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Production planning and control systems – a new software architecture Connectivity in target

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Abstract

Since the rise of production planning and control systems those systems were subject to changes and further development due to new requirements and possibilities. Recently, Industry 4.0 and especially the cloud manufacturing paradigm brought up new requirements as connectivity demands, which are not fulfilled by current realizations of production planning and control systems. To adapt such systems to connectivity requirements, current software architectures have to be revised. Therefore, within this paper a new software architecture for production planning and control systems is introduced providing a basis for data exchange in-between such systems.

Keywords: Planning and control systems; Software architecture; Industry 4.0; Cloud manufacturing

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1. Introduction

Production Planning and Control (PPC) systems are software tools that support enterprises by planning and scheduling their resources such as machines. The larger the pool of available resources and the more important the need of efficient scheduling, the more essential are such systems.

Trends in business theory and progress in IT as well as societal drivers continuously affect PPC systems' environment and requirements [1]. Therefore, it is important to track current trends and to adapt PPC systems. At present one trend is Cloud Manufacturing, where the pool of resources is extended immense by foreign resources and the need of connectivity between PPC systems rises [2]. Then, such systems have to have access to manufacturing resources across company's borders to find an optimal solution for a scheduling problem [2]. However, current implementations of PPC systems do not allow the required holistic view of available resources. Instead access is limited to in-house machine parks [3].

To adapt PPC systems to the need of connectivity, their basic structure has to be rethought. In this paper a new software architecture for connected PPC systems is presented and discussed. The paper's structure is as follows. In Section 2 related work is presented. Then, in Section 3, the system design for future PPC systems is introduced. Section 4 discusses the new design and gives outlook to further work.

2. Related Work

In this section the term PPC is defined and the characteristics of Cloud Manufacturing are discussed. Furthermore, current trends are enlightened for these fields.

2.1. Cloud Manufacturing

Cloud Manufacturing (CM) is the idea of offering and using manufacturing processes as a Service. This comprises services from product design and production up to product delivery [4]. Services are accessible for everyone registered in a certain network, namely a cloud platform. Cloud platforms for CM are a complex construct where the fields of IT, business management, innovation and manufacturing cumulate to an interdisciplinary entity [5].

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Once realized, CM promises flexible value chains where manufacturers and customers are loosely coupled and collaborations are initiated for a specific purpose. This flexibility and agility enables on-demand manufacturing and the possibility to handle complex tasks by well-orchestrated services. Especially for small and medium size enterprises, CM is a chance to access to larger order volumes, more complex processes and new business models [6].

Several publications address the challenges coming up with CM. For example, formulation of manufacturing service capability and resulting matchmaking is discussed [7]. The authors develop the ontology Manufacturing Service Description Language (MSDL) to describe and communicate capabilities and offers between companies. The language focusses on subtractive manufacturing processes. Similar ontologies with slightly different abstraction levels or industry focus are also available [8–10]. Actually, Cloud Manufacturing is realized through manufacturing platforms, where manufacturers can offer their resources and the platform mediates between requests and offers [11]. However, these platforms require redundant data handling and are not integrated into manufacturers' process flow.

To achieve the idea of CM, virtualization is an important factor. Resources and products are abstracted as (cyber-) physical objects and the entire enterprise transforms to a virtual enterprise that offers manufacturing-as-a-service. Key point of manufacturing-as-a-service is to make resources accessible as well as to exploit the access to a pool of (foreign) resources [3]. Even if enterprise' resources are presented virtually, organization and scheduling is still done by separated Production Planning and Control Systems.

2.2. Production Planning and Control Systems

"PPC" is a broad term, used for software tools supporting company's organization, planning and forecasting of production. In this paper "PPC" refers to a software tool organizing available resources such as machines. This includes capacity planning as well as material requirements planning. Resources are scheduled based on manufacturing requirements and basic conditions such as batch sizes and delivery dates [12]. Scheduling of machines, for example, is done by finding machines that meet the manufacturing requirements and occupying these machines in an optimal way. Optimality means to minimize an objective function of idle time, costs, time delays and quality and to find a tradeoff between these competing components [13].

To allow such complex computations, PPC systems require a digital copy of the company. Available resources, feedback of the shop floor, online data and production needs sum up to a huge amount of data that has to be processed and visualized. Current realizations of PPC systems address this need successfully [14].

