Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 51 (2016) 128 – 133

www.elsevier.com/locate/procedia

3rd International Conference on Ramp-up Management (ICRM)

An approach to reduce commissioning and ramp-up time for multi-variant production in automated production facilities

Christian Brecher[a], Simon Storms[a*], Christian Ecker[a], Markus Obdenbusch[a]

[a]Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, Chair of Machine Tools, Steinbachstraße 19, 52074 Aachen, Germany

*Corresponding author. Tel.: +49-241-80-27448, E-mail address: s.storms@wzl.rwth-aachen.de

A key requirement for future production facilities is to perform new production processes in a flexible and adaptive way with available and known resources. In this context, a comprehensive description (ontology) of involved components has a high significance. If certain technological aspects are missing during a production process, the production control should respond in a dynamic, versatile and adaptive (agile) manner to the overall value network. The possibility to describe the requirements of products for the necessary processes in the same namespace like the requirements of the necessary processes for the resources is a prerequisite to enable this behavior. Afterwards the different requirements will be placed in relation to the respective requirements. The aim is to define the necessary processes for the production based on the description of the product and the known resources in an agile way. Due to this a framework for a comprehensive description of automated production facilities, products and processes is described in this paper. The idea is that based on this framework a production facility can change the produced products without dedicated commissioning and ramp-up phases.

Peer-review under responsibility of the scientific committee of the 3rd International Conference on Ramp-up Management (ICRM)

Keyword: Automated production facilities, multi-variant production, requirement description, agile commissioning, service-oriented architecture

1. Challenges for the ramp-up of automated production facilities

The engineering of automated production facilities can be divided into different tasks. The tasks can be related to the respective resource's lifecycle targeting the phases of requirements engineering, constructional design, commissioning and ramp-up and production/resource utilization [1].

In case of mass or large-scale production all requirements related to the production facilities are effectively based on the produced product itself. In many cases where there are no resources available from former production scenarios the production equipment is specifically tailored to the respective task (green field) fulfilling the products requirements in machining capability [2].

To realize mass customization and a designated one piece flow this approach is not suitable any longer. Due to simultaneous planning and engineering of late changes in product specifications, both products as well as automated production facilities, relevant production requirements in many cases are not accessible. Additionally nowadays the future product spectrum (long term) can be unknown to this state. In these cases a specific commissioning or ramp-up planning is hard if not impossible. However, based on an interface consideration from a holistic point of view the interaction of products and production facilities can be analyzed and sufficient machinery capabilities identified. Here the single production process is key for understanding the correlation between the different engineering domains.

In case of mass customization the requirements as well as the importance of an integrated modeling frame are rising significantly. To avoid multiple commissioning and ramp-up for every new product a more suitable approach for versatile automation is still missing.

In this paper an interdisciplinary description scheme starting from a customizable product, available equipment and resources as well as the underlying production processes is developed. Based on this description and the opportunity of the production facilities to agilely respond towards changes in product specifications and hence process parameters within previously defined boundaries the time for commissioning and ramp-up will decrease significantly, in some cases even might disappear (refer to Figure 1).

Peer-review under responsibility of the scientific committee of the 3rd International Conference on Ramp-up Management (ICRM)
doi:10.1016/j.procir.2016.05.027

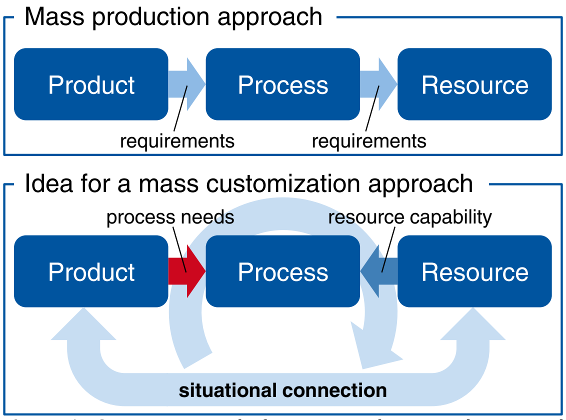

Figure 1. Common approach for mass production and situational connection from product and resource for mass customization

