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Approach for a Production Planning and Control System in Value-Adding Networks

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Abstract

The increasing demand for individualised high-quality products at low cost is forcing companies to offer products based on their core competencies in value-adding networks. To reach overall objectives, such as shorter throughput times or less inventory throughout the network, an intense transfer of progress-relevant information among the network partners is required. This publication presents an approach for a network-wide production planning and control (PPC) system focusing on technical, organisational and monetary dimensions. The proposed approach comprises the modelling of the value-adding network, the development of both a system architecture and an incentive scheme, as well as a hierarchical optimisation.

Keywords: Production planning; Control; Manufacturing network

1. Introduction

Manufacturing companies of the 21st century are exposed to challenging market trends. On the one hand, customers demand individual and complex high-quality products at low cost and with a short delivery time [1, 2]. On the other hand, the globalisation of markets accompanied by a greater supply of comparable products intensifies the competitive pressure on companies [3].

Consequently, a company's focus on its core competencies is becoming increasingly important [4, 5]. By offering specialised products or services of a lower real net output ratio in value-adding networks, companies aim to increase the collective efficiency and thus improve the competitive position of all partners [3].

A strong cooperation within value-adding networks, however, results in complex dependencies with regard to material flows between customers and suppliers [6, 7]. Short-term events such as rush orders, machine breakdowns or delays in transport can lead to delays in delivery to end customers. Especially when manufacturing companies aim at reducing inventory levels for reasons of cost cutting, unforeseen events can have a great impact on the entire value chain [8].

In order to meet the demanded delivery reliability, a cross-company coordination of the production logistics processes of the network partners is required [9]. Through Industrie 4.0 technologies, a consistent vertical and horizontal interconnection can be realised and, consequently, information of the utmost importance for coordinated production planning and control can be provided to the network partners [2, 10]. This publication presents an approach for developing a comprehensive production planning and control system that fosters a network-wide consistency of the information relevant for the coordination of production logistics processes. In order to ensure goal-oriented practicability, business-related questions in terms of incentive systems are also examined.

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2. Production planning and control in value-adding networks

Both production planning and control (chapter 2.1) and value-adding networks (chapter 2.2) will be introduced to set the scientific basis of the approach developed.

2.1. Production planning and control

The objective for production planning and control is the optimisation of the order fulfilment process for ensuring the on-time delivery of products ordered by the customers [11, 12]. The core function of PPC is to plan and continuously control any assembly and manufacturing process with regards to quantities, dates and capacities [10, 13].

According to the VDI (Association of German Engineers), the purpose of production planning (PP) is to determine production-relevant objectives and the necessary tasks for achieving them [14]. The logistics targets pursued are [15]:

- High adherence to schedules
- Short throughput times
- High utilisation
- Low inventory levels

Both adherence to schedules and throughput times can be assigned to logistics performance, whereas utilisation and inventory levels can be seen as dimensions of logistics cost. To achieve these (partly competing) targets, various planning and control tasks have to be carried out. Core tasks within the PP are, among others, the planning of manufacturing programmes, primary, secondary and tertiary demands and external procurements. To formulate a detailed production plan, an order scheduling accompanied by an alignment of required and available resource capacities is also necessary [13].

After setting the production plan, production control (PC) is responsible for the initiation and monitoring of the scheduled processes. In the event of deviations from the logistics target system, production control needs to trigger counteractive measures [14]. The interdependencies between different control levers and their implications for the logistics targets are illustrated in Lödding’s [16] model for production control.

2.2. Value-adding networks

In recent decades, companies have significantly reduced their real net output ratios. Porter [17] emphasised the cost advantage of specialisation as early as 1985. Typical reasons and objectives of specialisation and cooperation are [18, 19]:

- Learning curve effects and economies of scale
- Entry into new markets
- Increase in efficiency and effectiveness of order fulfilment
- Competitive advantages for all partners

In summary, companies hope to benefit from specialisation in terms of quality, time and cost.

