

INTEGRATING SMART PRODUCTION PLANNING INTO SMART PRODUCTION

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Abstract — Industry 4.0 R&D is currently driving the emergence of *Smart Production Environments (SPE)* where the manufacturing of new products takes place very flexibly and dynamically in several steps and locations, possibly distributed all over the world. Companies involved in such smart productions act in highly competitive global markets and always have to find new ways to, e.g., cut costs by changing to the best providers, or enabling, e.g., tax savings, to stay competitive. This can only be achieved by using the fastest, most effective, efficient, and flexible distributed collaborative production processes. In this context, a *Collaborative Adaptive Production Process Planning (CAPPP)* can be supported by semantic product data management approaches enabling production-knowledge representation; utilization, curation, and archival as well as knowledge sharing, access, and reuse in many flexible and efficient ways. To support such scenarios, semantic representation of production knowledge integrated into a machine-readable process formalization is a key enabling factor for sharing such explicit knowledge resources in cloud-based production knowledge repositories. Our approach of *Knowledge-Based Production Planning (KPP)* introduces such a method and already provides a corresponding prototypical Proof-of-Concept implementation. In this way, it can not only be used in production planning but also, e.g., in *Collaborative Manufacturing Change Management (CMCM)* as well as, e.g., in *Collaborative Assembly-, Logistics- and Layout Planning (CALLP)* both building on the results of CAPPP. Therefore, a collaborative planning and optimization from mass to lot-size one production in a machine readable and processable representation will be possible. On the other hand, KPP knowledge can be shared to support other types of innovation, collaboration, and co-creation within a cloud-based semantic production knowledge repository.

Keywords—Smart Production Planning Service, Manufacturing, Production, Assembly, Planning, Smart Product, Smart Service, Smart Production, Knowledge-based, Semantics

I. INTRODUCTION AND MOTIVATION

Industry 4.0 prototypes and implementations are currently introducing frameworks and standardization activities that increase flexibility in production and efficient resource management leading to smart factories using smart services and enabling smart products. Service-oriented Architectures and **Local Clouds** are presented in various approaches like e.g. [1][2][3]. In such approaches, loose coupling, late binding, and reconfiguration for smart production are introduced to support **Smart Products** and in **Smart Production Environments**. These approaches are highly regarded in Industry 4.0 environments supporting manufacturing industries. In the remainder of this paper, our semantic method of **Knowledge Based Production Planning (KPP)** is introduced. It complements the above-mentioned approaches by adding **Semantic Production Planning (SPP)** services for smart products.

SPP services offer a multitude of advantages beyond conventional production planning, such as machine-readable exchange formats, annotation options, and resource descriptions. In addition, SPP services provide a foundation for applying semantic searching, inferencing, mining, and machine learning. Our earlier work has already demonstrated that knowledge about the product itself (like properties, features, properties, etc.) is traditionally stored separately from the knowledge about its production (production processes, machines, automation) in different knowledge repositories. This separated distribution of knowledge contradicts the idea of Industry 4.0 and the so-called Smart Product approach aiming at an intelligent integration of product knowledge with production knowledge and with the product itself wherever possible. In their publication *Smart Services* [4], Stöhr, C. et al. define **Smart Services** as follows:

“A Smart Service is a digital service that reacts on collected and analyzed data based on networked, intelligent technical systems and platforms. In contrast to the technology of Industry 4.0 which can exist in just one specific sector, Smart Services require cross-functional areas. These areas provide services which respond to analyzed data of other areas. Areas can be different departments in one company or more typically different companies which function as players in a network.”

According to this description and properties, Smart Services are digital services and take advantage of the increasing number of technical systems with information and communication technology and sensors as well as their increasing cross-functional networking capacity, which is realized via the world wide web. The technical systems and products are also referred to as **Smart Products**¹ due to these properties. Therefore, the term Smart Product can stand for very different material goods and can therefore include complex industrial machines and systems. Furthermore, a smart product should have attached² all product-relevant information, *the product knowledge about itself as a product* as well as all production-relevant information, *the knowledge of its own production process* throughout the entire product life cycle. In consequence, the KPP approach offers solutions which enable to bind all product knowledge and all production knowledge to the representation of the “product to be produced” in a semantic way. Furthermore, KPP’s Smart Services³ and representations of Smart Products can be merged into a representation of a Smart Production.

