Knowledge-based Production Planning Support for Manufacturing Change Management

Based on Function Blocks and a Mediator Architecture

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ABSTRACT. *The manufacturing of a product takes place in several partial steps and these mostly in different locations to save tax or to use the best providers. Therefore, in the era of* ***Internet of Things (IoT)*** *and modern* ***Intelligent Production Environments (IPE)*** *are going to be inevitably based on a cloud-based repository and distributed architecture to make data and information accessible everywhere as well as development processes and knowledge available for worldwide cooperation. Semantic approaches for knowledge representation and management as well as knowledge sharing, access, and re-use can support* ***Collaborative Adaptive Production Process Planning (CAPP)*** *in a flexible, efficient, and effective way. Thus, semantic representations of such CAPP knowledge integrated into a machine readable process formalization is a key enabling factor for sharing such knowledge in cloud-based knowledge repositories supporting CAPP scenarios as required for e.g.,* ***Small and Medium Enterprises (SMEs)****. When such contributors work together on a product component production planning, they exchange component production and manufacturing change information between different planning subsystems which require, e.g., a standardized product-feature- and production-machine feature representation. These data exchanges are mostly based on applying the already established* ***Standard for the Exchange of Product model data (STEP)*** *for the computer-interpretable representation and exchange of product manufacturing information. Furthermore, the planning process can be supported by so-called* ***Function Block (FB)*** *based knowledge representation models, serving as a high-level planning-process knowledge-resource template. Web-based and at the same time Cloud-based tool suites, which are based on process-oriented semantic knowledge-representation methodologies, such as* ***Process-oriented Knowledge-based Innovation Management*** *(German:* ***W****issens-basiertes* ***P****rozess-orientiertes* ***I****nnovations* ***M****anagement,* ***WPIM****) can satisfy the needs of representing such planning processes and their knowledge resources. In this way, WPIM can be used to support the integration and management of distributed CAPP knowledge, as well as its access and re-use in* ***Manufacturing Change Management (MCM)*** *including* ***Assembly-, Logistics and Layout Planning (ALLP)****. Therefore, also a collaborative planning and optimization for mass production in a machine readable and integrated representation is possible. On the other hand, that knowledge can be shared within* *a cloud-based semantic knowledge repository. To integrate all these functionalities, this paper introduces a new method, called* ***Knowledge-based Production Planning (KPP)*** *and outlines the advantages of integrating CAPP with* ***Collaborative Manufacturing Change Management (CMCM).*** *In this way, an enabling basis for achieving ALLP interoperability in Distributed Collaborative Manufacturing and Logistics will be demonstrated.*

KEYWORDS: Function Blocks, DPP, CAPP, WPIM, Process Planning, Process-oriented Knowledge Management, Semantic Knowledge Representation, Mediator

1. Introduction, Motivation, and Problem Statement

The general concept of developing a knowledge-based and process-oriented CAPP support by using the WPIM method as a basis was proposed in [1]. The WPIM approach offers the possibility of modeling and representing innovation processes in a machine-readable semantic format and furthermore enables annotating the process representation in a semantic way with further planning content and knowledge resources. This whole representation structure can then later be accessed by means of semantic queries. However, so far WPIM has only been applied in domains like component design and distributed production planning. It also includes ***Product Life Cycle Management (PLM)*** support but it has not yet been practically applied in the domain of CMCM as a means of supporting ALLP in Collaborative Manufacturing and Logistics scenarios.

In parallel to the development of WPIM, Wang et al. have introduced a method for representing web-based ***Distributed Process Planning (DPP)*** activities in [3], [4] and [5]. In the following we will use slightly adapted excerpts from [3] to introduce the necessary concepts and rationale of the DPP method. The DPP method includes also the concepts of ***Meta Function Blocks (MFBs), Execution Function Blocks (EFBs) and Operation Function Blocks (OFBs)***.

