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Approach for production planning in reconfigurable manufacturing systems

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Abstract

To stay competitive and to fulfill the changing market needs, manufacturing companies have to adapt their manufacturing systems in frequent and short intervals. Hence, changeable and reconfigurable manufacturing systems (RMS) are proposed and discussed in a multitude of research publications. While production planning becomes increasingly complex in this context, it has to be reliable and quick at the same time. Therefore, the performance and flexibility of manufacturing systems depends on actual and suitable planning data with high quality and wide range. In this context, a new approach for production planning in reconfigurable manufacturing systems is exposed in this paper. Data models, a configuration management and a sequential method for the resource planning help to integrate reconfigurable manufacturing systems' key characteristics in production planning and control (PPC). Finally a prototypical application scenario, for the evaluation and demonstration of the feasibility of the planning approach, is outlined.

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Keywords: Production Planning; Reconfiguration; Scheduling

1. Introduction

Nowadays, manufacturing companies are affected by high dynamics [1] due to shortening product [2] and technology life cycles [3], increasing numbers of variants as well as the rising demand for individual products. Some of the central market requirements are: short delivery times, a competitive pricing due to low production costs and high product quality standards. The ability to adapt to these constantly changing market requirements therefore is a prerequisite for the global competitiveness of manufacturing companies [4, 5].

One approach to ensure companies' ability to act successfully in this environment is changeability. Changeable systems can be distinguished by the fact that they are able to react with their inherent flexibility but can also respond to unpredictable situations [1]. To fulfill this requirement, several approaches have been discussed in the research community. In production, major approaches for increasing changeability are reconfigurable manufacturing systems (RMS) [6]. However, planning is becoming complex. Hence, challenges in managing manufacturing companies include support systems for reconfiguration, e.g. production planning and control (PPC) [7].

The PPC is an essential interface between costumers' needs and manufacturing processes and is not able to manage changes in the short time and is limited by its flexibility [8]. The success of PPC highly depends on exact and high-quality planning data. A survey among companies of machine and plant engineering illustrates that todays' planning systems suffer from low quality, inactuality and low range in planning data which results in unrealistic delivery times [9]. In order to cope with these challenges, a more sophisticated planning approach and data for higher validity concerning planning results are needed. To ensure sustainable quality and good performance of production planning, reconfigurations and the ability of change in configurations of manufacturing systems as well as resources have to be considered in PPC.

In this publication an approach of a system for production planning with focus on reconfigurable manufacturing systems is proposed. The planning approach, including a capacity planning, machine scheduling and optimization, and the necessary data models as well as a configuration management are presented.

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2. Reconfigurable manufacturing systems (RMS)

The characteristics and descriptions of reconfigurable manufacturing systems had been analyzed in several research activities in the past [e.g. 5-7, 10-12]. In the following chapter definitions, applications as well as differentiations to flexible manufacturing systems (FMS) are outlined. Furthermore, requirements for production planning with RMS are stated.

2.1. Definition and classification

Reconfigurable manufacturing systems can be described as highly dynamic and evolving systems designed to cope with unpredictable situations [6]. In this context, reconfigurability is defined as the ability to change systems' behavior by changing its configuration [13]. Additionally, ElMaraghy differs between hard and soft reconfiguration [7]. While hard reconfiguration is realized through changes and modifications of hardware (e.g. changing spindles), soft reconfiguration is fulfilled with adaptions in software or organizational aspects (e.g. additional shifts) [7, 12]. One main characteristic of RMS is their rapid adaptability concerning hard- and software as well as their structure (e.g. adding, removing and modifying machine tools) [6, 7]. These changes are implemented with minimal efforts in time and costs [1, 6]. Due to this main characteristic, their functionality and capacity can be configured and reconfigured as needed to respond to changes in market conditions [1, 5, 6]. RMS can be described by key characteristics: modularity, integrability, customization, convertibility and diagnoseability (see Table 1) [6]. For reducing efforts for reconfiguration time and costs, modularity, integrability and diagnoseability are the key enablers. In contrast, customization and convertibility open up the opportunity to reduce the operational costs of these systems.

Table 1. Key characteristics of RMS [according to 6].

