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Method for a situation-based adaptation and validation of the manufacturing capability of assembly systems

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Abstract

This paper presents our approach and the developed method for a situation-based adaptation and validation of the manufacturing capability of assembly systems. After motivating the research the problem statement and the state of the art in the field of assembly planning will be discussed. Afterwards the overall approach will be introduced. The method, which is developed based on the approach will be discussed and the derived software tool, which will support the planner in his daily activities, will be presented and explained. The paper concludes with a summary and an outlook.

Keywords: Assembly System, Modeling, Factory Planning, Manufacturing Capability

1. Introduction

There are three major challenges concerning the efficient and economic operation of assembly systems. These are the increasing number of product variants and shorter product life cycles, the increasing alteration rate of the order composition and based on this the increasing numbers of set up procedures considering machines and equipment [1]. Additionally, external factors from the global market like the demand of customers for innovative, state-of-the-art and individual products, supply bottle necks or different types of crises affect the assembly systems, as well. The challenges derive from the so called mega trends – individualism, ageing, innovations in technology, sustainability – which directly influence the operation of assembly systems, through increased turbulences. [2]. This matter of fact, is already known in the scientific community and is approached by strategies to increase the flexibility and changeability of assembly systems [3][4][5][6][7][8]. Although, these strategies mainly focus on increasing the middle – long term changeability of assembly systems and their structures. To ensure an efficient and economic operation of assembly system in this turbulent environment, approaches and methods for short term adaptations, which allow a permanent and situation-based adaptation of assembly systems, have to be developed [9]. Thereby our approach aims at the manageability of the systems complexity, the enabling of an intuitive model development and the acceleration of optimization and adaptation processes.

After emphasizing the potential and the benefits of such a method, an overview of the Method for a situation-based adaptation and validation of the manufacturing capability of assembly systems is given. Afterwards the state of the art regarding contemporary methods for assembly planning and optimization is presented and the approach as well as the developed method will be introduced. The paper concludes with a roadmap for future research activities, which can be undertaken to drive the research for short term adoptions of assembly systems even further.
2. Problem statement and Motivation

Today’s manufacturing is influenced by enormous short term influences, considering product variants, order compositions and technical innovations. Customers are able to influence their orders even if they are already processed in the assembly system. Additionally, short term orders done by key account customers disrupt the already executed production plan. Furthermore customers are able to place last minute changes on the configuration or production process of the product, due to the increasing competition. This leads to permanent adaptations of the operation and the structure of assembly systems and cause failures of machines as well as ends in downtime of the whole system. In this environment a permanent adaption of the assembly system structure is not any longer optional. In fact it is a critical factor to ensure the competitiveness, to operate in a turbulent environment.

However, the modeling and subsequent simulation of an assembly system, with all the relevant data and information, is a time and knowledge intensive task. Today, commercial digital tools indeed support the modeling and simulation process through an efficient data and information management, resource libraries and process management, but do support the process of the model development and the integration of knowledge into a model in an insufficient way [10].

Thus a new approach has to be found to provide a valuable support for engineers in the production planning and control department. To ensure this valuable support the method has to support the modeling of the current situation of the assembly system and subsequently the analysis. Furthermore a procedure to identify discrepancies considering the optimal operation has to be provided. Thus the planner knows exactly if there is a need for an adaptation and when he has to initiate it. Additionally the method has to provide assessment criteria to evaluate adaptation concepts. This coherence is depicted in Figure 1.

3. Assembly planning and optimization – today

This chapter provides the state of the art considering the assembly planning and optimization methods. Additionally it presents approaches to structure assembly systems and increase their changeability.

3.1. Structure of modern assembly systems

To enable an active adaptation of the complex structure of assembly systems, different approaches have been developed. However all of these approaches employ the basics of System Theory [11]. This method is suitable to structure complex systems and provides a generic approach to describe them by consistent terms to be able to predict the future behavior and performance of a system. Thus a model developed from the system theory perspective comprises an arrangement of elements, which are defined through specific attributes, connections and different activities within a determined system boundary [12].

An important foundation for the structuring of assembly systems was provided by Westkämper. In this approach a production system consists of performance units, which are able to operate in turbulent environments, due to their system immanent characteristics. They contain factory objects and workers and operate self-controlled and self-organized. A performance unit additionally has relations to other performance units which enable an active cooperation. Thus a system is structured horizontal and vertical through performance units. This enables an efficient and short-time reaction to fast changing environments [5] (Figure 2).

Additionally there are further approaches to structure assembly systems and to increase their changeability. Thereby these approaches focus whether on the organizational or the technical aspects of an organization. Organizational approaches are developed by Wildemann and Warnecke. Wildemann pursues the approach of a modular factory. Thereby the assembly system will be divided in modules which perform a specific production task [13]. However, Warnecke follows an approach called the fractal factory. The assembly system in this approach is clustered in independent fratacls, which perform their production task independently [14].
approaches lead to an highly flexible structure to face internal and external turbulences on an organizational level.