Furthermore, Helgoson et al. explain in [6] that “Today, machining-feature based approaches combined with ***Artificial Intelligence (AI)*** based methods are the popular choices for process planners”. Their introduced approach is already based on a DPP modeling-method but does not yet support machine-readability and semantic interoperability of such models as it could be achieved by utilizing representations as available in nowadays semantic web technologies and as e.g., supported by WPIM. This means, while the proposed DPP approach is very useful and valid in terms of representing the product and machining features within MFBs, EFBs, and OFBs it does nevertheless not yet support semantic-web based cross-organizational and cross-domain knowledge sharing. This holds especially true for the areas of CMCM as a means of optimizing conceptually planned component production processes and at the same time enabling them to be re-used as ALLP knowledge representations.

However, this is necessary to make such knowledge more widely available e.g., to be shared in collaborations of SMEs within CAPP, CMCM, and ALLP activities.

Furthermore, the relevant CMCM and ALLP knowledge to be integrated with the machine readable CAPP knowledge representations is currently not available in a machine-readable semantic representation at all. Moreover, this knowledge cannot easily be automatically shared, managed, accessed, exchanged, and re-used within collaborations that take advantage of cloud-based semantic repositories of CAPP-, CMCM-, and ALLP-knowledge. Besides, it is aiming at optimizing a conceptual CAPP instance for component production to also include ALLP and its optimization, ideally beyond planning domains and across organizational borders. If such a semantic and process-oriented integration of CAPP- and ALLP support based on a CMCM knowledge representation utilizing semantic-web technologies would exist, it could be very well supported by other semantic-web enabled technologies and in this way become interoperable. Therefore, an integration of cloud-based semantic CAPP and CMCM knowledge repositories with other e.g., AI, CAPP-, and MCM-support technologies could be achieved by means of integrating them based on the semantic web software development paradigm.

Based on this insight, in our preceding paper "Supporting Production Planning through Semantic Mediation of Processing Functionality" [22], we have already been describing in detail the applying and implementing necessary DPP and semantic-web integration approach for KPP within a so-called ***Mediator Architecture (MA)*** [14]. Such MAs are typical for distributed implementations of semantic-web repositories and are solving semantic integration challenges as well as integrating several local knowledge sources into a global, potentially cloud-based, semantic repository. From the point of view of WPIM, we have also demonstrated the domain models for MFBs, EFBs and OFBs can be covered by a semantic integration in this repository with the existing WPIM domain concepts of **WPIM-Master Processes**, -**Process Instances**, -**Tasks** and –**Activities.** Thus, it supports the integration of WPIM- and DPP-based knowledge modeling, as well as the semantic representation of DPP knowledge to become available as a knowledge-based support to CAPP activities.

To support this analysis of related work, the ProSTEP iViP Association [20] published a White Paper, called "Manufacturing Change Management (MCM)" [19]. MCM deals with the management of changes during production and continuously collaborates with the Production Planning Phase and vice-versa. That can achieve learning about optimization opportunities in the area of assembly, logistics and layout dimensions of the overall planning and change management processes. In the remainder of this paper, KPP will be explained in more detail and we will show the interoperability, usability, and in general the usefulness of KPP as an input and output process for MCM.

2. State of the Art and Related Work

2.1. Function Blocks

FBs are initially defined in the IEC 61499 standard [7], which explains the usage, development, and implementation of FBs in distributed industrial processmeasurement and -control systems in a component-oriented approach [8]. IEC 61499 was developed jointly from the existing concepts of FB diagram in the Programmable Logic Controllers (PLC) language standard IEC 61131-3 [9] and standardization work concerning Fieldbus [9]. An FB is an event-triggered component containing algorithms and an Execution Control Chart (ECC) with inputs and outputs of data and events. A literature review to FB is available in [3] [4].

2.2. *Distributed Process Planning*

As outlined in more detail in [3], the three core components of the DPP are namely the planning processes of ***Supervisory Planning (SP), Operation Planning (OP)*** plus a new ***Execution Control Planning (ECP)***. These are explicitly modeled in a conceptual ***ICAM Definition for Function Modeling (IDEF0***, where '***ICAM***' is an acronym for ***Integrated Computer Aided Manufacturing***) process formalization model together with their inter-relationship and dataflow.

2.3. *Meta, Execution and Operation Function Blocks*

MFBs are used in this research to encapsulate machining sequences (of setups and machining features) and only contains generic information about process planning of a product. It is a high-level process template, including, e.g., suggested cutting tool types and tool path patterns, for subsequent manufacturing tasks.