Though, in view of trends such as cloud manufacturing, available resources are not only restricted to one single company. Companies start outsourcing their production partly or completely. Then, it is no more sufficient to be aware of in-house resources. Instead, PPC systems have to have access to all available resources in a network of companies to guaranty optimal scheduling in future.

It follows that requirements on a PPC system have to be reconsidered. Table 1 lists characteristics on PPC systems in general and gives trends on how their relevance is shifted in view of the stated trends. Since resources are more distributed storage capacity is less important. Likewise correctness in terms of choosing the best suitable machine for production will be less significant. It is more important to meet business economic needs such as low cost and fast delivery. As before, PPC systems have to be reliable and to answer to requests at any time. Contrarily, considering huge and distributed data sets, performance and connectivity are important requirements on an up to date PPC system [2].

At present the problem of production planning based on distributed resources is solved in two ways: (i) Start requests for each separated PPC and compare the solutions [3]; (ii) Creating a new database containing all available resources of a production network. This database is then used in a single PPC system [15]. Case (i) is time complex and involves communication between company's representatives. The large the network the less attractive is this method. Case (ii) is error- and loss-prone, since it is difficult to keep such a fused database up-to-date. On top, the more companies are involved the more storage capacity and performance will be an issue.

Some concepts in business economics already discuss the idea of decentralized business models where planning takes place across companies borders [1]. Publications on cloud based PPC systems and the question of their architecture, orchestration and information flow are only considering one company [15].

Summarizing, it is necessary to revolutionize current PPC systems such that they fulfill the stated requirements. In the following it will be discussed how PPC systems could be changed in order to meet the demand for connectivity.

Table 1: Requirements on modern PPC systems, based on [2].

Requirement	Description	Trend
Storage Capacity	Capability to store large datasets.	-
Correctness	Feasibility of planning results.	-
Reliability	Stability of the system in terms of availability.	o
Performance	Planning efficiency in terms of calculation time and optimality of the achieved solution.	+
Connectivity	Capability to interact with other PPC systems or plan throughout company borders otherwise.	++

Trends are given in comparison to actual implementations. (-) less important, (o) equivalent, (+) more important, (++) much more important.

3. Software Architecture of Production Planning and Control Systems fulfilling Connectivity Requirements

In this section, a software architecture of PPC systems meeting the demand for connectivity is presented. It was discussed that neither a PPC system equipped with a common database with redundant data nor communication involving human power are acceptable ways to connect resources of different manufacturing companies. Therefore it is proposed to create a network of PPC systems where PPC systems are able to communicate requests and resource availability. The software architecture is discussed in two levels of abstraction. First a specification describes the ideas of application and usage, followed by the system design describing suggested implementation approaches.

3.1. Specification

In Figure 1 an example for a small network of PPC systems is pictured. The network of PPS systems results in a graph where knots are manufacturing companies or intermediary agents and edges are weighted by commissions. For each knot local production cost is computed. PPC systems can search for possible producers by requesting their partners. Those, again, can either pass the request to their partners or decide to offer local production. In a PPC network the amount of available resources and possibilities multiples at once.

An example of planning is pictured in Figure 2, where a manufacturing company wants to produce a designed product. This company has two business partners and additionally has indirect access to the resources of multiple manufacturing companies via a mediate platform. One of the partners has a subcontractor to whom he could outsource production. The manufacturing company is not able to produce locally therefore the PPC system sends requests to the PPC systems of its partners. Business partner B offers production for 54 $ per part without commission since he can produce locally. Business partner A can either produce locally or forward the query to the subcontractor. Therefore, he always calculates commission and subtracts them from production costs if production is done locally. The subcontractor is underemployed and therefore calculates only 42 $, while the mediate platform always charges a fee of 16 $ but its participants don't. Finally the optimal choice for production is to outsource production to the subcontractor of business agent A.

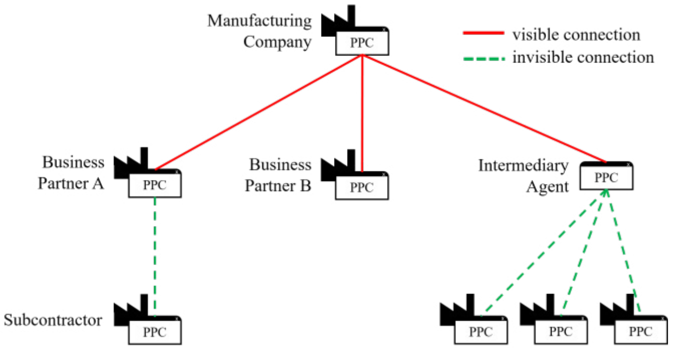

Fig. 1: Example of a production planning and control systems network.

