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Method for Multi-Scale Modeling and Simulation of Assembly Systems

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Abstract

This paper presents the on-going research steps aiming at the development of a Method for Multi-scale Modeling and Simulation of Assembly System. The focus lies on the Assembly System Base Model and its integration into the whole method. After motivating the research, the developed method and the conceived model of the assembly system is introduced, by using the proposed methodology. The presented approach aims at the manageability of the systems complexity and the acceleration of optimization and adaption processes. It concludes with a roadmap shaping the next steps and activities.

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1. Introduction

Today’s world of manufacturing is confronted with megatrends like individualism, urbanization and breaking innovations in technologies as well as turbulences driven from the markets and finance [1]. With these statements Westkämper characterizes in short the new boundary conditions of manufacturing. This implies that manufacturers have to react fast to changes in a global market and simultaneously take the growing demand of customers considering innovative, state-of-the-art and individual products as well as sustainable production methods into account [2].

To stay competitive in this environment manufacturers have to face and realize different challenges like shorter product life cycles, increasing number of product variants and the efficient integration of innovative technology into their production system. These challenges induce a growing number of adaptation and optimization processes, which lead to production systems that are characterized by evolved structures with high complexity and diversity. Especially the assembly system is affected by this development, since it has to react continuously and immediately to changes in the market [3].

As a link between the production and the sales department, manufacturers have to employ sufficient knowledge-based methods and tools, which enable an efficient and fast modeling and simulation of assembly systems and their corresponding processes. Thus, the understanding of complex interdependencies between factory objects, the infrastructure and production parts can be achieved. Furthermore adaptation scenarios and optimization measures considering the assembly system can be assessed [4]. To achieve this valuable support for manufacturers, this paper introduces an approach aiming at the development of a "Method for Multi-scale Modeling and Simulation of Assembly Systems". This approach aims at the manageability of the systems complexity and the acceleration of optimization and adaption processes. It is represented by a knowledge-
based method for modeling and then simulating the assembly system in all its scales, to allow an efficient scenario analysis. Through this a significant reduction of the needed modeling time and experience can be achieved. Within this approach, as a first step, the technical aspects of a hybrid assembly system, consisting of Factory Objects. Thereby a Factory Object is defined as follows:

A Factory Object, of a specific scale, is a machine, tool, device, workplace, transport system, manufacturing equipment, or manufacturing resource which is required to fulfill the purpose of manufacturing and/or logistic processes. It is defined through its scale, position, and condition (state of a Factory Object) over the time. Its interdependencies (infrastructural boundaries or their sequence in the manufacturing process) with other Factory Objects and scales are approached as well. Thus, two different classes of Factory Objects can be defined: a) Temporary (mobile) Factory Objects, whose scale, position and condition changes over the time; b) Permanent Factory Objects (mainly immobile), whose scale and position remains constant, in opposite to its condition, over the time.

The logistics and the material flow resources will be considered, as well. The organizational the social aspects and the connection with Enterprise Resource Planning (ERP) and Manufacturing Execution System (MES) are at the moment leaned in secondary plan.

After emphasizing the potential and the requirements for such a method, an overview of the method for Multi-scale Modeling and Simulation of Assembly Systems is given. Afterwards the approach for the Assembly System Base Model is introduced. The paper concludes with a roadmap for future research activities to support a multi-scale modeling and simulation of assembly systems.

2. Problem Statement and Motivation

As stated, a model is a valuable instrument to manage the complex and evolved structures of an assembly system and to enable its active as well as continuous planning, adaptation and optimization [5]. It consists of Factory Objects, their characterization and interdependencies in a transparent and comprehensive way. Thus a consistent understanding and an efficient communication of all involved planning partners can be assured [6].

However, the system modeling and subsequent simulation of a complex evolved system like an assembly system is an knowledge and time intensive process. The effort can grow fast and sometimes exceeds the benefits of the resulted model [7]. Thus, the modeling process has to be supported through suitable methods and digital tools. Today, commercial digital tools enable the reduction of the effort to model and simulate complex systems through a sufficient data management, support functions and a structured resource and process management [8]. But most digital tools lack in supporting planners considering an efficient model development process and in the integration of knowledge as well as additional documentation into a model [2]. Thereby, while performing an adaptation or optimization process the planner gets insufficient feedback from the digital tool what consequences or changes the performed adaptation generates for the whole assembly system. This leads to the fact, that in conventional models of assembly systems interdependencies between and semantic characteristics of Factory Objects have to be interpreted, constrained by human knowledge. Additionally, those models are not fully transparent to all actors [9].