With respect to the decreasing real net output ratios, companies are forced to cooperate with partners in supply chains respective value-adding networks in order to manufacture products that can be offered to end customers [20]. In order to emphasise the differences between traditional supply chains and pioneering value-adding networks, the two terms need to be distinguished from each other:

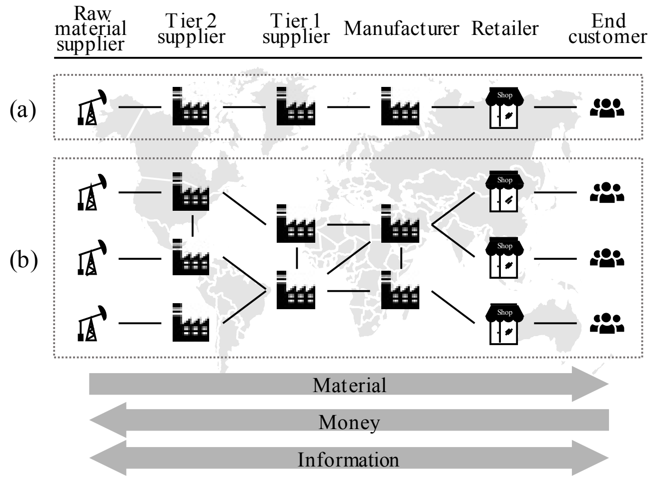

Fig. 1. (a) Supply chain; (b) Value-adding network.

A typical supply chain (see Fig. 1. (a)) ranges from the source of supply, the raw material suppliers, up to the point of consumption, the end customers [21]. Supply chain management (SCM) takes into consideration the intercorporate design, planning and control of flows of goods, information and money throughout the whole supply chain [22]. The core aspect of SCM is the customer-oriented synchronisation of supply and demand at an early stage. The coordination of the partners’ procurement and production plans results in lower bullwhip effects and reduced inventories [20]. However, the cooperation also leads to high interdependencies between the partners and complexity with regard to linked value streams. For handling unexpected short-term events, the supply chain operations reference (SCOR) model [20] includes a supply chain event management (SCEM). The SCEM is based on rules that are predefined by the supply chain partners and applied in case the conditions are fulfilled.

Due to shortening product life cycles, the volatility of customer-supplier relationships increases though. Companies are forced to affiliate to new value-adding networks and to cooperate with unknown partners within a short period of time. In addition, companies will participate in multiple supply chains building their own value-adding network (see Fig. 1. (b)) in the future [23]. Therefore, predefining a set of rules for each customer-supplier relationship as implemented in SCOR does not meet the future requirements. A consistent, flexible and extensible system that integrates and synchronises the production planning and control of each partner is necessary.

3. State of the research

Scientific research has been dealing with questions of entrepreneurial cooperation in value-adding networks for some years now. The following sections provide an overview of relevant research work.

3.1. Network-wide production planning and control

Reinhart et al. [24] presented methods and approaches for dynamic, cross-company cooperation relationships. The main focus was on the design of competence-centred corporate networks in order to combine the advantages of flexible small and medium-sized companies with the economies of scale of large companies. Network-oriented production planning and control, however, was not focused on in depth.

Genc et al. [25] developed an early warning system for an adaptive failure management in value-adding networks. In order to achieve transparency and to identify critical conditions early, Genc et al. [25] based their scientific work on the RFID technology. He elaborated internal measures and strategies for reacting to unexpected events. A cross-company information exchange for enabling an overall PPC optimisation was not taken into consideration though.

Lanza & Moser [26] introduced an approach for the strategic planning and design of changeable value networks, considering identified configurations. Arndt et al. [27] outlined a methodology for the simulation-based control of global production networks. The aim was to use an agent-based simulation model to evaluate the performance of networks as a function of multicriteria target systems and to derive site-specific strategies. In both approaches, however, no cost-oriented optimisation of the production logistics processes was carried out.

Prinz & Ost [28] developed a procedure model to increase transparency in production networks with the aim of reducing overall costs. Based on an analysis and visualisation of the existing network, potentials for improvement and cost savings could be identified and a sound foundation for strategic decisions could be created. Although Prinz & Ost [28] took a cost-oriented view, they did not consider network-oriented production planning and control and the relevant information flows more deeply.

Witthaut et al. [29] investigated the planning and control of value-adding networks through the integration of smart objects and smart finance respective payment approaches. Witthaut et al. [29] focused in particular on the development of strategies for the decentralised control of logistics chains and the prototypical implementation of these in a model-based system. Despite examining decentralised business processing, they placed no emphasis on overall cost optimisation throughout the entire value-adding network.