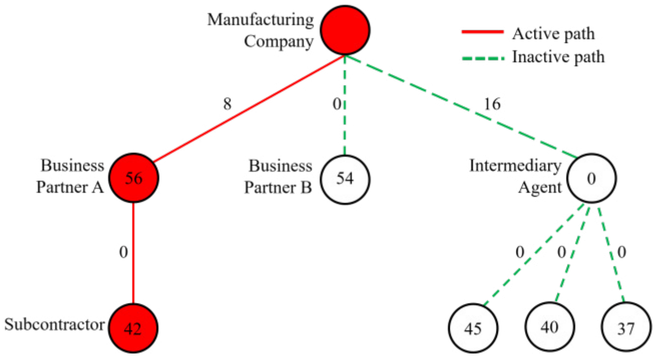

Fig. 2: Example search graph for production planning and control systems.

Evaluating by costs is only one possibility. Other factors such as time could also be important. Then production time is local cost and edges are weighted by a factor that combines product logistics and handling issues such as transportation.

Finding the most suitable partner is an algorithmic task. One possibility to find a path in a weighted graph that is related to minimum cost is the A* algorithm. This algorithm is proven to be complete, optimal and to explore a minimum amount of nodes in a graph under certain constraints [16].

The retrieved minimal set of use cases for a PPC system to participate in the prior introduced graph are pictured in Figure 3. Each system does have two different types of users: (i) internal users and (ii) external systems. The intended external systems are other PPC systems that want to place an order enquiry. The PPC system can decide for each enquiry if an external system is considered as customer or not, based on its internal set of rules. These set of rules should represent the owner's strategy and can fall back on known relations, managed by the internal user.

If an incoming enquiry is accepted this releases planning of production as if it was triggered by an internal user. Internal resource requirements are estimated and order enquiries are forwarded to further PPC systems. After a specified period of time the forwarded requests are aborted and external offers are compared with the estimated internal resource requirements. Again based on the company's strategy the derived costs are now calculated including potential agency fees for passing on orders to subcontractors as discussed prior.

3.2. System Design

In the foregoing section a setup was presented where PPC systems fulfil the demand for connectivity. It was discussed how PPC systems could gain connectivity by creating a graph of PPC systems. It was proposed how edges and knots could be labelled and how the "best" manufacturer can be found in such a graph. In the following a possible architecture of a single participant of the network is presented. There are two key components which have to be addressed in graphs. Namely, (i) communication and (ii) processing of received data locally. Local processing of data was discussed in the foregoing section.

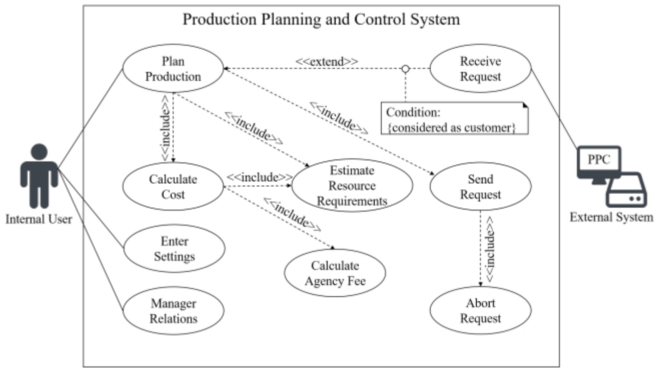

Fig. 3: Use Cases of a connected Production Planning and Control System.

There are several possibilities when communication between PPC systems can take place. This could be either on the level of databases or between PPC systems directly. Each manufacturer has his own policy on how to calculate costs and occupy resources. Thus, each PPC system has a proper underlying structure and concept including managing of databases that represent local resources, resource capability as well as their availability. This results in special algorithms for optimal scheduling. Therefore, in this paper, basic implementation and database structure of a single PPC-agent are not prescribed. Instead, to realize connectivity and communication between PPC systems directly, each local PPC has to be equipped with a “connection-component”. This connection-component is pictured in Figure 4 (b), whereas Figure 4 (a) does represent the simplified PPC architecture based on the Aachener PPC model [12].