¹ <https://www.ecom-ex.com/de/explosionsschutz/ex-lexikon/begriff/smart-product/>; Smart products are intelligent products and components that are able to interact and collect data and communicate with each other during their manufacturing and phase of use.

² at RAMI in a so called container or component shell [german: Hülle, Schale].

³ The term “Smart Services” refers to data-based, individually configurable service offers, digital services and products that are organized via platforms. [see https://wiki.iao.fraunhofer.de/index.php/Smart_Services and [Bull15].

A Smart Product representation has to contain Smart Product information. This information has to be semantically represented and machine readable/interpretable. A Smart Product representation has to contain its own Smart Production plan. In this context, a **Collaborative Adaptive Production Process Planning (CAPPP)** [CAPPP-4-SMEs⁴][5] can be supported by semantic product-data management approaches enabling production-knowledge representation, utilization, curation, and archival as well as knowledge sharing, access, and re-use in many flexible and efficient ways. To support such scenarios, semantic representations of production knowledge integrated into a machine-readable process formalization is a key enabling factor for sharing such explicit knowledge resources in cloud-based knowledge repositories. With KPP we introduce such a method and provide a corresponding prototypical Proof-of-Concept (POC) implementation.

II. BACKGROUND

The relevant background and state of the art is briefly summarized based on a slightly adapted excerpts from [6,8], various other earlier work on semantic process-modeling, and the **Reference Production Planning (RPP)** recommendation of the *ProSTEP iViP Association* [7]. It also introduces the necessary concepts of information integration and mediation as well as of mediator architectures as a background for the semantic integration and mediation. The three core components of the **Distributed Process Planning (DPP)** are *Supervisory Planning*, *Execution Control Planning*, and *Operation Planning*. These are formalized in a conceptual **ICAM Definition for Function Modeling (IDEF0)**, where 'ICAM' is an acronym for **Integrated Computer Aided Manufacturing** process model together with their inter-relationship and dataflow. Building on this formalization, KPP supports capturing, representation, management and re-use of knowledge around production planning processes. In this way, KPP supports both, a knowledge and a process perspective in a combined manner. Therefore, activities of a process can be annotated with resources, such as, e.g., experts and documents. The formal semantic schema of KPP and the corresponding POC implementation is based on the **Resource Description Framework (RDF)** [9] and the *Neo4j graph database system*⁵. In this way, RDF enables semantic access provided by the **SPARQL Protocol And RDF Query Language (SPARQL)** and **Cypher (a declarative query language for Neo4j)**. The **Web Ontology Language (OWL)** [10,11] 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 production knowledge. With the concepts of **Master Processes (MP)**, **Process Instances (PI)**, as well as Activities and Tasks the separation of modeling and capturing generic and instance specific process knowledge is supported. In this way, the process artefact representation of KPP allows (re)using process components and their associated machine-readable knowledge resources in a seamless way.

Furthermore, **KPP** is a POC implementation of the formal concept of the above mentioned RPP recommendation. The

RPP is an end-to-end reference process that can be adapted to individual needs and is divided into three maturity level-related phases: **Concept Planning (CP)**, **Rough Planning (RP)** and **Detailed Planning (DP)**. Thus, it can be seen as a high-level template for creating a concrete production planning process that takes individual company-specific and location-specific conditions into consideration in an adaptive way.