Characteristic	Description
Modularity	Modular structure of components and controls
Integrability	Standardized interfaces for quick integration of new components and technologies
Customization	Customized flexibility and control
Convertibility	Short conversion times
Diagnoseability	Traceability of product quality during ramp-up

In contrast, flexible manufacturing systems are built up with all possible set-ups concerning flexibility and functionality [5] and can adapt only within their a priori pre-determined flexibility with different flexibilities (e.g. process and product flexibility). This includes producing only a pre-defined product spectrum and production amount within their flexibility corridor [7]. Adaptions, which go beyond this flexibility, require substantial efforts. To summarize, FMS are limited in capacity as well as in functionality [6]. Adaptions inside their flexibility can be managed rapidly and at low cost. However, one disadvantage is the high initial capital investment for the inherent and often not used flexibility [6, 7].

The significant differences between FMS and RMS are systems' flexibility and scalability concerning capacity and flexibility in particular (see Fig. 1). To meet market requirements, reconfigurable manufacturing systems provide on demand customized flexibility through scalability to incrementally realize different functionalities and capacities [5, 7]. In contrast, flexible manufacturing systems feature a general a priori-fixed flexibility and are able to change inside their inherent flexibility. Whereas FMS can produce multiple products at installation time, RMS are designed for a certain product portfolio (e.g. product A at the beginning and B+C in the last extension stage).

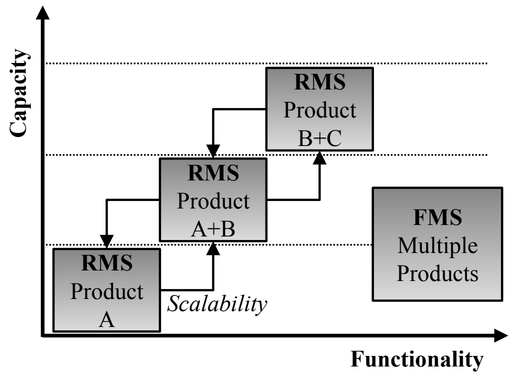

Fig. 1. Capacity and functionality of RMS and FMS [according to 6].

2.2. Requirements for production planning

The significance of scalable functionality and capacity of RMS as well as the availability and quality of planning data are the main enablers to cope with todays' constantly changing requirements in the field of PPC.

Due to these challenges, the key characteristics of RMS, as discussed before, need to be integrated in the production planning and control. For this purpose, the planning data primarily have to feature the functionality and scalability of these systems and their manufacturing resources. In this context, different capacities subjected to systems' and resources' configuration are one possible approach. Additionally, planning data are to be distinguished by their convertibility e.g. changes between different planning data sets have to be described and proceeded in short time. In order to cope with the characteristics of RMS, planning data need to be adaptable and the integration of changed data has to be enabled. As a consequence of the change in planning data, new methods for production planning and allocation need to be developed. The consideration of different configurations and the scalability concerning functionality and capacity is inevitable to increase flexibility and adjustability of planning approaches for RMS.

3. State of the research

The production planning and control (PPC) supports manufacturing companies in their order processing. As one main function, the PPC fulfills the task to plan and control production processes in terms of quality, schedule and capacity [14]. Besides a high on time delivery, traditional command variables are a constant and high load factor. In addition, planning has to ensure high process efficiency and reliable planning results [15]. In the area of PPC approaches often use presumed production parameters (e.g. fixed machining times and lot sizes) and configurations of production resources. Existing systems for the compilation of production plans are able to handle small batch sizes and can adapt to changes in production processes in many cases, but at the same time are limited concerning flexibility and adaptability [16]. Thus, Wiendahl describes a framework for a changeable PPC system and illustrates elements and enablers for changeability in PPC [8]. The main focus of this approach is a PPC design matrix for the structural configuration and change processes in the PPC. RMS and adaptive planning data are not investigated in this approach.

3.1. Planning data and manufacturing resources

The quality and efficiency of production planning depends on highly stable planning data. Furthermore, planning data has to include the functionality of production systems and resources. These planning data is called master data and is divided into material and resources data, work plans as well as data about suppliers. An approach for increasing planning data quality is “High Resolution Production Management” (HRPM) [15]. The focus hereby is the regulation of the whole PPC based on real-time data and high-resolution information in production for adaption of company structures and processes. The consideration of reconfigurations in the production systems is not discussed.

A concept to adapt master data for adaptive scheduling is presented by Geiger and Reinhart [17]. The described approach uses radio-frequency identification (RFID) technology for the acquisition of product-specific emergence data from the shop-floor. With these product-specific data work plans can be steadily adapted to the current conditions in the production situation and a dynamic allocation of resources is implemented. The concept is strictly designed for adapting throughput times. The product-based control of production processes is described by Ostgathe and Zaeh [18]. The system consists of data models, a knowledge-based system and an organizational structure. Resource data and models are based on standards and guidelines for manufacturing resources. Furthermore, resource models are detailed by boundary conditions and formal descriptions of skills. The two approaches described above are designed for adaptive scheduling and product-oriented approaches. They do not support skills of RMS to the planning approaches.

