Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia CIRP 3 (2012) 269 – 274

www.elsevier.com/locate/procedia

45th CIRP Conference on Manufacturing Systems 2012

Intelligent Management of Manufacturing Knowledge: Foundations, Motivation Scenario and Roadmap

M. Landherr[a,b,]*, C. Constantinescu[b,c]

[a]*Graduate School of Excellence advanced Manufacturing Engineering – GSaME, Nobelstr. 12, 70569 Stuttgart, Germany*
[b]*Fraunhofer Institute for Manufacturing Engineering and Automation – Fraunhofer IPA, Nobelstr. 12, 70569 Stuttgart, Germany*
[c]*Institute of Industrial Manufacturing and Management, University of Stuttgart – IFF, Nobelstr. 12, 70569 Stuttgart, Germany*
* Corresponding author. Tel.: +49 (0)711 970-1851; fax: +49 (0)711 970-1009. *E-mail address*: martin.landherr@gsame.uni-stuttgart.de

Abstract

Information is one of the key enabler for transformability of factories. As factories have to be able to adapt their processes very fast according to the changing environment, the approach introduced here aims at supporting production process planning and optimization. The performed activities are guided by configuration concepts and methodologies. First the great potential of employing knowledge-based systems in production process planning is emphasized. Afterwards the questions will be answered, what knowledge is relevant, how this knowledge is modeled and how it is used for the configuration of production processes. The contribution closes with a roadmap of future activities.

Keywords: Manufacturing Knowledge Management; Ontology; Manufacturing Process Configuration; Semantic Web; Factory Planning.

1. Why Data Management in Insufficient

Factories are highly complex socio-technical products [1]. Westkämper stated this paradigm in 2005 but it is still up to date and its implementation holds great potential for the manufacturing industries. They are caught in a crossfire of influences that determines the increasing need for flexibility and transformability [2]. Due to the global competition, they have to be able to react in a fast way without great effort on changing conditions to ensure economic efficiency. New or legacy products, new technologies on product or production side or new requirements coming from the market induce the continuous adaption of existing production facilities [2]. The key success factor influencing all scales of a factory (figure 2) and its transformability is manufacturing knowledge [3]. It is composed of data that is needed for planning and operating production systems. But these data have not only to be stored. They have to be enhanced with relevance and purpose so that they can be put into context, categorized, calculated and corrected [4] to intelligently support factory planning and optimization activities. The intelligent modeling of manufacturing knowledge as the basis for an appropriate representation of relevant production information represents an important topic in many fields of research [5].

Due to the exponentially increasing amount of data and knowledge relevant for factory planning and optimization, manufacturers need to enable a proper reuse to tap the full potential [6]. It is hardly possible for one or a team of production engineers to have all these information in mind. Therefore we search for a possibility to support factory planning and optimization activities by enhancing digital tools with the ability to recognize room for improvements in an (semi-) automatic way. This is of a very interdisciplinary character. On the one hand there is the need for a detailed understanding of the production process being planned [7]. This understanding is based on knowledge

doi:10.1016/j.procir.2012.07.047

and experiences of experts in the field of manufacturing engineering that usually have limited interest in information technologies (IT). On the other hand, the handling (storing, modeling, maintaining and representing) of this large amount and high complexity of information is a challenging task for IT experts that in turn do not have complete knowledge of the production processes. [8]

The approach introduced here aims at the (re-)configuration of production processes through the intelligent management of manufacturing knowledge. The development of a semantic rich model of manufacturing knowledge lays the basis for the envisioned knowledge-based configuration system. For this purpose, the characteristics of manufacturing knowledge management are presented compared to the requirements of traditional knowledge management. Afterwards an intelligent manufacturing knowledge modeling is stated as a way of meeting the gathered requirements, arising from the specifics of manufacturing knowledge. In section 4, the topic of the configuration of production processes is clarified. It is to emphasize, that the approach does not consider business processes. The modeling of knowledge of how to produce a certain product for planning and optimization activities is in the focus of this research field. The next section explains the way of using an intelligent modeling of manufacturing knowledge for the configuration of production processes. Due to the fact, that this topic is very interdisciplinary, the contribution at hand closes with a roadmap of following research and development steps.

2. Specifics of Manufacturing Knowledge

This section aims at the clarification of manufacturing knowledge focusing on the specific requirements related to its management. The terms of data, information and knowledge will be clarified to ensure a common understanding, in advance (figure 1).