KPP takes advantage of all these concepts and semantically integrates them into one integrated, distributed, and collaborative three-level CAPPP approach for supporting production planning. Furthermore, KPP integrates production planning knowledge resources along process representations of the planning process. In a broader sense - Smart means nothing else than Semantic. Thus, KPP can be called a Smart CAPPP Service for Smart Products or better a Smart CAPPP for Products with a Smart Product Lifecycle. Hence, KPP integrates the CAPPP and DPP planning as well as the related resources with semantic technology. The already presented concepts of DPP and RPP were expanded and based on KPP concepts in order to represent the transformation of the **Supervisory Plan (SP)** into an **Execution Control Plan (ECP)** and this one into an **Operational Plan (OP)** in an optimized manner. In the understanding of KPP, the CAPPP and DPP planning processes and their resource knowledge is represented by planning activities consuming and producing planning knowledge resources. These can be, e.g., so-called **Function Blocks (FB)** [6] overall levels of CAPPP activities from **SP Process (SPP)** activities through **ECP Process (ECPP)** activities to **OP Process (OPP)** activities. This is described in more detail in [12, 24]. The mediation process is also performed in a three-level **Mediator Architecture (MA)** [13]. Figure 1 displays the three level MA. The first mediator is called the **SPP Mediator** and integrates **Meta Function Blocks** 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. On the second planning level of the MA the so-called **ECPP Mediator** supports the above-mentioned ECPP activity. It takes up the results of an earlier iteration of the SPP-mediator on the first planning level, i.e., a **Meta Function Block** and provides an **Operation Function Block** to the subsequent **OPP Mediator** on the third planning level as well as 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 **Execution Function Blocks (ECPP Mediator)** for the OPP activity. This three-tier architecture can support a Semantic Information Integration Process by providing data from distributed data repositories, combining and integrating various data schemata and corresponding formats into a single semantic-enabled globally integrated schema and format. Moreover, it enables a semantic mediation process that supports requesting, accessing, and collecting/gathering/combining data from

⁴ <https://www.capp-4-smes.eu/>

⁵ <https://neo4j.com/>

different distributed manufacturing- and planning knowledge resources in a semantically integrated way.

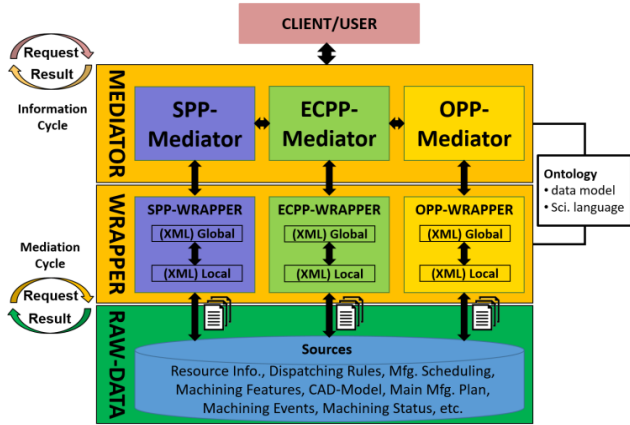


Fig. 1. Conceptual Architecture of the KPP Mediator

III. MODELLING THE KPP ONTOLOGY

The goal of successful production planning is to ensure that all of a company's production processes run smoothly. Production processes or manufacturing processes can be divided into the following areas according to DIN 8580 [14][15]:

- formative manufacturing
- subtractive manufacturing
- additive manufacturing

In addition to these component manufacturing process types, there is manufacturing by assembly, which is described in accordance with VDI guideline 2815 [16] as the “assembly of parts and / or groups into products or into groups of higher product levels in manufacturing”. These products are manufactured by the described manufacturing processes in an own company or manufactured by other companies and then integrated logistically into the component production or assembly. Thus, the manufactured product of a company can be used as a raw material, consumable, or as a component for assembly in another company. Based on these recommendations, the above outlined analysis results and concepts as well as a domain and data model, a suitable ontology was developed for KPP and specifically for the domain of production planning. The KPP ontology was created in the application Protégé using a top-down procedure and is available in OWL format. Starting with the root element Product, the other areas of the domain follow, always with the aim of organizing and managing knowledge in order to then share it. In the KPP ontology, the transfer of knowledge or knowledge exchange related to a product can be regarded as essential. Against this background, the root element Product is legitimate for the ontology. The ontology created in this way can also be relevant for other applications and products. Some classes are listed below as an example:

Product

Comment: „A product. Products may be finished products or parts of other products.“

Attributes: Name

Relations: Process, Prozesselement, Material

URL: kpp.fernuni-hagen.de/ontology/#Product

Person

Comment: „A person“

Attributes: GivenName, FamilyName, Title, Jobtitle, Phone, Homepage

Relations: Person, Organization, Language, Function, Role, Document,

Method, Skill, Process, Functionblock, Source

URL: kpp.fernuni-hagen.de/ontology/#Person

Machine

Comment: „A machine or mechanical device“

Attributes: Name, WorkingSpace, LayerStrenght, ...