Khan et al. [30], on the other hand, used mathematical models to examine the impact of information exchange in supply chains on the profitability of partner companies. They considered the correlation between environmental and social cost drivers and order quantities. However, they did not focus more deeply on PPC.

The central starting point for increasing the efficiency and effectiveness of value creation in networks is the exchange of information between the partner companies, which is necessary for target-oriented production planning and control. Service-oriented platforms serve as technological enablers to ensure the exchange of information in networks [31]. Andres et al. [32] introduced a cloud platform concept that facilitates cross-company collaboration. By processing the data being gathered in real time data throughout the whole supply network with certain algorithms, both production and delivery plans can be optimized. However, Andres et al. [32] do not take short-term events that require to countermeasure or economic incentives for engaging on such a platform into consideration.

Groggert et al. [33] dealt with possibilities for collaborative production planning and control in the cloud as part of their research work. In order to meet current entrepreneurial challenges, they developed a problem-solving approach to merge the previously isolated consideration of PPC across companies on an IT platform. However, Groggert et al. [33] neither integrated an incentive system to foster information exchange nor an overall optimisation.

3.2. Incentive systems for fostering information sharing

Data analysing and knowledge-generating services on external cloud or on-premises platforms are one of the key aspects of Industrie 4.0. Despite the technological feasibility of Internet-based services and platforms, however, their market success is often dependent on the existence of a sustainable digital business model [34]. The same applies to the exchange of information between cooperating companies, regardless of the technological means used to accomplish. An adequate business model, in particular the underlying revenue model and incentive system respectively, is crucial in order to ensure the sharing of information at the network level without favouring any individual. Seidenstricker et al. [35] developed an approach for the design of new business models for distributed production systems. Based on the Value Proposition Design by Osterwalder et al. [36] and an associated revenue model, Seidenstricker et al. [35] suggested defining the "Value Chain and Processes" business model element, including the necessary technologies, competencies and key resources. Production planning and control, however, was not addressed.

The Association of German Engineers [37] as well as Pöppelbus & Durst [38] have already developed structured procedures for business model innovation (so called canvases) in the environment of Industrie 4.0. While the Association of German Engineers [37] focused on the target-oriented design of platforms, Pöppelbus & Durst [38] concentrated on Smart Services in particular. Both canvases provide a generic framework that takes cross-company data exchange into consideration. PPC perspectives, as well as approaches for developing application-specific incentive schemes were not taken into consideration though.

Gassmann et al. [39] investigated best practices of business models having disruptive impact on their respective industries for years. Gassmann et al. [39] came up with 55 typical patterns of successful business model innovation that can principally be adapted to concrete use cases, such as the development of specific value-adding networks. Patterns for network-oriented PPC, however, were not focused at all.

The scientific community conducting research on value-adding networks discusses revenue models such as gain sharing for the allocation of generated revenues among the partners [18]. A concrete calculation basis integrating the value added through information sharing has not been derived though.

3.3. Research motivation

A low or even lacking exchange of information between cooperating companies leads to local, intra-corporate optimisations with regards to production planning and control. The consequences are, for example, the outsourcing of stocks to suppliers or service providers, bullwhip effects and capacity expansions in the form of additional resources and work shifts [13, 40]. From a network perspective, local solutions do not result in an overall cost-optimal process flow.

According to a study by BITKOM & Fraunhofer IAO [41], the basic technological prerequisites for the implementation of efficient and effective interconnected value-adding networks are given by current developments in Industrie 4.0.

From the literature review, however, it can be stated that none of the existing approaches focus on a system for optimising production planning and control on a network level in depth. The effects of unexpected events, such as disruptions, on the entire value chain have so far been insufficiently considered [8]. By achieving an increased exchange of PPC-relevant information throughout the whole value-adding network, the potentials available in relation to the efficiency and effectiveness of production logistics processes can be further exploited. For this purpose, an incentive system that fosters the coordination of cross-company value-adding processes also needs to be developed.

4. Approach for a production planning and control system in value-adding networks

This section presents an approach for developing an integrated, network-wide system for planning and control of production logistics processes in cross-company value-adding networks. The architecture designed of the network-wide PPC system is exemplarily depicted in Fig. 2.