A methodology for resource planning in the highly variable production of the food industry is presented by Moeller [19]. Initial point of his methodology is the modularization of products. According to this step, Moeller arranges the planning system to a variable and stepwise target system (cost, time and quality) which is extended to the interoperability and combination of resources. Reconfigurable manufacturing resources are not part of the aforementioned research activity, but the general understanding of manufacturing resources and integration in planning processes can be used for the planning approach.

3.2. Planning in reconfigurable manufacturing systems

Several authors highlight the potentials of reconfigurable manufacturing systems and reconfigurations in production systems [e.g. 7, 20-23]. Karl and Reinhart describe a methodology for strategic planning of reconfigurations in manufacturing resources [21]. The methodology is applied twice in the life cycle of assembly manufacturing resources (AMR): at first in the initial phase and second before reconfigurations are executed. The focus of this approach is the displaying of all possible reconfigurations of assembly manufacturing resources and the final evaluation of these reconfigurations with the help of key performance indicators. This approach describes a methodology for planning reconfigurations on AMRs, but does not focus on PPC.

An agent-based approach with a negotiation model for production planning in reconfigurable manufacturing enterprises has been developed by Bruccoleri et al. [22]. The multi-agent system supports the decentralized decisions in plants. Each plant is described with certain production skills for a product family and a geographical position. The negotiation for allocating production plants to product groups takes place every three months. Focus of this research activity is the level of production plants and networks. The increasing complexity due to the multi-agent-system is a main disadvantage of this approach. In addition, it does not consider skills of RMS on the lowest planning level.

The selection of a configuration for RMS is described by Youssef and ElMaraghy [23]. Basis for this planning approach are constraint procedure, genetic algorithm and tabu search. The concept consists of two phases. In the first phase near-optimal alternative configurations of RMS for a possible demand scenario are derived. Focus of the second phase is the derivation of alternatives configurations from those used in the initial phase. In this context, configurations include both arrangements of machines as well as the selection of equipment and processes. Main focus of the approach is the selection of a configuration for the system or network level. Furthermore, the approach selects a configuration for a reconfigurable system for a certain demand scenario for achieving the best performance with respect to operational costs. To summarize, the approach misses the consideration of individual skills of reconfigurable manufacturing resources. Predominantly, the network-level is addressed. The general definition of configurations and their application in planning RMS can be used for the following approach and the design of the data models.

3.3. Conclusion

In fast changing environments, a quick and efficient adaption of manufacturing systems becomes important. As a consequence, reconfigurations in manufacturing systems raise the complexity of planning and scheduling processes [22]. However, the state of the research illustrates that no continuous approaches for production planning and scheduling for reconfigurable manufacturing systems are available. In addition, the consideration of the key characteristics of reconfigurable manufacturing systems and resources in the production planning process is inevitable for increasing flexibility in production management.

Based on the aforementioned research activities in the area of production planning, the following potentials for a new approach can be identified: integration of the functionality and scalability of RMS in production planning, increasing flexibility of planning data by integrating skills of RMS in planning data and realization of high transparency as well as high-quality data due to the actual conditions of manufacturing resources and their configurations.

4. Approach for production planning in reconfigurable manufacturing systems

4.1. Overview

The research goal of this approach is the development of a system for production planning in RMS. One main focus is the integration of the capability of reconfigurations in RMS into the production planning process. The approach enables the integral utilizations of the key characteristics of RMS in the production planning. The single elements and the schematic structure of the system are illustrated in Fig. 2 and described in the following sections.

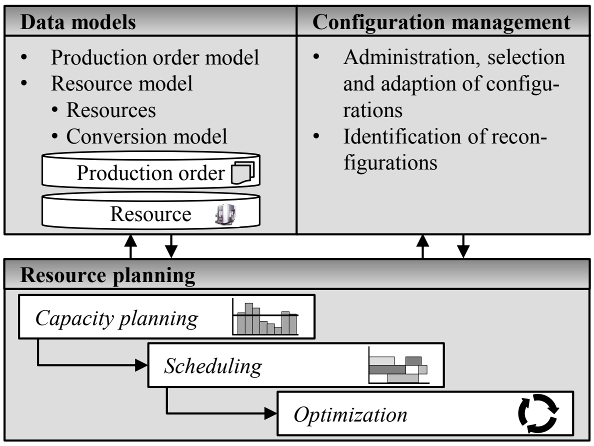

Fig. 2. Overview and structure of the planning system.