The gain a reduction of the effort and of the required knowledge for modeling and simulating complex systems is the employment of reference models. Existing reference models consist of theoretic planning procedures or workflows, to give an overview what information has to be used in a specific stage of the planning or how a model can be developed efficiently [10][11]. The issue with these reference models is that there is insufficient support through manufacturing resource libraries or digital tools to accelerate the model development. In fact, a suitable modeling method and a digital tool have to be selected by the actor based on own experience and knowledge. Reference models cover whole planning processes of factories, in all its scales from network to site, segment, production system, machines and workplaces and technical processes. This results in a generic structure. [7] but ensures a broad application area for the many industrial sectors and types of factories, by taking into consideration the corresponding adaptations. These additional customizations are time intensive, as well [12]. Existing reference models for the planning or modeling of assembly systems are generic and do not explicitly refer Factory Objects, their features and their interdependencies in a suitable manner [13].

These challenges represent the motivation for the development of the method introduced here. Modeling of complex systems, as presented, is a difficult task which requires a huge amount experience, effort and implicit as well as explicit knowledge. To address these issues, this paper proposes a Method for Multi-scale Modeling and Simulation of Assembly Systems. It
enables an efficient modeling of the current state of an assembly system through the use of a Modeling Procedure. An integrated manufacturing resource library with predefined and/or configurable Factory Objects and interdependencies for each scale of an assembly system accelerate and reduce the effort for the modeling process. A suitable Modeling Language, an enhancement of the Value Stream Mapping, increases the usability for the planner. The employment of a modeling language from the field of semantic web technology in the background of the method enables the embedding of knowledge within the model. This reduces the required experience and knowledge to model an assembly system and to get a detailed understanding of the system's behavior. Additionally, it is the basis for the description and analysis of various planning solutions and scenarios.

3. Method for Multi-Scale Modeling and Simulation of Assembly Systems

The overall approach of the research aims at the development of a method for an efficient and scalable modeling and simulation of an assembly system in all its scales, based on a manufacturing resource library, a suitable modeling language and a modeling procedure, that enables a knowledge-driven and continuous optimization of the assembly system as well as scenario analysis. To reach this ambitious goal, five pillars, depicted in Figure 1, have to be developed, employed and combined in one method. The pillars Modeling Languages, Resource Library, Modeling Procedure, and Optimization will be shortly described in this Section. The pillar Assembly System Base Model, which is the focus of this paper, will be presented in a more detailed way in the following Section. The foundations of this approach, the state of the art, the concepts for developing a method that enables the modeling of complex systems and existing other methods are presented in [14].

Modeling Language

This approach employs two modeling languages. The first one enables a suitable and intuitive employment of the method for an actor. Therefore the Value Stream Mapping [15] will be enhanced with required notations, e.g. to model the layout. Thus, the actor is provided with an easy to use and established graphical modeling language. In the background a semantic web technology modeling language, e.g. Ontology Web Language (OWL) will be employed for the purpose to add semantic to the classical modeling method. This enables a semantic characterization of Factory Objects and a proper modeling of interdependencies between them. Furthermore the XML-based language can be employed as a data exchange format between digital tools and data models.

Manufacturing Resource Library

The resource library supports the planner to develop a model of the assembly system with less effort and needed experience. It consists of Factory Objects for every scale of the assembly system. These Factory Objects are predefined and/or configurable. Furthermore the Resource Library contains interdependencies between Factory Objects and processes, thus a knowledge-based modeling is enabled. The different resources can accessed through the employment of a data model, which is based on the Assembly System Base Model presented in the following Section.

Modeling Procedure

On the one hand the modeling of assembly systems will be structured according the scales and supported through the employment of flexible workflows and established procedure. This enables less experienced planners to develop models efficiently. Furthermore the model development is performed in two steps. In first step the existing assembly system is modeled on the fly” directly in the shop floor e.g. with a tablet PC. Thus, the layout and the internally interdependencies of the Factory Object and between the Factory Objects can be modeled. In a second step this rough model can be detailed and optimized. On the other hand the modeling will be supported through an easy to use drag and drop function and an intuitive Graphical User Interface (GUI).

Optimization

By embedding knowledge into the model, an active analysis, configuration and optimization will be supported. While adapting the model the characterized interdependencies enable a proper visualization and understanding of the systems behavior through e.g. color coding or notes. Furthermore real data from Manufacturing Execution Systems and Product Life Cycle Management Systems can be used for simulations.
to identify the most suitable planning scenario by employing into the method integrated optimization functions.

4. Assembly System Base Model

This section presents in detail the pillar Assembly System Base Model. The model is approach according different scales. These scales are based on the "Stuttgart Enterprise Model" (SUM), which approaches a production system as a complex socio-technical system, consisting of subsystems and performance units [16]. The approach introduced here considers the SUM scales starting from the production system, production cells up to machines and workplaces. The SUM organizational aspects are at the moment leaned in secondary plan. Technical processes are employed to structure the modeling. But the optimization of the technical processes will not be considered in this stage, due to their high complexity and modeling effort [17]. The overview of the scales of the Assembly System Base Model is depicted in Figure 2. Thereby the system boundary includes all relevant areas for the manufacturing of a product from the incoming goods to the shipment area. Additionally the provided infrastructure (e.g. electricity, gas, hydraulic and pneumatic systems, ICT) and the in-house logistics are considered.