Technical approaches in contrast focus on machines and workplaces to achieve a flexible and changeable reconfiguration of assembly system elements. Thereby UEDA developed the Bionic Manufacturing System, which is based on living organisms. Thereby the assembly system is structured by modelons which contain genetic as well as knowledge based information. Furthermore the modelons can adapt to different turbulences [15]. KOREN pursues an approach which is called Reconfigurable Manufacturing System. Within this approach the reconfiguration of assembly system objects is achieved through modularization. These modules contain specific functions and can be changed according to the specific influences [16]. Another technical approach was developed by GOLDMANN. This approach is able to react fast to customer needs, due to the agile structures. In this approach the qualification of the workforce is a key issue to achieve a fast reaction [17].

The presented organizational and technical approaches to structure assembly systems are able to increase the changeability and overcome predefined flexibility corridors. However, the Stuttgart Enterprise Model developed by WESTKÄMPER combines both the organizational and the technical perspective. Thus, this approach will be considered in the development of our method.

3.2. Assembly planning and optimization

Another important area, while developing a method for situation-based assembly systems are the assembly planning and optimization procedures. In the mid 80s different researcher developed factory planning methods to provide enterprises an advantage in an more and more globalized environment [13][18][19]. In the 90s these approaches and methods were implemented in the industrial praxis. Today’s assembly planning, which is based on this approaches and methods, does not differ to much from these. The general structure is similar. It contains the phases “goals and basic principles”, “Structure planning”, “Detail planning” and “Implementation”. The difference is the increased focus on the needs of assembly system planning.

To ensure a structured planning of assembly systems, modern approaches focus on project-oriented procedures. Thereby the complex relations between different planning phases and internal as well as external influences are considered and thus an integrated planning of an assembly system can be achieved. Additionally important information exchanges between departments, which are concerned by the planning process, are enabled. Detailed steps considering the assembly planning can be consulted in the resent scientific literature [20][21][22][8].

However, these approaches and methods follow an sequential procedure – Normal Planning. Thus, if there is a change in the assembly system concept, the planning procedure has to be redone. This assumption is depicted in Figure 3.

Additionally to the assembly system planning methods, there are various methods for the assembly system optimization. These methods derive from the “Toyota Production System” which contains different methods and procedures to optimize an existing assembly system. The goal of these methods and procedures, like Kanban, Poke Yoke, Single minute exchange of die, are the orientation of the assembly system considering the customer needs and the avoidance of processes that do not contribute to the value creation [23]. These methods mainly focus on processes in an closed system boundary. Considering a situation-based adaptation of an assembly system these methods are not suitable for our approach, due to their lack of consideration of complex interdependencies between different factory objects.

3.3. Software supported assembly planning and optimization

Consequently, these presented methods are integrated in digital tools, which support planners in performing planning and optimization tasks. However, due to the high effort considering the modeling of the current situation of an assembly system, this often times will be avoided. Additionally developed models are generated for a specific purpose. If there is a change or another application needed, the model development process has to be redone [24]. However, there are innovative approaches, which pursue small software applications, which are designed for a specific task. These software applications – so called engineering apps – are able to provide an intuitive and efficient utilization. Thus, planners are able to analyze and assess different adaptation concepts [25]. For the presented approach, the concept of small software applications will be taken into account to provide an optimal support for planners.

Concluding the state of the art regarding an situation-based adaptation and validation of manufacturing capability of assembly systems is depicted in Figure 4.
4. Situation-based adaptation and validation of manufacturing capability of assembly systems - approach

To enable a permanent and situation-based adaptation of assembly systems, the shortcomings of today’s approaches considering the short-term adaptation have to be focused on. Therefore in a first step the three major influences considering the economic operation of an assembly system and their complex interaction have to be investigated. These are the order composition, the increasing number of product variants and last minute changes as well as the technical disruption (Figure 5).

Starting from a normal planning of the assembly system, which is based on preplanned capacities and production volumes an optimal structure will be implemented and operated. While operating the assembly system different short-term influences occur and induce a divergence considering the optimal operation point. Therefore different short term based actions have to be identified to react properly to the occurring divergence. These short-term actions are induced from the changeability drivers known as mobility, scalability, universality, configurability and modularity [7].

Another important fact is the possibility to develop a model of the current situation of the assembly system. Due to the fact, that former changes and adaptations in the assembly system generated an evolved structure, available layouts and information are not always up to date. This induces a need for a fast and efficient model development procedure. It is based on the method of the value stream design, but combines process-oriented and object-oriented modeling. This procedure was presented in detail in our former research activities [26].

Furthermore an assembly system base model was developed to ensure an further efficient modeling of the current situation of an assembly system. The assembly system base model contains factory objects and interdependencies. These elements are structured through the “Stuttgart Enterprise Model” (SUM), which describes an enterprise based on the System Theory [5]. In our approach the SUM-scales assembly system, assembly cell and machines and workplaces are considered. For every SUM scale relevant factory objects and interdependencies are allocated. This enables an efficient modeling of a specific part of an assembly system. The foundations of the assembly system base model and the state-of-the-art are presented in detail in [27].