EFBs are the FBs that are ready to be downloaded to a specific machine. Basically, an EFB can be created by instantiating a series of MFBs associated with a task. Each manufacturing task corresponds to its own set of EFBs.

OFBs has the same structure as that of an EFB. However, an OFB specifies and completes EFB with more detailed, machine-specific data about machining processes and operation sequences.

2.4. *WPIM*

The concept of WPIM was developed to support capturing and usage of knowledge around innovation processes [1] [2] [10]. It assumes that innovation has both a knowledge and process perspective, which needs to be used in a combined manner. Therefore, activities of a process can be annotated with resources, such as experts and documents [10]. The semantic schema of the WPIM application and the corresponding tool suite is based on the ***Resource Description Framework (RDF)*** [11] and enables semantic-based searching by using the ***SPARQL Protocol And RDF Query Language (SPARQL)***. The ***Web Ontology Language (OWL)*** [12] [13] allows to model concepts in classes and replaceable relationships between such classes of concepts. These enabling technologies provide a well-defined formal semantic representation supporting the formal description of machine readable knowledge. With the concepts of ***Master Processes***, ***Process Instances*** as well as **Activities** and ***Tasks*** the separation of modeling and capturing generic and instance specific process knowledge is supported.

2.5. *Semantic integration within knowledge-based information architectures*

As outlined, e.g., in [15] data, information, and knowledge integration can be understood at varying levels of interoperability and heterogeneity. In the following, we will describe this a bit more in detail based on a slightly adapted excerpt from [15]. When trying to share distributed and heterogeneous data, a number of technical challenges must be overcome. The Extensible Markup Language (XML) [16] provides a simple and very flexible syntax for structuring many kinds of data, metadata, content, and knowledge resources to enable their exchange. For example, this can be done in different ways, e.g. in an XML ***Document Type Definition*** (DTD) or an ***XML Schema Definition (XSD, XML Schema)*** [16] [17] to specify the allowed nesting structure and (in XML Schema) the data types of XML elements.

2.6. *Mediator Architectures*

Mediators are a standard approach in the construction of information system architectures. They have originally been introduced by Wiederhold in [14] as early as in 1991 when the web was still in its infancies and the semantic web did not even exist. However, since then, the use and application of these architectures in building web-based information systems supporting, data, information, and knowledge integration has grown into a de-facto standard. A typical mediator architecture has a number of local data sources are “wrapped” as XML sources and subsequently combined into an integrated global view. Thus, a client application or the end user is provided with the illusion of querying a single, integrated (or global) database with one integrated schema.

3. Knowledge-based Production Planning

KPP as it has been developed within CAPP-4-SMEs and is based on all the already outlined concepts, methods and technologies. It combines all the advantages to one distributed and collaborative approach for supporting production planning in a knowledge-based way by integrating production planning knowledge resources along process representations of the three levels of the planning process. Hence, it integrates the DPP planning process as well as the related resources with FBs and the semantic WPIM technology. The already presented steps of DPP were expanded and adapted to WPIM and turning **the supervisory plan** into an **execution control plan** and this one into an **operational plan** in an optimized manner. Therefore, KPP also consists of a three-level process model. In the understanding of WPIM, the DPP planning process and resource knowledge is represented by planning activities consuming and producing planning knowledge resources. These can e.g., be FBs over all levels of CAPP activities from ***SP Process (SPP)*** activities through ***ECP Process (ECPP)*** activities to ***OP Process (OPP)*** activities. This is described in more detail in the related Paper [22]. The mediation process is also performed in a three-level MA. **Figure 1** displays the three level MA. The first mediator is called the ***SPP Mediator (SPPM)*** and integrates MFBs and other relevant and potentially distributed resources for the SPP activity. A down-stream DPP mediation can be implemented by means of two analogously derived additional mediators on the second and the third DPP level.