Firstly, an overview of the operating principle of the PPC system will be given in chapter 4.1. The approach (see Fig. 3) that is necessary for developing a use case specific network-wide PPC system is detailed in the following chapters 4.2 - 4.6.

The focus will be on technical, information-related and organisational dimensions of production planning and control. In order to be able to guarantee a target-oriented implementation, business questions in the form of an incentive system shall also be investigated.

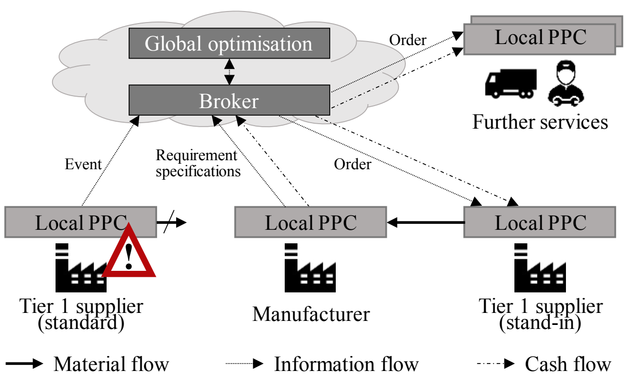

Fig. 2. Overview of the PPC system.

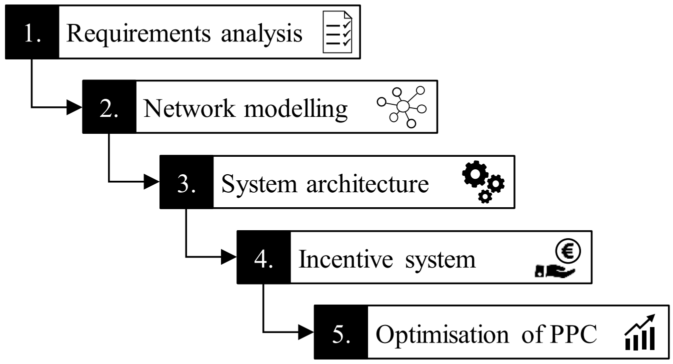

Fig. 3. Approach for developing a network-wide PPC system.

4.1. Overview

The PPC system introduced in this publication allows an optimisation of the total costs with regard to production logistics processes in flexible, cross-company value-adding networks. Fig. 2 gives an overview of the service-based solution concept.

The technical basis of the concept forms a platform upon which PPC services can be flexibly offered, instantiated and orchestrated. In order to guarantee a high practicability of the PPC system, a purely global optimisation across company boundaries does not seem to be effective, as this would require to exchange sensitive data of great amount. Therefore, the aim is to implement a knowledge-based and hierarchical optimisation process on two levels. On the lower level, services search for local and company-specific production planning and control solutions. The services offer typical PPC features, such as demand planning, scheduling or capacity and sequence planning (see chapter 2.1). To ensure a high level of sovereignty and security of sensitive data, these services are applicable both on public and on private clouds.

On the upper level, a cross-company service merges the local solutions as boundary conditions into an optimisation algorithm to find an overall cost optimum. By deriving a global solution that is based on the aggregated local results of the individual companies, the data traffic can be reduced.

A service broker is the intermediary between the services (see Fig. 2). The broker represents a neutral entity who is responsible for the data transfer among the partners and the overall optimisation as well as for business purposes. E.g. in case of a machine breakdown at the standard Tier 1 supplier, the local PPC service tries to reschedule the production plans on a company basis first. If the required delivery dates cannot be guaranteed, an event is generated and sent to the Broker. As the Broker has found the optimal stand-in supplier that meets the specific requirements, the order is transmitted accordingly.

4.2. Requirements analysis

In order to ensure a target-oriented development of a custom-designed production planning and control system, a variety of information needs to be gathered. The aim is not only to consider the technical, but also organisational and financial dimensions.

Firstly, an analysis of the existing or intended value-adding network is essential. Relevant aspects to be taken into consideration are among others:

- Partners (roles, core competencies, etc.)
- Products and services (functions, product structure, components, etc.)
- Order fulfilment (production processes, production sites, order penetration points, IT infrastructure etc.)

Based on this information, challenges for coordination of the identified partners need to be investigated. Of particular interest in this context is the integrability of each partner into the PPC system using interfaces such as OPC UA. As a result, application-specific requirements for the configuration of an overall optimised planning and control system can be derived.