Relations: Prozesselement, ProductionType, Material

URL: kpp.fernuni-hagen.de/ontology/#Machine

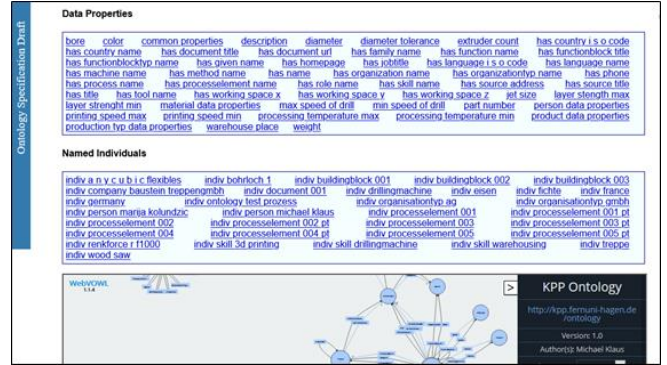


Fig. 2. Web presentation of the KPP ontology, visualization of the relationships

The complete list of all classes, object and data properties, descriptions and the ontology itself are stored as a moving image file on the KPP server and linked within the KPP application⁶.

IV. REMAINING CHALLENGES

After modelling the initial KPP ontology, the following remaining challenges of applying KPP's smart production planning services based on the KPP ontology to Smart Products and Smart Production can be identified:

A. Late binding

Following Delsing's ideas [1], a smart product is manufactured using smart services in a smart production environment. However, if the associated production plan was carried out and completed in advance, it is deprived of the possibility of late binding in the production process, i.e., a late and flexible assignment of, e.g., production/manufacturing machines. This means: When production planning has already been carried out in advance, it must remain changeable. Production planning has to be attached dynamically to the smart product and must remain changeable until the whole production is completed. Therefore, calculation and execution of the production plan should take place at the latest possible time.

B. Reconfiguration

If the number of products to be produced or component configurations changes, the production plan must remain predictable and changeable even after the start of production. Therefore, planning should also take lot sizes or the optimization of production processes into account. A simple example of such a reconfiguration need can be considered as a starting point: Instead of initially 50 now 100 identical components need to be produced. How can an allocation of machines and resources be planned and optimized? A similar

⁶ <http://kpp.fernuni-hagen.de/taxonomy/>

example of a planning reconfiguration question would be: If two or more product variants will be produced alternately or one after the other, how can throughput and set-up times be planned and optimized?

C. Loose Coupling

The following three attributes describe Loose Coupling⁷ and help to realize different life cycles: Autonomy - a service exchange is not supervised. Distributed - services are distributed over several devices. A system is responsible, owns the information and can decide whom to share with.

V. PROPOSED APPROACH

In the remainder of this paper we present our idea of applying Knowledge-based Production Planning in order to address the following research questions:

- How can production-relevant information be annotated to the product – to become a Smart Product?
- Which interfaces and services should a Smart Product provide, to enable access to production-relevant information in Smart Production Environments (SPE)?
- Which Smart Services are required for short-term and flexible changes/extensions/adoptions of production-relevant information during Smart Production?

KPP offers approaches and solutions to these key questions of integrating smart production planning into smart production. We first want to demonstrate alignment and conformity of the approaches of Service oriented Architectures and Local Clouds with KPP. In a second step we outline, how KPP enriches these existing approaches and frameworks. Finally, we answer the named research questions.

At first, we argue that our KPP approach is compliant to, fully integrable into and consistent with the Arrowhead Framework and Service oriented Architectures (SoA) and Local Clouds [17] as well as Loose Coupling, Mediation, PLM, IoT / IIoT [18] approaches as well as Semantics [19][20] and Smart Production, Smart Factory and KPP's smartening Services in general.