Process Planning in general is done based on the information which material and resources are required. These information result from Material Requirements Planning and Capacity Planning. Scheduling is an algorithmic task, where an optimization problem aims to minimize “costs” while occupying machines. To do so, material and manufacturing data stored in a database need to be accessible. Data is organized by Data Managemant. The connection-component is an intermediate layer that has to be integrated into the current PPC process. For example, if local resources are not available it is decided to request other PPC systems. Conversely, request from neighbouring PPC systems are input to the local PPC system via the connection-component. Finally, the future architecture is an extension to current implementations and does not severely change their structure.

The proposed architecture results in a heterogeneous PPC graph, including databases with SQL and NoSQL paradigms as well as different mathematical models calculating the “most optimal” scheduling. Although a heterogeneous PPC graph circumvents the problem of interoperability between databases and mathematical models in PPC systems the problem of interoperability between requests on PPC systems rises. The presented architecture is only valid if the connection-components are given a common language defining queries. Instead of queries on databases, manufacturing requests can be formulated more abstract in the form of standardized requests. This includes formulating of manufacturing capabilities and basic condition. In the context of distributed manufacturing and virtual enterprises the development of ontologies for manufacturing services is already discussed in literature. MSDL [7], for example, is an ontology that was developed in order to describe manufacturing capabilities. Thus, MSDL could be used as common language to formulate manufacturing requirements and therefore queries. Missing information, such as business management information or accounting information, could be supplemented inspired by the Manufacturing Execution System (MES) standard VDI 5600 [17].

Once a common language is found, one has to think of the problem of where and how the description of required capabilities is generated. Normally, such requirements are formulated in Computer Aided Manufacturing (CAM) systems. In this paper, where manufacturers are connected, it is assumed that network participants are equipped with CAM systems and the expertise to handle them. Thus it is obvious to extend CAM systems with the ability to translate the manufacturing requirements to the common language. In addition to a common language, participants have to agree on possible weights of the paths and their definition. Production costs can be calculated per part or for the entire order; in dollar or euros. It has to be unambiguous how weights are calculated in order to ensure optimality.

The presented software architecture is designed to address the demand of missing connectivity abilities of today’s PPC systems. However, the new design also has to meet the other requirements discussed in Section 2. Since local data and structure remain the same, systems are at most as reliable as before. Even if connection is disturbed, in-house resources are still available. Since data storage is distributed and processing is done for each system separately neither storage capacity nor performance (neglecting latency) will be an issue. To avoid delays due to disconnection and latency, queries are stopped after some time. In particular, this is important for large graphs where queries could be forwarded several times. It is expected that these interrupts do not effect performance seriously since the more instances are involved (the more one request is forwarded) the more commission will be calculated.

So far organization, structure and information flow in the graph of PPC systems were discussed. Now implementation issues will be considered. Linkage between PPC systems needs to be platform and implementation language independent in order to allow existing systems to adapt and companies to contribute to the new planning network. With the requirement to keep initial effort as low and communication overhead as small as possible it is reasonable to adapt the Representational

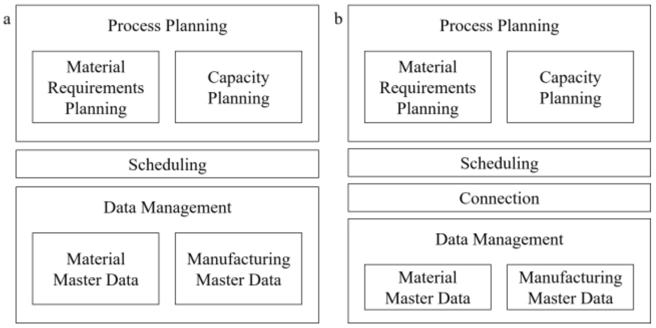

Fig. 4: (a) Todays PPC architecture; (b) future PPC architecture.

State Transfer (REST) paradigm [18], as it is state of the art for web services and supported in most applications. Since security and privacy concerns have been identified as one of the big obstacles in prior research for the CM paradigm [6], linkage should be secured and correspond to the state of the art. This requirement leads to the adaption of a Transport Layer Security (SSL), implemented as communication via Hypertext Transfer Protocol Secure (HTTPS), in addition to the adaption of Open Authorization (OAuth) to implement authentification on the application itself. Machine-processable self-description of the service can be achieved using the Web Application Description Language (WADL).