4.3. Network modelling

After clarifying the requirement specifications, the specific network has to be modelled. According to the above-mentioned categories partners, products and services and order fulfilment (see chapter 4.2), a holistic model of a value-adding network consists of several dimensions. Therefore, application-specific models representing roles, products and services, processes, IT interfaces and customer orders are to be developed.

To generate the models and to formally describe the relationships within the network, a consistent and profound modelling language is required. As the Unified Modeling Language (UML) as well as the Systems Modeling Language (SysML) offer the ability to link the different dimensions, both are suitable. Additionally, in order to illustrate the benefits of the applied overall optimisation, the representation of the network in a simulation environment is advisable.

4.4. System architecture

Having set the basis with the requirements specification and the subsequent modelling of the network, the next phase is characterised by the design of the necessary architecture for the PPC system. As a first step, the data to be exchanged among the network partners need to be determined. The reason is the necessity that the subsequently developed system architecture can guarantee the exchange of this data in appropriate quality and quantity and within the required time intervals.

After that, the service architecture needs to be determined and implemented. One of the key points during this step is the definition of the PPC services, their functions as well as their interfaces relevant for the information exchange between the network participants.

Furthermore, emphasis has to be placed on the development of the service broker. Besides functional aspects, it has to be determined, which partner is in charge of the related tasks. Potential brokers are, for example, banks, insurances, one of the value-adding partners or any other neutral firm or entity.

In order to meet the future customer expectations, the network must be able to integrate new partners or data flows efficiently. The aspect of adaptivity must be considered during the configuration of the system architecture.

4.5. Incentive system

Within the following stage, it is necessary to design an incentive system that promotes the information exchange among the network partners. If companies see a financial advantage, they will be increasingly willing to integrate certain data into the network in real time and thus contribute to the optimisation of production logistics processes in the value-adding network. Consequently, several individual modules are required: Firstly, an approach is needed to increase cost transparency in production systems. This serves as the basis for an evaluation model for quantifying the value of data generated within a company. This in turn helps in analysing and reducing the total costs of a holistic value-adding network.

The next step is the development of a business transaction concept on which the information exchange is founded. The basis of this transaction concept is a revenue model, which ensures the integrity and equality of all the partners. Potential revenue models to be taken into consideration for the respective use cases are: gain sharing, licensing, pay-per-data, etc.

4.6. Optimisation of PPC

Based on the network model, the architecture implemented and the designed incentive system, the optimisation of the planning and control of production logistics processes is executed. The goal of the mathematical optimisation is the reduction of the total costs incurred in the value-adding network. For this purpose, the pre-developped algorithm for calculating the order-specific, cross-company and cost-minimal configuration of the production logistics processes needs to be adjusted in accordance to the application-specific requirements. Having found a valid solution for the optimisation problem, the information flows necessary for the implementation of the production control measures are then derived. Once the information required has been determined, the transaction of the data and the fixed remuneration can take place.

5. Conclusion and outlook

Current market developments require an increasing specialisation of companies in selected products or services accompanied by an intensifying cooperation in networks. Increasing efficiency and effectiveness of cross-company production management is required in order to meet the production logistical objectives, such as the delivery dates to the customers, despite a rising complexity within the value-adding processes. For this purpose, an increased exchange of information between the partners is essential.

This publication presents an approach for the application-specific development of a comprehensive, network-oriented system for production planning and control. This approach results in a global optimisation of the material flows across all value-adding steps within the network as opposed to a local, intra-company consideration of production processes. The approach comprises the following phases: (1) Requirements analysis; (2) Network modelling; (3) System architecture; (4) Incentive system; (5) Optimisation of PPC.

The described PPC system offers great potential for optimising the (partly competing) logistics targets, especially in networks with large buffer stocks. By fostering the information exchange, inventory levels can be reduced throughout the network without risking a deterioration of the adherence to schedules. Due to its high adaptivity, however, the PPC system and the approach for its specific development can be applied to value-adding networks of varying sizes and across industries.

The objective of the provided publication is to give a synopsis of the approach to illustrate the encompassing operating principle of the developed PPC system. The various approach steps as well as the implementation and validation within a use case will be detailed in further publications.

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