans or checking the feasibility of orders. Thus it will extend the flexibility of all production facilities of the company.

5   Conclusion and Outlook

In this contribution a novel skill-based asset management system was presented that aims at supporting the lifecycle management of technical assets in long- to short-term planning activities as well as the vertical integration between different IT systems in a manufacturing enterprise. First the need for such a system was highlighted by examining the current research in the fields of digital factory, asset management and skill-based planning. Then the concept of the skill-based AMS was presented as a part of the ongoing work on the European project SkillPro.

In order to realize a real-time decision making support, further research should be focused on both horizontal and vertical integration in realizing PLM-concepts of frontloading from production to product development or to factory planning and vice versa. As shown in fig. 3 this includes the consideration of an appropriate B2B integration of all stakeholders of the factory. Furthermore, a skill-based AMS can be a data management fundament for cyber-physical systems serving as a service integration platform for technology providers and operators.

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