Secondly, we argue, that KPP and its derived process-orientation will refine existing SoA architectures and support Life Cycle Value Stream and Value Adding Processes in **Intelligent Production Environments (IPE)** and for Industry 4.0. Finally, we include and enrich I4.0 by KPP and its **Smart Services**, e.g. our so-called **Smart Planning Service** plus further **Semantic and Smart Services** for SoA and Local Clouds guided by the above-mentioned research questions.

Supporting knowledge-based and process-oriented production planning has to be process-oriented and knowledge-based, has to include modeling and representing processes in a machine-readable semantic format, has to support annotating the semantic process representation in a semantic way, and has to support documentation, access, and re-use through semantic queries, archival, and preservation. KPP optimizes processes in manufacturing industries, with the aim of automating process flows and allocating the required machines (resources) for the respective production step (process). For this, the required production step must be analyzed (e.g. drilling, turning, milling) and a mapping to the

machine park is to be carried out. The result is a semantically annotated process model that can be executed as an executable machine control file (e.g., a function block) on a distributed machine park. In our ongoing research we are currently working on Smart Production Environments and I4.0 enriching services, e.g. on so called "Smart Services" as Reconfiguration Services, Mediation Services and Collaboration Services as well as Searching, Inferencing and Mining Services.

VI. STATE OF ART AND RELATED WORK

Beyond Semantic Web basic technologies an alignment of the RAMI 4.0 Life Cycle Value Stream with semantics, semantic search and semantic applications is needed. In our understanding, semantics and W3C Semantic Web Standards enable connected data and help to realize the Industrial Internet of Things (IIoT) [21] as well as the „Connected World“ of Industry 4.0. In *Semantic Applications* Hoppe/Humm/Reibold give a deep insight into Semantic Technologies, the Semantic Web Stack, W3C Semantic Web Standards and Annotation as a value adding process ... “... *this enrichment process is also a kind of data integration, since the keywords accompanying the content or derived from them are integrated with the modeled knowledge to form a new knowledge source.*” [19]

The **IDS Reference Architecture Model (IDS RAM)** version 3.0 is provided by the **International Data Spaces Association (IDSA)** constitutes the basis for a variety of software implementations, and thus for a variety of commercial software and service offerings. It is driven by the reuse of existing technologies e.g. interorganizational information systems, data interoperability and information security are well established fields of research and development, with plenty of technologies available in the market [IDS RAM, p. 10]. The work of the International Data Spaces initiative is guided by the idea to use existing technologies e.g., from the open-source domain and also standards e.g., semantic standards of the W3C.

“The International Data Spaces (IDS) is a virtual data space leveraging existing standards and technologies, as well as governance models well-accepted in the data economy, to facilitate secure and standardized data exchange and data linkage in a trusted business ecosystem.” [IDS RAM⁸, p. 9]

Additional data services e.g., for data analysis, data integration, data cleansing, or semantic enrichment are foreseen, to improve the quality of the data exchanged in the International Data Spaces [IDS RAM, p. 24].

The Arrowhead project is providing the Arrowhead Framework and a couple of working IoT based automation examples as open source as is. The Arrowhead Framework [2] technology architecture is based on the concept of local clouds that consist of System of Systems (SoS). [https://www.arrowhead.eu/]. The Arrowhead vision is the enabling of collaborative IoT based automation. This is addressed by the creation of the Arrowhead Framework where IoT automation components and devices are abstracted as services thus enabling interoperability between almost any IoT device. The collaborative automation is implemented and tested in 22 demonstrators across five application verticals,

⁷ <https://www.arrowhead.eu/article/local-automation-clouds/>

⁸ <https://www.internationaldataspaces.org/wp-content/uploads/2019/03/IDS-Reference-Architecture-Model-3.0.pdf>

smart production (manufacturing and continuous processes), smart buildings and infrastructures, electro-mobility, smart energy and the virtual market of energy.