Data is created by arranging characters in a certain way using defined syntax. This syntax is provided by natural or computer language. Information requires a description of the data to equip them with a meaning. This meaning is commonly called semantic. Additionally to it, there is the need for a context. Information is only understandable with a meaning and the complete circumstances, in which the data occurs. Knowledge is created by interconnecting information with the possibility to derive new information. [9] In the field of semantic web technologies, this creation of new information is called reasoning. The ambitious objective presented in this contribution is the partial shift of creating new information from the human into the models and digital tools for planning and optimizing production processes. Manufacturing knowledge is the umbrella term for all knowledge that is created throughout the whole life cycle in all scales of a factory (figure 2).

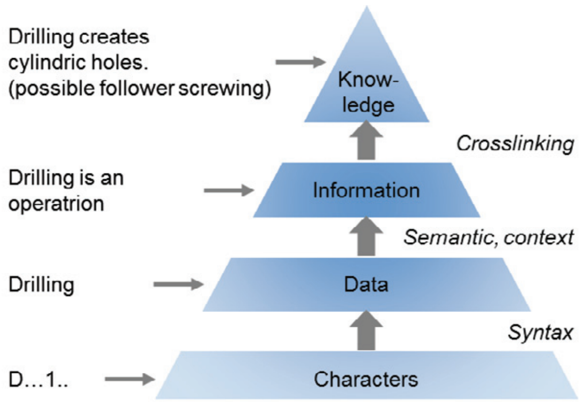

Fig. 1. From Characters to Knowledge [9]

In literature, there are manifold guidelines and descriptions of factories as complex systems with their own life cycle starting from first strategic considerations to planning, executing and dismantling [10]. This life cycle lasts usually more than 30 years in which the factory gets continuously adapted and optimized [11]. Every change e.g. through new products, processes or manufacturing resources is accompanied by new data, that have to be stored and provided in a way that enables its proper reuse. One of the greatest challenges concerning the data management is the provision of the right data at the right time or rather in the right context. As an initial step, based on the concepts and ideas of system theory the factory can be considered as a composition of several units in different scales. The Stuttgart Enterprise Model offers a holistic model of a factory classified in seven scales [12]. This decomposition and the understanding of interdependencies between the single scales and units enable a separation of the information in packages that can be handled more easily. There is not only a need for a resilient data management but also a great potential by offering knowledge through the machine, namely the methods and digital tools for planning and optimizing the factories. The provision of current information is one of the requirements for the realization of (soft) configurability of production systems [13]. The lowest scale of this model is represented by the processes. This contribution focuses on the technical aspects of the processes.

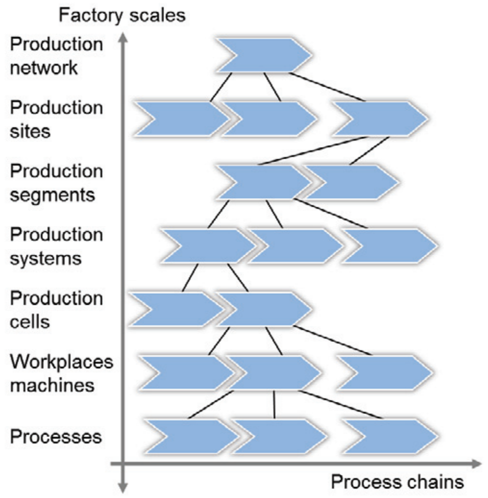

Fig. 2. Factory Scales [12]

It is the scale, where the knowledge of how to produce a certain product is created and used. It represents the interface between the product and the production resources and facilities. Due to this central role and a lack of profound support of activities concerning this scale, this contribution aims at the knowledge integration into the methods and digital tools for production process planning and optimization. In its core, the planning and optimization of production processes is a creation of new or improved ways of producing goods. The information sources for this activity are summarized in Figure 3.

The requirements to the capabilities of the production processes can be derived out of the product documentation. This documentation is comprised of the product model and all drawings with required and recommended quality features (e.g. surface, tolerances), the complete bill(s) of materials, the inspection requests and the design protocol with a history of changes [14].