2. State of the art

Nowadays, mostly specialized modelling languages are used within different domains of production engineering to design and analyze systems [3]. For different types of information and requirements the data is processed in separate tools [4]. Recent developments in manufacturing system engineering methods and available software tools target the extension of the product specific data base on which the design of production systems is conducted [3]. In this context Product Lifecycle Management (PLM) provides required methods and processes for managing and developing products from a multi-domain multi-variant perspective [5]. It implements a product centered approach essential for managing mass customized products and handling the associated quantity of data.
PLM from a resource centered point of view, however, is difficult to apply due to the requirement for a general formulation of process models and their connection towards a product's lifecycle. Especially the definition of mechatronic (multi-domain) and functional relationships is complex.
In this context the modelling language AutomationML [6, 7] supports automation system planning by formalizing automation relevant planning aspects (geometry, structure and plc code). To further integrate the separated domains a standardized naming convention is missing. Here eCl@ss can provide a framework including the semantic description of automated production facilities which helps forming mechatronic relationships [8, 9].
For seamless engineering and development of automation systems across different disciplines a combined approach is suitable. However, during commissioning, process qualification and ramp-up of such facilities a correlation to the respective products is indispensably.
A different description model for products and processes is provided and explained in the IEC 62264 [10]. The idea behind this framework is the specification of interface content for the communication between manufacturing control units and other enterprise sections. Hereafter two models provided by the IEC 62264 are focused: the Process Segment Model (PSM) and from a product centered point of view the Product Definition Model (PDM). Both PDM and PSM subdivide specifications into Parameter, Personnel, Equipment, Physical Asset or Material related groups (Figure 2).

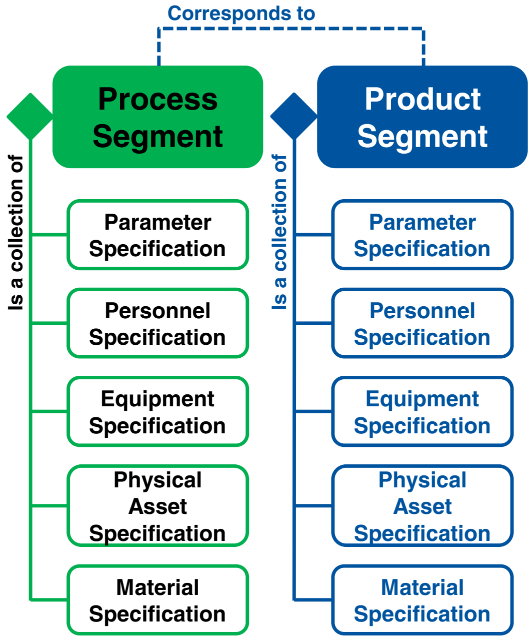

Figure 2. Process and Product Segments according to [10]

The PSM is a hierarchical model, in which multiple levels of abstraction of manufacturing processes are defined. The combination of all PSM's describes the overall capability of the described resource.
The PDM contains the required information for resources to realize a specific production process.
On the described basis this paper will outline a solution for a comprehensive description of an integrated product, process and resource (PP&R) relation. It is thereby conform to the IEC62264's PDM for products and PSM for processes as well as AutomationML and eCl@ss for resources.
The research field of Product-Centric-Control (PCC), which targets the qualification of products with information and process data in a way, that it can control the production resources on demand [11] has to be considered in the context of the automation of production as well. The approach in PCC is to equip products or product carrier with a defined identification marker (AutoID). This marker contains the PDM or refers to a database location where it is stored. When arriving at a process station the product/product holder transmits the current and the overall targeted state. Based on present information about its capabilities the process station can then identify the possible state transitions, which result in product states closer to the targeted state. Thus, this approach requires a previous process qualification of each transition capability and is therefore only applicable for well-known production boundaries and not for a multi variant production with in advance unknown products.

In a suchlike future environment the tasks of human workers will be different to their today's work contents. They will be part of a production network and realizing value adding decision making based on process intelligence and experience. Thereby they can act as soft sensors to ensure quality and efficiency [12, 13].
The given state of the art shows that there is no overall approach for product, process and resource description. Especially a domain across (mechatronic) approach is missing. The specialized modelling languages used in the different domains

across a product or resource lifecycle require a framework with the capabilities to accommodate the model information.