VII. INTEGRATION CONCEPT

The concept and methodology of Represa/Delsing [1][2][3] of autonomous production workstations in **Service Oriented Architectures (SoA)** and based on **Local Clouds** [1] as well as Smart Products, Smart Factory [22], Smart Service [23], IIOT [18] and the Arrowhead Framework [2] are highly respected and rewarded approaches and implementations in the environment of Industry 4.0 and by industrial partners of manufacturing companies.

Represa/Delsing presented on ICPR25⁹ their approach of a SoA and of local clouds in SoA workflows for **Autonomous Production Workstation Operation, Reconfiguration and Synchronization**. Manufacturing systems need to change and adapt to these new architectures e.g. Industrial IoT (IIOT):

“For this purpose, there are emerging technologies that will enhance the automation systems and fill the gaps. Some of the key technologies that are currently in the spotlight are: Cyber-Physical Systems (CPS), Internet of Things (IoT), cloud computing, big data analytics and information technology, which constitute the Service Oriented Architecture (SOA). These technologies do not come from the automation field, so there is a need for integration such that they meet the requirements of the area.” [3].

Represa/Delsing implemented their use cases within the Arrowhead framework [2][3]. The aim of these use cases can be summarized by decoupling the ISA-95¹⁰ architecture [3]. *“Autonomous workstation operation consists of operation independent of a connection to an upper layer of the factory network, in an ISA-95 architecture this would be the MES layer in charge tracking, execution, planning, etc.” [3].*

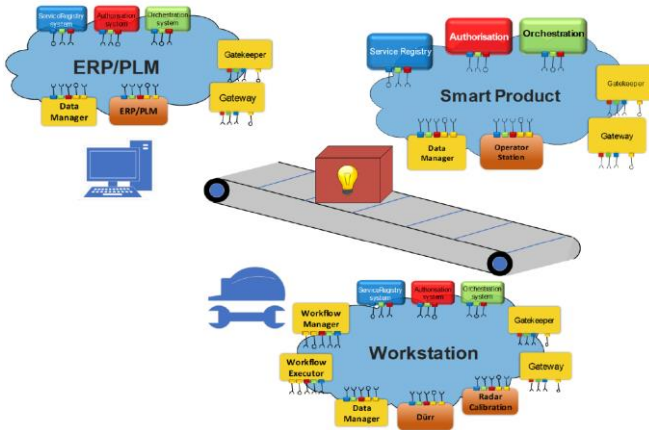


Fig. 3. Local clouds in (SoA) workflows [3]

The autonomous workstations shown by Delsing in Figure 3 offer the advantages of distributed and local production. Figure 4 shows the possible extension by KPP with the smart services for planning. In the following we present this integrative approach. As displayed in [Fig. 3] there is neither a MES system nor a MES layer shown or required. In legacy architectures Production Planning requires support by MES systems. Fig. 3 displays an architecture for Smart

Products/Smart Production which requires a Smart Production Planning.

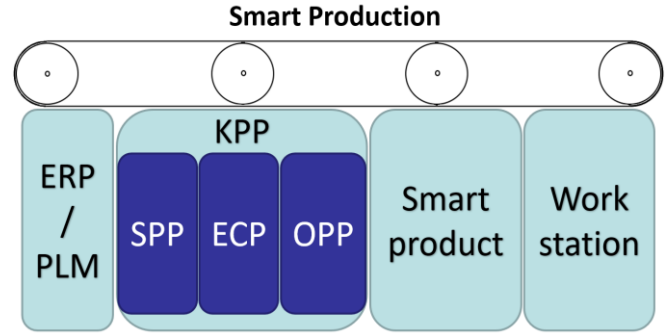


Fig. 4. Possible extension KPP with the smart services for planning

As displayed in Fig. 4 there is neither a MES system nor a MES layer shown or required. In legacy architectures Production Planning requires support by MES systems. [Fig. 4] displays an architecture for Smart Products/Smart Production which requires a Smart Production Planning. KPP can offer such a required and knowledge-based, semantic, Smart Production Planning for Smart Products/Smart Production. KPP will offer these missing planning data in a so-called Smart Production Plan replacing a legacy MES for a SoA. Furthermore, Represa/Delsing [3] pointed out two major aspects of their approach: SoA and Local Clouds as the enabling factors. Both are well supported by KPP methodology and KPP architecture. The KPP Ecosystem is process oriented, has standardized and open interfaces, and can store data in local clouds. In addition, KPP supports Arrowhead Framework properties like loose coupling and different life cycles of products. In its definition, the Arrowhead framework has as objective to keep the advantage of loose coupling by following the SOA paradigm [2]. Any framework or architecture following these properties, should be a valid candidate to be used in a scenario where workstations need to adapt to shop floor changes [3].