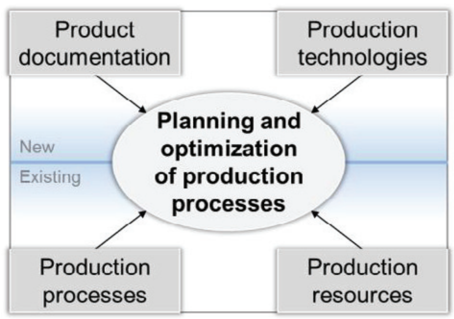

Fig. 3. Information Sources for Planning and Optimization of Production Processes

As a source of what is possible in manufacturing (e.g. surfaces, precision) production technologies can be used. These two aspects enable the composition of new production processes. But it is evident, that current factories are caught in a continuous adaption. Existing production processes have to be modified due to an economic adaptation according to changed conditions and requirements arising from several drivers (e.g. markets, government and innovation). The consideration of existing production processes is required to enable this adaptation. Due to the fact, that the existing production processes are commonly characterized by the capability of producing certain product architectures, there is a lack of knowledge about what impedes the actual manufacturing capabilities. This is the reason for integrating existing production resources as a source of information for the planning and optimization of production processes.

Currently available data management systems enable the proper provision of data for planning and optimization activities. Digital planning tools are capable of modeling and simulating manufacturing facilities and operations to handle the complexity. But the creative aspect is not supported at all. There is no feedback from the digital tool about the quality of the solution. They are not capable of recognizing failures done by the user. The digital tools are not able to provide knowledge in sense of creating new information by interconnecting available information in an (semi-) automatic way. It is of great potential to support this knowledge-intensive activity of planning and optimizing production processes. The approach introduced here presents the capability of creating new information with help of an intelligent manufacturing knowledge modeling.

3. Intelligent Manufacturing Knowledge Modeling

The storing of knowledge in a computer system to enable a (re-)use and a creation of new information by the machine is a challenging task. The challenge is caused by the properties of knowledge itself. Knowledge occurs in an unstructured way (cf. human mind), it is semantic-rich, it is highly networked and its meaning is strongly dependent on its context [9]. Thus, there is the need to structure the knowledge without losing its semantics and to transfer it within its network (crosslinking) together with a set of relevant contexts. This transformation of knowledge from a reality into the machine is called knowledge modeling. Due to the fact that it is not possible to model all knowledge of a real system, there is an abstraction on relevant knowledge for a certain problem.

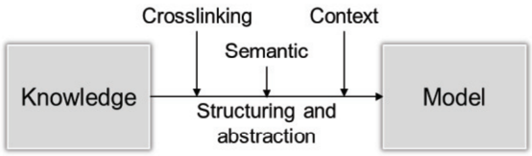

Fig. 4. Knowledge Modeling

Therefore an analysis of the problem and an identification of relevant knowledge including interrelations and context have to take place in advance (cf. section 2). It is always a pressing need to know what the object to be modeled and what the objective of modeling is before starting to model. In the case at hand the object is the knowledge about the production process with the objective of supporting process planning and optimization activities with (semi-) automatic generated suggestions of possible production process configuration.

Knowledge-based systems have the ability to solve a certain problem in an automatic way that is usually solved by using human intelligence. There are many different concepts of realizing knowledge-based systems. An overview is available in [16]. The abstract architecture of knowledge-based systems is illustrated in figure 5.

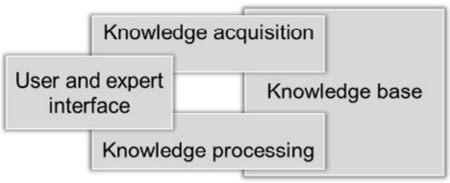

Fig. 5. Abstract Architecture of Knowledge-Based Systems

They are all build on explicit knowledge bases. For the approach introduced here ontologies are used to model the knowledge base. For the realization of intelligent manufacturing knowledge modeling, representing and processing, logical relations between the product and the production process, and between the respective production operations, a rule-based ontology is used. To ensure a common understanding of the knowledge modeled the sender and the receiver need the same formalization of the syntax. This is guaranteed by the use of the same language for modeling the ontology. The Web Ontology Language (OWL DL) allows not only the explicit formalization of knowledge objects and cross-linked interrelations, but also provides the possibility to integrate rules into the ontology itself [17].

This approach satisfies the requirements of representing manufacturing knowledge for the knowledge-based support of production process planning activities:

1. Conceptualization and storing of manufacturing knowledge.
2. Well-defined formalization of semantics and syntax to enable automatic reasoning.
3. Powerful description and convenient expression of relations and constraints.
4. High compatibility through XML-based formal syntax and high acceptance through UML-based graphical syntax.