3. Requirements analysis and approach for a comprehensive description

In the following requirements and necessary characteristics of a multidisciplinary description framework for PP&R are discussed. In addition to an isolated property description of the single Product, Process or Resource the aim is to give a possibility for relating product and process requirements to characteristics of available resources. Based on suchlike evaluation a decision, for example for the structure of a value network and resulting execution dependencies for automated production facilities shall be enabled.
The requirements of a PP&R consideration form a network of dependencies, which need to be introduced as whole into planning processes where different PP&R's interfere with each other (compare Figure 3). To be able to formulate these dependencies the modeling scope for a single PP&R shall now be described according to its building blocks.

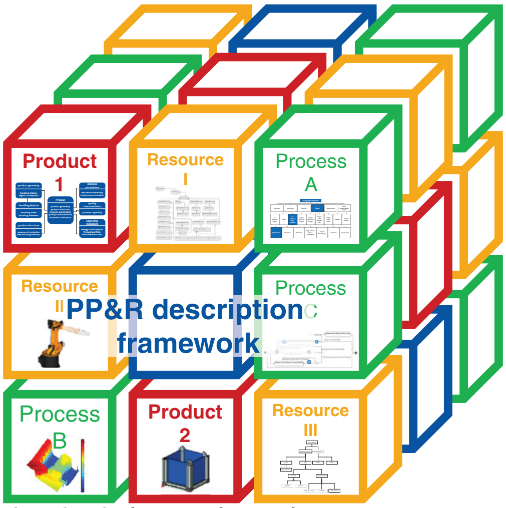

Figure 3. PP&R description framework

Product

For the product description different aspects influence the interaction within a single PP&R as well as throughout a PP&R network.
The product geometry will give information about dimensions and tolerances covered by CAD and embedded into PLM approaches. However, a comprehensive description model has to provide further information containers. For example for planning and executing handling operations specific interfaces need to be defined (size, position and orientation) in relation to the product's geometry, which can be formulated from basic shape elements (prismatic, round, not continuously) to allow for a more flexible resource identification process [14]. If there are regions of the product exhibiting special treatment (such as painted surfaces) there need to be special regulations regarding the handling process. A possibility for modeling these product properties and restrictions for specific geometrical areas are feature based approaches extending a geometric representation model [15].

Next the product's structure needs to be analyzed since a product usually consists of other products. An assembly for example can be made of parts or other subassemblies. The different elements of an assembly need to be connected to instances of the general object type description carrying all assembly relevant information. Dependencies among these assembly object instances as well as to the overall product have to be described considering possible production sequence alternatives as well as the manufacturing resources' flexibility. Therefore a general framework has to provide a generic modelling scheme and dedicated methods, which allow for the definition and evaluation of boundary conditions influencing production organization. Boundary conditions such as capacity (resource) and load (production requirement) call for flexibility and can lead to changes of an assembly sequence if there is not a single but equally valid assembly graphs [16]. Thus situational decisions can be enabled within the production's value chain.
In addition to product geometry and structure it is also necessary to capture process specific requirements by the product in terms of technology parameters such as the feed rate for machining or the torque of a screw connection. After single process steps or predefined quality gates quality checks such as measurements or functional testing are necessary. Therefore quality characteristics like process capability measures (Cp, Cpk) are possible requirements originating from the product influencing both process definition and resource utilization. To support rational decision making furthermore economic indicators such as energy or material consumption, throughput times and product specific resource utilization (machine hours) need to be connected to customer's orders, which consist of a bill of materials (BOM) hence a list of product structure instances.

Process

A process description builds the interface between the product's requirements and the resources capabilities including process specific physical effects and phenomena. [17] forms a general overview on relevant production process technologies but there is no overall modeling scheme integrating them. Each of six given major technology groups is divided in up to nine groups, which again are separated in up to nine subgroups resulting in 151 different production processes. Today technology planners use extensive expert-oriented engineering systems, which are mostly heterogeneous developments for specific planning tasks. Hence, a formal integration is cumbersome and for automatic evaluation needs to be traced back to a set of common parameter naming conventions as part of the IEC's PSM.
To match resource capabilities it is specifically important to define possible value ranges for different process parameters. For a screwing process (Group 4.3.1 in [17]), for example, it is necessary to give information about the required tool torque in order to realize a given product's screw connection force. The torque then needs to match the feasibility profile of an automated screwdriver. Other parameters can be the tool interface, the vertical adjustment, required accuracy in position and process repeatability.
In a multi-variant production environment the information of the given example immediately reaches large quantities, which shows the requirements for lean information distribution as key requirement to the modeling framework.