VIII. PROOF-OF-CONCEPT SCENARIOS

To complete the demonstration of integrating KPP two possible POCs scenarios are outlined. First, in Fig. 5 our sandbox example using Building Blocks to show how KPP planning services can be used for assembly and building sequences and product configurations, e.g. quantity of stair-steps [23].

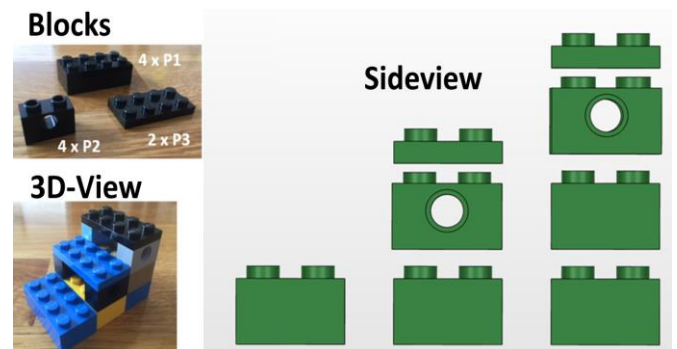


Fig. 5. Building Blocks example

⁹ ICPR25, 25th International Conference on Production Research Manufacturing Innovation

¹⁰ ANSI/ISA-95 Enterprise-Control System Integration; known internationally as IEC/ISO 62264

Second, in Fig. 6 the Turbocharger example describes planning services for distributed manufacturing of charger components by evaluating the implemented interface between KPP and SAP [24].

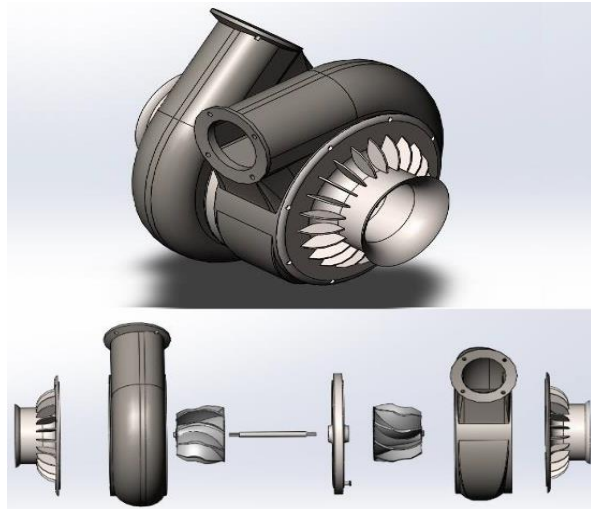


Fig. 6. Turbocharger example

Both scenarios use the KPP ontology and semantics to support smart planning services within the KPP Ecosystem [19][20][23]

IX. CONCLUSION AND CONTRIBUTION

KPP addresses the remaining challenges from section IV and offers targeted approaches and improvements through its methods and tools. Therefore, KPP is a possible candidate to enrich the Smart Production Environments as e.g. enabled by the Arrowhead Framework. Furthermore, KPP is on its way to support such a Semantic Ecosystem for Smart Production in an integrated way. KPP's contribution in the Smart Factory Scenario is to offer KPP Smart Planning Services that make production more flexible enabled through reconfiguration, late binding and loose coupling. KPP also contributes to connect semantic description of planning data containing product-relevant and production-relevant data directly to the product. As novelty within this work we have presented our KPP production ontology and envisioned an initial approach that enables that KPP's different production planning support services can be seamlessly integrated in Industry 4.0 Smart Production Environments. In Summary KPP enriches local clouds in Service oriented Architecture (SoA) workflows by KPP Planning Services.

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