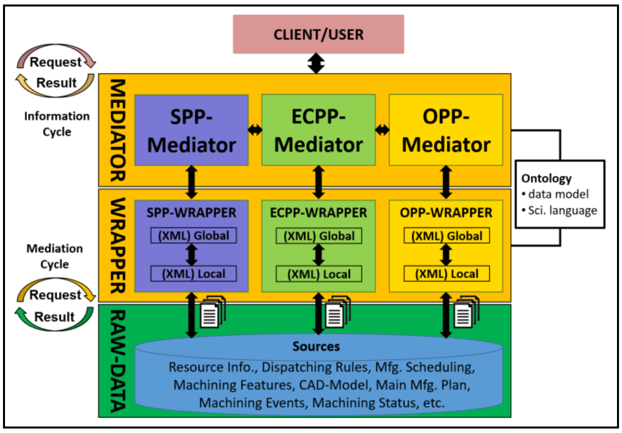

Figure 1: Conceptual Architecture of the KPP Mediator

On the second level of the MA follows then the deduced and so-called ***ECPP Mediator (ECPPM)*** which supports the above-mentioned ECPP activity. They assimilated at least an earlier iteration of the SPP-mediator as MFB and an OFB of the subsequent ***OPP Mediator (OPPM)*** (level 3) and various other relevant and potentially distributed resources. Coming from the machining-data point of view, the corresponding up-stream mediation process starts from machines with a defined need of steering information which can be harmonized by using wrappers and offering a mediated interface to clients. The third and final level of the MA of the KPP process forms the again derived ***OPPM*** and completes the mediation process. This integrates relevant and potentially distributed manufacturing knowledge resources as FBs and by the second level generated EFBs (ECPP Mediator) for the OPP activity. This three-tier architecture can support an Information Process by, providing data from distributed data repositories, combining various data schemata and corresponding formats into a single semantic-enabled global schema and format.

3.1. *KPP Support for MCM*

The already mentioned MCM settles between the planning phase and the actual production phase of a product. Furthermore, it responds to possible changes arising only during the set-up and pretesting of the planned production phase such as, e.g., the deviation of the current state of the real system from the current state of planning. In this sense, it is a possible downstream but also interdigitated and collaborative process of the KPP. The aims of MCM are the long-term production efficiency relies on a well-coordinated interplay between planning improvements and ongoing optimizations, the optimization of sustainable implementation of planned production processes, and the identification and minimization of discrepancies between the planning and production process and the improvement of the synchronization between production planning and production. In this way the MCM process can be considered as a consumer of a production plan provided by KPP.

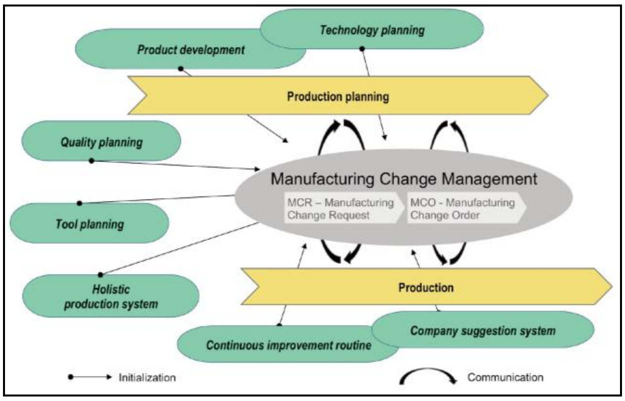

Figure 2: MCM Model by ProSTEP iViP [19]

At the same time, it can be considered as a producer of optimization input for production planning. This can be enabled by means of passing on production plans represented in the KPP method to the MCM process and feeding back production plans with optimization annotations from the MCM process into the KPP process. This occurs in order to update representations of Master Process that have been used as a basis for the KPP-based production plan.

4. Conclusion and Future Work

This paper has presented an innovative method to support KPP in the manufacturing domain based on semantic process representations producing and consuming function blocks and other relevant planning resources for manufacturing planning. On the basis of several sample data sets, we will also demonstrate in our future work the query, search and representation for information as well as the functionality of the KPP wrapper technology for the domain of manufacturing planning. Thus, also the complete three step mediator architecture will be demonstrated. Furthermore, we will evaluate the KPP method. This includes applications of KPP to Assembly, Logistic and Layout Planning as well as feeding KPP planning results into MCM infrastructures and consuming MCM-produced manufacturing change requests by means of the KPP infrastructure as a method to optimized production process templates. Therefore, future production planning activities will be enabled to take advantages of lessons learned during set-up and pre-testing as a means of optimization of production planning.

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