Resource

Fundamental information of production relevant resource specifications covers the respective process-related capabilities such as the maximum dimensions of a workpiece for a machining

center. In this case the bounding box into which the workpiece geometry needs to be placed is determined by the working area of the involved spindle kinematics. For machine tools these descriptions can be part of an overall machine profile often termed Machine Capability Profile (MCP) [18], which in general is not related to single products or orders and needs to be extended by definitions for general production equipment such as handling devices, tools, logistics, etc.
In case of loosely coupled material transports, for example via driverless transport system (DTS), especially the interface geometry of the respective resource is important. To allow the flexible feeding of different production resources a standardized geometry couple is required to determine the transfer of goods.
To fully capture the intrinsic capabilities of a resource to support flexible commissioning processes usually domain specific modeling (DSM) [19] is applied. However, to adapt material flows and utilize resources within the boundaries of a multi-variant production environment, the deduction of a characteristic classification scheme to represent a simplified MCP can be sufficient.
Therefore all physical entities shall be described including their functional components. The functionality will result from the combination of resource and process descriptions.
Thus a uniform structure and naming convention for a suchlike PP&R description framework is an important prerequisite. The downstream situational linking of PP&R needs to integrate this common namespace for the algorithmic implementation for example for production planning or other (automated) workflows.

4. Use case - Screwing automation

The use case considered in this paper is a robotic assembly system for flexible screwing automation. Figure 4 shows a possible demonstration scenario using a six-axis industrial robot, an automated screwing tool and a flexible clamping device as different physical assets of a production cell.
In the following the PP&R approach is applied to this scenario in order to support flexible process commissioning.

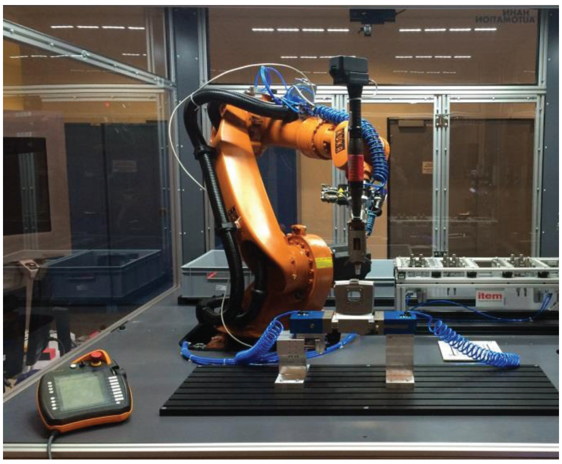

Figure 4. Demonstration scenario - Screwing automation

Product

The focused assembly step addresses the joining of two parts, a housing forming the base part and a lid as part to be attached (Figure 5). The parts are joined by 4 screw connections represented by 4 instances of a product segment model. The parts are related to a product, which is manufactured in different sizes and can have optional configurations defined by the customer according to a modular design scheme. However, all variants share the general housing-lid-screws PDM relation associated with the product.

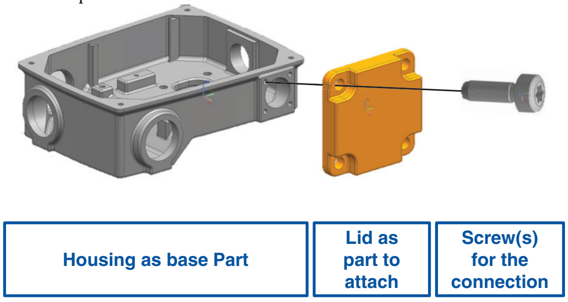

Figure 5. Product for the use case in screwing automation

To support assembly process commissioning each component's product segment contains assembly relevant information modeled as assembly features. Assembly features follow a common type convention so they can be identified and grouped for different segment variants (here variable object sizes).