Fig. 2. Structure of the Assembly System

An assembly system consists of different Factory Objects, which are required at different scales and purposes of manufacturing. In this approach every scale is defined through its purpose in the manufacturing process and through its allocated Factory Objects. The purpose of a scale can be e.g. the pre-assembly of product components or the supply of an assembly line with the necessary infrastructure. Thus, every scale can be seen as a single unit with specific Factory Objects. Figure 3 illustrates the characterization of these two different classes of Factory Objects. Thereby the Temporary Factory Object changes its position and condition for every instant of time, e.g. unloading materials and resources at a machines and/or a workplace or moving from one workplace to another, but changes its scale just from the instant of time "t4 to t5" and "t5 to t6". However, the Permanent Factory Object changes its condition with every instant of time, e.g. processing of material, stand-by or failure, but does not changes its position or scale. The position, scale and the condition, in other words the context, of the Factory Objects and scales can be captured through sensors, e.g. RFID, GPS or force, based on the “Smart Factory” approach [18].

Fig. 3. Classes of Factory Objects – Temporary and Permanent Factory Objects

Within this approach the captured data is processed by suitable processing methods and is subsequently provided to other systems or applications (e.g. MES, ERP Digital Factory) and shared between them. The “Smart Factory” methods, the two classes of Factory Objects and their characterization enable the development of an evolvable model. This means that the model can develop gradually over the instants of time. Thus, for every Factory Object as well as scale the actual context can be acquired and used in a simulation model.

Each scale and Factory Object, whether Temporary or Permanent, can be further characterized through its Infrastructural Boundaries and interdependencies. Thereby every Factory Object has specific infrastructural requirements to guarantee its efficient and proper operation. A specific scale, however, can provide different infrastructural boundaries. For both, these are e.g. electricity, auxiliary resources, and access to pneumatic, hydraulic or ICT systems. By modeling these perspectives the model can tell the actor, if his planned assumptions can be realized within the actual state of the assembly system, or not. Figure 4 depicts these aspects to clarify this, a simple example follows.

A planner wants to optimize the assembly line by replacing the Permanent Factory Object 1 (FO1P) with a newer version (the newer version is depicted in Figure
4). This Factory Object requires the Infrastructural Boundary 9 (IB9), let’s assume it is the requirement for a hydraulic access, but the scale Assembly Line does not provide this access, yet. The model will tell the planner that an issue arises, which is assigned through the corresponding lightning (Issue). Thus, the actor has to search for alternatives, like adapting the scale or replacing the machine with another machine.

Furthermore the interdependencies between single Factory Objects and scales can be described. Thereby e.g. the manufacturing sequence or transportation route can be defined through an ontology in the background of the Method for Multi-scale Modeling and Simulation of Assembly Systems.

Therefore the semantic web technology Ontology Web Language (OWL), mentioned in Section 3, will be employed. Thus, the model can assign scales and Factory Objects, which are influenced by the planners’ adaptations. Through this the planner gets a better overview and understanding of the impact his adaptation will generate. Furthermore the benefits or the cost can be estimated more precisely, before the adaptations are actually realized.

These described mechanisms are the bases of the Method for Multi-scale Modelling and Simulation of Assembly Systems and enable the modelling of an evolvable model. Additionally, it is the basis of a knowledge-based resource library, which reduces the effort of modelling an assembly system as well as its adaptation processes.

5. Conclusion and Roadmap

The research results will be merged in a Method for Multi-scale Modeling and Simulation of Assembly Systems. This paper presents the on-going research steps aiming at the development of a Method for Multi-scale Modeling and Simulation of Assembly Systems. This method will reduce the required effort and knowledge for modeling and further simulating the assembly system in all its scales. The four necessary pillars Modeling Languages, Resource Library, Modeling Procedure, and Optimization, which have to be further developed, are introduced and their main functions in this approach are shortly described. Furthermore, the fifth pillar Assembly System Base Model which is the focus of this paper is described in detail. This base model is structured in different scales and characterized through relevant Factory Objects and interdependencies. Therefore the basic theoretical characterization of the Factory Objects is shown and the benefits of the Assembly system Base Model are described.

The suitable embedding of knowledge into the model itself, by characterizing the context of the Factory Objects and their Interdependencies with other Factory Objects and scales is defined. To enable the knowledge embedding, the Ontology Web Language will be employed. The development of the Method for Multi-scale Modeling and Simulation of Assembly Systems is an on-going and complex research topic where future steps are of huge interest. Thus, the next steps are as follows:

- the development of the knowledge-based manufacturing resource library
- analysis of the interdependencies between the assembly system scales and Factory Objects,
- enhancement of the Value Stream Mapping Method to according the Method requirements,
- the data exchange with Manufacturing Execution and Enterprise Resource Planning Systems.

References