A prerequisite for the production planning is the formal description of production resources and production orders. Thus, there is a need for generic *data models* representing configuration-based skills of resources and requirements of production orders. The data models comprehend all information to enable the approach for production planning with RMS. Based on the data models, the *configuration management* is to select and adapt possible configurations of manufacturing resources as well as matching skills of manufacturing resources and production order requirements is taking place. In addition, reconfigurations are to be identified and new configurations are generated. With the help of the data models and the configuration management, a suitable sequential *resource planning* approach consisting of three steps (capacity planning, scheduling and optimization) is developed and enables the utilization of the key characteristics of RMS in production planning.

4.2. Data models

The successful production planning for RMS is dependent on the representation of the key characteristics of RMS in planning data as well as a suitable modeling of these data.

The production order model is designed to describe the product and process-specific requirements. According to Ostgathe and Zaeh [18], the production order model derives in organizational (e.g. last delivery date and max. production costs), technological (e.g. material) and geometrical (e.g. size) information. Furthermore, the data model is enhanced with alternative process plans and process-specific information (e.g. machining time). With all this information available, comprehensive requirements for production orders can be described and therefore provide the basis for matching these requirements with resources' skills and configurations.

RMS are divided in multiple manufacturing resources. The individual skills of each resource in the system are described in the resource model. The general classification of manufacturing resources' characteristics are based on recognized standards (e.g. DIN 8580 for technology skills) and several research publications [e.g. 18, 24, 25]. In particular the general performance, the feasible production operations and technologies (e.g. milling) as well as the geometrical characteristics (e.g. available space) of manufacturing resources are to be adopted and transferred to resources' configurations. Furthermore, the data model includes dynamic, configuration-based planning data (e.g. machining time, capacity and machine hour rate). The derivation of possible configurations enables the representation of scalable functionality and capacity – the main characteristic of RMS – in planning data. In this context, a configuration describes all possible settings of a manufacturing resource and is divided into technical (C_{Tn}) and planning (C_{Pn}) aspects (see Fig. 3).

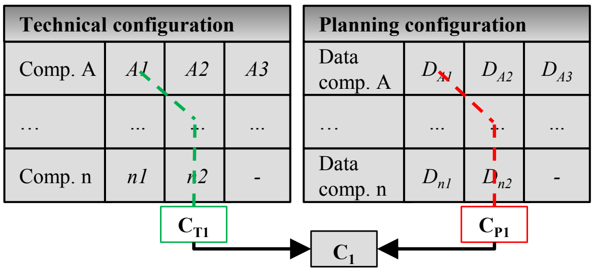

Fig. 3. Technical and planning configuration of a manufacturing resource.

Each technical configuration is derived by the setting of several components. The sum of planning skills of each component results into the planning configuration. The agglomeration of these two types of configurations results in one possible configuration for a manufacturing resource. Additionally, a configuration can be modified, removed or added by a reconfiguration. Last but not least, the resource model includes a conversion model for description of configuration changes. Changes in configurations can be described as a retooling of the component constellations of each resource and resetting of the describing planning parameters. These changes transfer a manufacturing resource from a defined state or position to another defined state. The conversion model itself is designed to describe the efforts for changing the configuration (e.g. time and costs).

4.3. Configuration management

The main goal of this system element is the preselection of suitable configurations of manufacturing resources for each production order. Hence, the configuration management is responsible for the administration, the selection and adaption of existing configurations in the planning system. Moreover, new reconfigurations can be identified. In this context, a reconfiguration represents changes both for existing technical and planning configurations by adding, removing or adapting components planning parameters. Reconfigurations of manufacturing resources may occur if matching between available configurations and requirements yields no result. In this case, the configuration management derives a new configuration based on existing configurations (e.g. C4 for resource 1 in Fig. 4) and describes this new configuration with technical and planning skills.

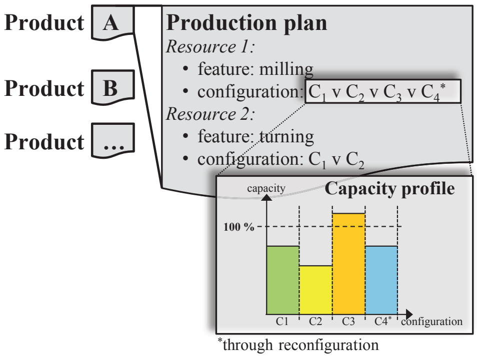

Fig. 4. Production plan with configurations for each production order.