For the housing for example geometric feature definitions regarding the location of an alignment surface are required to support relative positioning of the lid. To then tighten the screws segment specific parameters such as the required force/torque are defined (during product engineering) as they vary with the size of the respective objects. At the interface to the resources additional specifications are necessary to enable the selection of a possible tool-screw combination (for example Torx as a suitable interface for automated screwing).

Process

For the housing-lid-screws assembly two PSMs define the interaction of the described PDMs. To position the lid to the housing a PSM references the two assembly features representing the relevant alignment information based on their type names. The 4 screw connections joining the lid and the housing are part of the second PSM. Therefore, to support commissioning PSMs have to integrate PDM type definitions into a general sequence definition of a specific process or task and be able to extract the underlying technological parameters such as geometric relations, physical expressions or control relevant data. Additionally PSMs need to reference resource capabilities, which can be applied for a process. For example the motion path for positioning the lid has to be mapped to the collision free handling of a gripper attached to the robot's flange.
The process cycle for the assembly depends on the product's assembly graph. Therefore a consideration of feasible process orders is necessary leading to edges of the graph. The edges represent execution dependencies, which are modeled as Product Segment Dependency (Figure 6) and help determining a possible assembly.

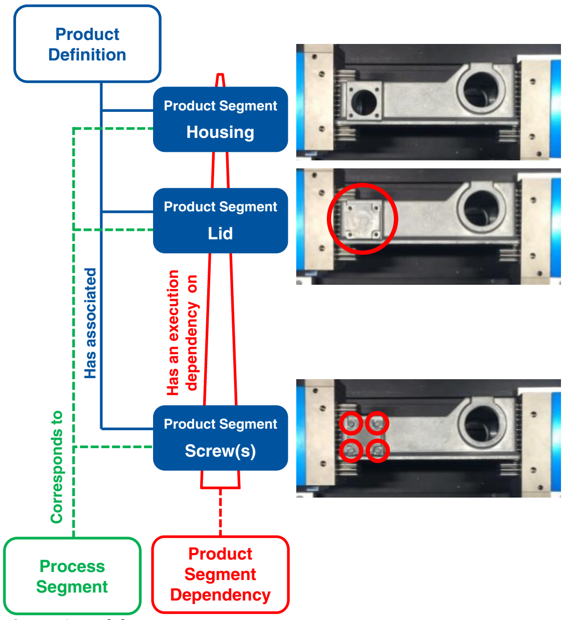

Figure 6. Model use case

Resource
Resources for automated processes can be modeled using automationML, which refers to COLLADA as an open file format for kinematic 3D models (suitable for robots and tools, etc.) and PLCopen for defining control behavior. Thus resource models especially support virtual commissioning tasks such as collision free planning of handling motion and the transfer of singular process steps towards integrated sequences. However, to apply virtual commissioning in the PP&R approach also product (and in some cases process) models need to support COLLADA as their geometric representation.

To combine the different resources within a consistent context, eCl@ss as a broad classification convention is used. The screwing use case would hence consist of an "Articulated robot" (27-38-01-01) classified under "Robots" (27-38-01), "Robotics, Assembly" (27-38), "Electric engineering, automation, process control engineering keywords" (27) within eCl@ss Version 9.1. Other resources are "Rotational screwdriver (electric)" (21-05-08-04) with a "Bit for Torx screws" (21-04-42-02), which for example has the property "size of the inner star" (02-AAI615) and needs to match the dimensions of the Torx screw (product) to realize a designated screwing process.

5. Discussion and Summary

The presented approach for a comprehensive description of automated production facilities is based on the three domains product, process and resource (PP&R). Extending state of the art approaches of product lifecycle management (PLM) the developed description framework provides possibilities for contextualizing the different domains of product and production system design and engineering by enriching standardized model formats with requirement and capability information. The objective of this approach is to put production facilities in the position to respond agilely to product changes without dedicated commissioning and ramp-up phases. The use case of screwing automation applies the concept to a practical example.