4. Configuration of Production Processes

A production process is the way of producing a certain product or product architecture. It can be summarized as a transformation of material or services from an input to an output state with help of an amount of coupled operations [18]. The approach is to support the planning and optimization of production processes with configuration concepts and methods.

In this context configuration means to find a solution by combining predefined components, which satisfies costumer needs without violating any constraints [19]. Configuration models describe the structure and the constraints. Due to working with predefined components, there is a need for finding the right granularity of decomposing production processes to make them reusable for other production processes. The decomposed elements are called operations. These operations are modeled as configuration objects to represent the capabilities and constraints of the single object. But the sticking point with planning and optimizing production processes is that the capabilities and constraints of a complete process is more than the pure addition of single production operations. The operations have interrelations between other operations that are not always the same. So these interrelations depend on both, the previous and the following operation (cf. context). While modeling production operations with all their capabilities, characteristics and constraints and with all their interrelations to other production operations, a very complex net of single production operations and manifold interrelations is developed [20]. Production operations or production processes can be well described using available production process planning and data management solutions [21]. But the challenging task of considering the above mentioned interrelations in these planning and management tools is not solved at all.

5. Motivation Scenario for Intelligent Manufacturing Knowledge Modeling

The approach introduced here meets the challenge of representing the high complexity of interrelated production operations in one feasible configuration model with help of ontologies. Before modeling such a big ontology, a motivation scenario is created for evaluating the potential of the approach. For the modeling, the ontology editor protégé from Stanford University is used [22].

The following simplified example (figure 6) serves as the motivation scenario illustrating the concept of the approach introduced here. It is an easy assembly of a table with the four production operations: clamping of the table plate, pre-drilling, positioning of the table legs and screwing. The process is modeled within the process model, which is part of the production process configuration ontology. In another part, the product model, there the products are modeled. A component that is used for the table assembly is a connecting element. For the scenario two kinds of connecting elements are modeled: friction fit connecting elements like nails and form fit connecting elements like screws. The last part of the ontology relevant for the example is the relation model. There the rule is defined, that the process operation screwing needs a connecting element of the class form fit.

In the example, the failure is made while planning the production process, that the production operation screwing uses a nail as a component. This failure is immediately recognized by the ontology itself through the integration of all relevant relations and rules into the model itself. This motivation scenario presents the capability and the potential of the approach. Initially knowledge was defined and a clear differentiation to data and information was given.

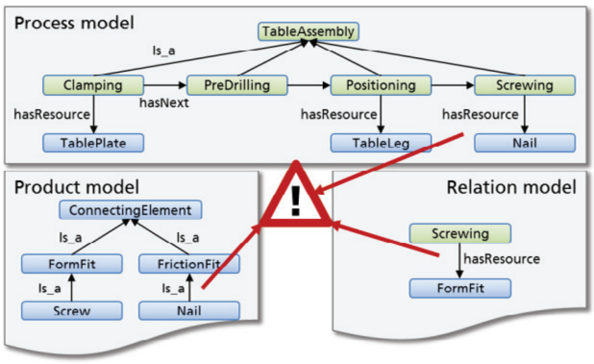

Fig. 6. Simplified Example for an Intelligent Manufacturing Knowledge Modeling

Knowledge is created by interconnecting information with the possibility to derive new information. The interconnection of single production operations are of special interest to reach the goal of making production processes (re-)configurable [23]. The OWL DL has the capability to represent these interconnections and interrelations in a networked structure. With combining the information not only from the process and product model but also from the newly introduced relation model, the model itself is able to derive new information in form of the recognition of the failure mentioned above.

6. Research and Development Roadmap

After designing and evaluating the above mentioned motivation scenario as a feasible approach for the configuration of production processes, the production process knowledge ontology will be developed. There are some standards and guidelines for describing production processes [24] [25] [26]. These standards will be evaluated regarding their usability for the introduced configuration task. Afterwards the selected standard(s) will be adapted to fit to the ontology-based approach. Only when this task or a modularized part is completed the knowledge can be integrated into the ontology by creating, analyzing and defining rules according to expert knowledge. This knowledge retrieval for configuration knowledge modeling will take place by a strong collaboration with companies in the field of manufacturing systems engineering. In parallel, the development of a graphical user interface (GUI) to enable the use of the production process configuration model will be performed. This GUI will not be used for a knowledge acquisition because in the first lane, protégé as a well-known ontology editor will be used. As it is not the objective to develop a new production process planning and optimization tool, the question about suitable interfaces and communication possibilities to other tools will be answered.