Additionally a resource library supports the planner while developing a model of an assembly system. It consists of specific factory objects for every scale of the assembly system. These factory objects are predefined by the engineer and thus can be reused. Furthermore the resource library contains interdependencies between factory objects and processes, thus a knowledge-based modeling is enabled. The different resources can be accessed through the employment of a data model, which is based on the assembly system base model.

The Manufacturing Capability also has to be considered. While planning a new adaptation concept the structure and therefore the performance of the assembly system is influenced. Therefore different key performance indicators, which are common in the manufacturing industry, have to be assessed and aligned. Thus the performance after an adaptation of an assembly system is ensured.
5. Situation-based adaptation and validation of manufacturing capability of assembly systems - method

The method for a situation-based adaptation and validation of manufacturing capability of assembly systems, derives directly form the presented approach. Thus, the method comprises 6 steps to perform an adaptation. These steps are sequentially structured, but do have interdependencies between them.

The first step comprises the analysis and the model development of the assembly system of interest. Based on the definition of the system boundary, the assembly system with its containing assembly cells, workplaces and machines as well as processes will be analyzed. Relevant factory objects, their parameters and the interdependencies between them, will be identified and included into the model. This model is the basis for the further adaptation process.

The second step comprises the identification of the short term influences, which generate a divergence considering the optimal operation of the assembly system. This divergence arises for example through fast lane orders, technical failures, organizational issues or machine downtime.

The third step of our method consists of the development of adaptation concepts, which are able to reestablish an optimal operation. Therefore short term based actions are identified and integrated into the method. With this short term based actions, a fast and efficient reaction to external and internal turbulences is enabled. The time horizon of these actions is in total 1 shift to 1 day. This will ensure a fast solution of the existing issues. The output of this step is different adaptation concepts, which have to be assessed to identify the most effective one. The short term actions are structured into four different groups. These groups contain actions which are suitable to overcome short-term influences and ensure an economic assembly system operation.

The fourth step consists of the assessment of the developed adaptation concepts. Therefore the presented method contains industry driven key performance indicators to ensure the performance of the assembly system. Due to this fact, this method can be employed in the industrial praxis. Therefore the current and historical key performance indicators will be investigated. The adaptation concepts will be assessed with the same key performance indicators. Afterwards they will be compared. Through this procedure a loss of performance after an adaptation will be eliminated. Additionally the time, which is needed to employ the adaptation concept, will be assessed by using the estimated change time. Thus, the time an adaptation concept ramp-up will consume can be provided and the production loss can be forecasted.

The fifth step is the selection of one adaptation concept. Therefore not only the results of the key performance indicators comparison will be taken into account, but also the sustainability of a concept. For example, even if an adaptation concept consumes more time and economic effort to be implemented, if this concept provides advantages regarding future fast and efficient adaption, this concept should be implemented. This procedure will ensure a high competitiveness of the enterprise overall.

The sixth step is the support of this procedure through an digital tool. This allows the reuse of models and a fast analysis procedure. Therefore an app-based tool was developed, which supports the modeling process and the analysis of common key performance indicators. It contains a resource library to enable a fast and efficient modeling process. Once the existing factory objects are integrated further model developments will take less time.

Figure 6 presents the steps and the interdependencies of our method for situation-based adaptation and validation of manufacturing capability of assembly systems.

6. Software Tool

For the sufficient support of the planer, a software tool was developed. This tool supports the model development process as well as the development of adaptation concepts. The core of the software tool is the “assembly base data model”. This data model contains relevant factory object classes, which can be instantiated and stored in the resource library. This procedure enables an efficient modeling of the assembly systems due to the re-use of existing factory objects out of the resource library.

The instantiated factory objects additionally enable the assessment of the performance through the use of key performance indicators. Thus the current performance situation and the performance of the adaptation concepts can be...
compared. Thus, the manufacturing capability can be ensured through the key performance indicator comparison.

Another important pillar of the software tool is the graphical user interface. This user interface is designed to enable an intuitive usage of the software tool. Figure 7 describes the arrangement and the function of the graphical user interface.

![Fig.7: Graphical User Interface of the software tool](image)

The software tool is written in the mark-up language JSON (Java Script Object Notation). The advantage of JSON compared to XML (Extensible Mark-up Language) is the decreased complexity and storage needed. Thus the software tool runs on portable devices, which allows a model development process directly in the shop-floor.

7. Conclusion and Roadmap

This paper presented our research regarding a our method for situation-based adaptation and validation of manufacturing capability of assembly systems. Therefore the motivation to start with this research and the state of the art considering assembly system planning and optimization was presented. Afterwards the short term influences considering the operation of an assembly system were introduced and the approach to face these issues was presented in detail. Out of this approach a method was derived which consists of six steps.

The situation-based adaptation and validation of manufacturing capability of assembly systems is an on-going and complex research topic where future developments are of huge interest. Thus, the next steps research focuses can be as follows:
- Research considering the short term influences and the interdependencies between the manufacturing and the assembly systems
- Acceleration of the model development and the analyzing of influences considering the assembly system.
- Evaluation of the method in an industrial use case
- Further development of the software tool

8. References