Based on the modeling and specification of handling features it is for example possible to automate planning (and commissioning) tasks in a multi-variant production environment. The approach helps to save time and cost in production and process planning (mostly of skilled labor), resource qualification (path teaching of robots or programming of PLCs) and during ramp-up.
Future challenges will be the development and implementation of the overall model framework and the description of the production processes. Another challenge will be the acceptance of the framework. By using established standards like the described DIN 8580, IEC 62264, eCl@ss and AutomationML the acceptance of potential users to apply the framework hopefully will be high.

Acknowledgements

The support of the German National Science Foundation (Deutsche Forschungsgemeinschaft - DFG) through the funding of the graduate program "Ramp-up Management - Development of Decision Models for the Production Ramp-Up" is gratefully acknowledged.
The IGF-project 18446 BG (MoDemo) of the research association GFaI (Gesellschaft zur Förderung angewandter Informatik) was supported via the AiF within the funding programme „Industrielle Gemeinschaftsforschung und –entwicklung (IGF)" by the Federal Ministry of Economic Affairs and Technology (BMWi) due to a decision of the German Parliament.

References

1 *Stark J*. Product Lifecycle Management. In: Stark J, Hrsg. Product Lifecycle Management. London: Springer London; 2011: 1 – 16
2 *Kull H, Hrsg*. Mass Customization. Berkeley, CA: Apress; 2015
3 *Ferrer BR, Ahmad B, Lobov A, Vera DA, Lastra JLM, Harrison R*. An approach for knowledge-driven product, process and resource mappings for assembly automation. 2015 IEEE International Conference on Automation Science and Engineering (CASE); 2015: 1104 – 1109
4 *Schleipen M, Drath R*. Three-view-concept for modeling process or manufacturing plants with AutomationML. Factory Automation (ETFA 2009): 1 – 4
5 *Saaksvuori A, Immonen A*. Product Lifecycle Management. Berlin, Heidelberg: Springer Berlin Heidelberg; 2004
6 *Schmidt N, Lüder A*. AutomationML in a Nutshell; 2015
7 *Drath R, Lüder A, Peschke J, Hundt L*. AutomationML – the glue for seamless Automation Engineering. 13th IEEE International Conference on Emerging Technologies and Factory Automation : 15-18 September 2008, Hamburg, Germany: 616 – 623
8 *Einsporn T, Hausmann F*. eCl@ss. The leading classification system. in Informatik LIVE: 387 – 389
9 *Hepp M, Leukel J, Schmitz V*. A quantitative analysis of eCl@ss, UNSPSC, eOTD, and RNTD content, coverage, and maintenance. IEEE International Conference on e-Business Engineering (ICEBE'05): 572 – 581
10 *German Institute for Standardization*. IEC 62264 - Object Models and Attributes of Manufacturing Operations (2014); 2014
11 *Brecher C, Obdenbusch M, Storms S, Herfs W*. Individualized production in the Smart Automation Lab. Contribution to 3. Industry 4.0 Industrial & Internet Summit Munich. Haar: Franzis Verlag GmbH; 2015

12 *Zamfirescu C, Pirvu B, Gorecky D et al.* Human-centred Assembly. A Case Study for an Anthropocentric Cyber-physical System. Procedia Technology 2014; 15: 90 – 98
13 *Hall DL, Jordan JM*. Human-centered information fusion. Boston: Artech House; 2010
14 *Gyulai D, Kádár B, Kovács A et al.* Capacity management for assembly systems with dedicated and reconfigurable resources. CIRP Annals - Manufacturing Technology 2014; 63: 457 – 460
15 *van Holland W, Bronsvoort WF*. Assembly features in modeling and planning. Robotics and Computer-Integrated Manufacturing 2000; 16: 277 – 294
16 *Brecher C, Behnen D, Breitbach T, Herfs W*. Assembly Motion Planning using Controlled Collisions. Conference Proceedings of the 4th International Conference on Applied Human Factors and Ergonomics (AHFE): 4059 – 4068
17 *German Institute for Standardization*. DIN 8580 - Manufacturing processes - Definitions, classification (09/2003); 09/2003
18 *Newman ST, Nassehi A*. Machine tool capability profile for intelligent process planning. CIRP Annals - Manufacturing Technology 2009; 58: 421 – 424
19 *Kelly S, Tolvanen J*. Domain-specific modeling. Enabling full code generation. Hoboken, N.J.: Wiley-Interscience; IEEE Computer Society; 2008