References

[1] Westkämper E, Gottwald B, Fisser F. Migration of the Digital and Virtual Factory to Reality. *CIRP Journal of Manufacturing Systems*; 2005.
[2] Wiendahl, H.-P., Reichardt J, Nyhuis P. *Handbuch Fabrikplanung*. München: Hanser; 2009.
[3] Weimer T. *Informationsmodell für die durchgängige Datennutzung in Fabrikplanung und –betrieb*. Heimsheim: Jost-Jetter; 2010.
[4] Guideline VDI 5610. *Knowledge management for engineering – Fundamentals, concepts, approach*. Berlin: Beuth; 2009.
[5] Europe's Intergovernmental Research Organisations. Towards the Next Framework Programme for Research, Technology and Innovation – *EIROforum Position Paper on FP8*. 2011.
[6] Chryssolouris G, Mavrikios D, Papakostas N, Mourtzis D, Michalos G, Georgoulias K. Digital manufacturing: history, perspectives, and outlook. Proceedings of the Institution of Mechanical Engineers, Part B: *Journal of Engineering Manufacture*. 2008.
[7] Neumann M, Constantinescu C, Westkämper E. A Method for Multi-Scale Modeling of Production Systems. *4th CARV*, Montreal; 2011.
[8] Guideline IEC/TS 62768 (Draft). *Guidelines for product committees for the preparation and processing of source definitions for Data Element Types*. International Electrotechnical Commission. 2011.

[9] Bodendorf F. *Daten- und Wissensmanagement - Zweite, aktualisierte und erweiterte Auflage*. Berlin Heidelberg: Springer; 2006.
[10] Guideline VDI 5200. *Factory planning - Planning procedures*. Berlin: Beuth; 2011.
[11] Grundig CG. *Fabrikplanung - Planungssystematik-Methoden-Anwendungen*. München: Hanser; 2006.
[12] Westkämper E, Zahn E. *Wandlungsfähige Produktionsunternehmen - Das Stuttgarter Unternehmensmodell*. Berlin Heidelberg: Springer; 2009.
[13] ElMaraghy HA. Flexible and reconfigurable manufacturing systems paradigms. International *Journal of Flexible Manufacturing Systems*. LLC: Springer Science + Business Media; 2006.
[14] Norm DIN ISO 16792. *Technische Produktdokumentation - Verfahren für die digitale Produktdefinitionsdaten*. Berlin: Beuth; 2008.
[15] Mukherjee A, Mitchell W, Talbot B. Adaptation of a focused factory to new objectives: The influence of manufacturing requirements and capabilities. *Business Strategy Over the Industry Lifecycle Advances in Strategic Management*; 2004, Volume 21, 161-198.
[16] Beierle C, Kern-Iberner G. *Methoden wissensbasierter Systeme*. Wiesbaden: vieweg; 2006.
[17] Staab S, Studer R. *Handbook on Ontologies*. Berlin Heidelberg: Springer; 2009.
[18] Dangelmaier W. *Theorie der Produktionsplanung und – steuerung*. Berlin Heidelberg: Springer; 2009.
[19] Mittal S, Frayman F. Towards a generic model of configuration tasks. *Proceedings of the 11th IJCAI*; 1989, S1395-1401.
[20] Landherr M, Constantinescu C. Configuration of Factories and Technical Processes: Which Role Plays Knowledge Modelling?. Madison: *44th CIRP ICMS* 2011; 2011.
[21] ElMaraghy HA, Kuzgunkaya O. Urbanic, R.J. Manufacturing Systems Configuration Complexity. *CIRP Annals - Manufacturing Technology*; 2005.
[22] Online source, accessed 2012/01/16, http://protege.stanford.edu/.
[23] Dashchenko AI. *Reconfigurable Manufacturing Systems and Transformable Factories*, Berlin Heidelberg: Springer; 2006.
[24] Norm ISO/IEC 15288. *Systems engineering - System life cycle processes*, Geneva; 2002.
[25] Norm DIN 8580. *Manufacturing processes - Terms and definitions, division*. Berlin: Beuth; 2003.
[26] Guideline VDI 2860. *Assembly and handling*. Berlin: Beuth; 1990.