4. Discussion

A graph of connected PPC systems, as lined out in chapter 3, does have the main advantage to increase the pool of accessible machinery for companies and cloud manufacturing platforms. Hence, the system will strengthen especially small and medium companies and empower CM end users to utilize industrial production technology.

As mentioned in previous sections in a graph setup it is important to consider communication and usage of communicated data. This paper discussed what to communicate, how to transfer data technically and how to integrate incoming data into the standard scheduling task. However this does not consider the problem of how to decide for the best proposal. Normally, the best solution for a scheduling problem is calculated by solving an optimization problem. Available resources are known in advance and at the same time. Additionally, every resource is stored in the same database, which means that resources are given the same parameters p_i. Under these conditions solving the optimization problem is a standard task and the optimality of the solution does only depend on the algorithm that was token. A standard optimization problem is stated as:

$$\min f(f_{cost}, t_{time})$$
$$s.t. p_i \geq p_{bound}$$

Where the functional f depends on functions that compute costs and times. The side conditions restrict the parameter set such that only feasible resources are considered. The parameter restriction is originated in the CAM tool. There are several publications considering the formulation and solution of this optimization problem [19].

Unlike connected PPC systems. The amount of resources is not known in advance, resources have different attributes and optimization problems in PPC systems are stated different. Optimization parameters are likely to exist in one system but not in another. Besides, due to possible delays the optimality of a solution does also depend on time.

Those different situations do rise several questions: (i) How to formulate requests in order to receive as many proposals as possible? The task is to set requirements on the resources to schedule as strict as necessary to ensure that the final part can be produced as desired. On the other hand, the more parameters are set and the less parameters can vary the less positive responses likely. (ii) How long to wait for answers? Waiting for answers rises the possibility to receive an optimal solution in the sense of product quality and production time and cost. However start of production is delayed. It may be reasonable to adapt waiting time to the complexity and feasibility of the part to produce. If yes, how to quantize complexity and feasibility? (iii) Does it make sense to send several requests with varying restrictions and optimization goals in order to avoid that unimportant parameter settings reduce the amount of proposals? This would allow to learn how to formulate a request in the best way. Then it would even be possible to learn from foregoing request and proposals about the best way to ask as well as the capability of the graph as a whole.

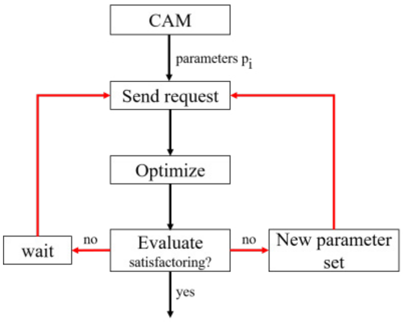

Fig. 5: Outline of a thinkable metaprocess.

A thinkable metaprocess to overcome these obstacles is outlined in Figure 5. The optimization itself is looped through in this metaprocess until the result are satisfying. However, the definition of when results are acceptable or not acceptable bring up a whole new challenge.

This discussion points out that the optimization problem itself has to be rethought in the setup of connected PPC systems. To answer the listed questions further research is necessary.

5. Summary and Outlook

This paper addresses the requirement of connectivity on PPC systems in the context of Cloud Manufacturing. Since current implementations do not fulfil the requirement, this paper proposes a new software architecture that allows communication between PPC systems. In the stated setup, PPC systems of different manufacturers are given a connection component that enables participating in a graph of PPC systems. The stated goal is to create a graph of systems that finally acts simultaneously to a single graph database; to create a network in which queries are spread over the network and performed on multiple databases. Products can either be produced locally or a request can be sent to a neighboring manufacturer. Requests can be forwarded resulting in commission fee. This gives rise to business models in future, where companies sell their network or commission fee are given added value, for example in the means of easier transfer. This paper is limited to a conceptual design, implementation remains a future task. When doing so, the adaptability and completeness of MSDL or other ontologies has to be checked. Furthermore, the pictured optimization problem has to be analysed in detail.

The presented network focusses on companies with manufacturing expertise. However, today customers want to be involved into the whole product design more intensively. They want to design their individual product and to be able to order their product. This gives rise to software platforms and networks where companies as well as individuals are looking for potential producers. Then, automatic formulation of required resources is indispensable. Since these requirement information are originated in CAM systems, future CAM systems should need a minimum of human interaction and manufacturing knowledge (CAM-as-a-service).

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