The administration of all possible configurations implies monitoring of the actual configurations of each resource and securing of validity of planning data as main functions. In case of changes in existing configurations, adaptions are executed. One additional function is the selection of configuration by matching skills (e.g. milling and capacity) of manufacturing resources and production order requirements. Based on these results, possible configurations of all those resources involved in the manufacturing process are chosen for a production order (see Fig. 4). Each configuration can be described by e.g. an individual capacity profile or machine hour rate based on the selected configuration.

4.4. Resource planning

In order to assess the achieved target, a new method for resource planning for reconfigurable manufacturing systems is needed. The planning approach is a stepwise process and divides into capacity planning, scheduling and optimization. The main aim of this approach is the utilization of skills and the illustration of the scalability of RMS in the production planning. Furthermore, the integration of reconfigurations into the planning process and the selection of configurations for manufacturing resources is in focus.

In the context of *capacity planning*, matching of capacity requirements and offered capacities precedes. Each configuration provides a capacity profile (see Fig. 4) to the planning approach. With the help of this profile, a preselection of configurations, which are possible for the demand scenario, is executed. Consequently, several configurations are eliminated and only adequate configurations with a fitting capacity profile will be left.

After the capacity planning is finished the *machine scheduling* generates alternatives of possible production sequences and allocations of manufacturing resources under consideration of possible configurations and their necessary boundary conditions (e.g. restrictions in configurations). In the first step of scheduling the operations of the production order are assigned to the available resources.

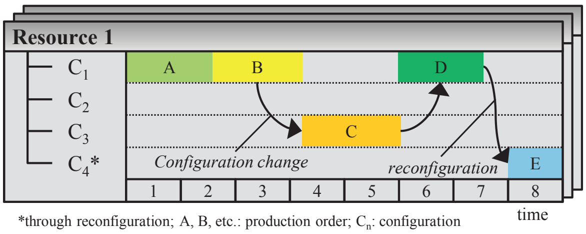

Fig. 5. Resource allocation with configurations and configuration changes.

As costs of operation for RMS depend on configuration [6], an *optimization* approach is executed. This step finalizes the configuration of each resource in the manufacturing sequence for the production order. Input data are the alternative resource allocations as well as command variables (e.g. short delivery time or low production costs). Further changes in the configuration (described by conversion model), restrictions (e.g. handling unit is not available, C1 is not possible) and the actual state of each resource will be taken into consideration. In the case multiple resources meet the requirements; the selection is done according to the best achievable performance with the possible configuration. The result of this step is a sequence of production orders on each resource including a suitable configuration (see “Resource 1” in Fig. 5). To ensure a high planning actuality, the selected configurations as well as the sequence for the production orders are circulated to the data models and the configuration management.

5. Application

For implementation and validation purpose of the presented approach, data models for production planning with RMS are currently developed with formal and generic descriptions in a first step. Therefore, a prototypical description with the data models of different manufacturing resources is conducted. The focus of this step is the general description of reconfigurable manufacturing systems and resources by adequate planning data.

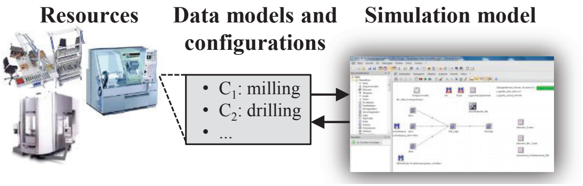

Fig. 6. Prototypical application scenario.

Next step is the buildup of a simulation model based on the data models for the purpose of a validating platform (see Fig. 6). Then, the set-up of the complete planning system including the configuration management as well as the resource planning approach is realized. Furthermore, the configuration management is linked with the data models and the planning system. Last but not least, methods of production planning for reconfigurable manufacturing resources have to be assessed which meet the challenge to use the key characteristics RMS in planning approaches.

6. Conclusion

In order to cope with changing market conditions, manufacturing companies have to adapt their manufacturing systems frequently. In regard to these challenges, existing approaches do not support the production planning for RMS sufficiently. Furthermore, planning data are still limited in their functional range and do not represent the key characteristics of RMS. The approach, described in this paper, takes account of production planning for reconfigurable manufacturing systems. Data models and configuration management enhance the representation of RMS characteristics in planning processes. Based on these data a stepwise resource planning approach generates and optimizes resources' allocations.

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