59th ILMENAU SCIENTIFIC COLLOQUIUM
Technische Universität Ilmenau, 11 – 15 September 2017
URN: urn:nbn:de:gbv:ilm1-2017iwk-106:1

SINGLE ITEM PRODUCTION WITHIN COLLABORATIVE NETWORKS

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ABSTRACT

Manufacturing in collaborative networks is an attractive strategy to cope with volatile customer demand. Not only high volume but also single item manufacturer have to deal with this challenge. To make matters worse, single item manufacturers do not have reliable data regarding process time to collaborate in this type of networks. This research analyzes the application of type representative method in collaborative networks of single item manufacturers. The method simplifies the calculation of unknown process times. In this paper, the authors suggest the determination of a factor *f*, which describes features of enterprises in collaborative networks and helps to improve the calculation of cost.

Index Terms – Collaborative networks, single item production, type representative, decision model, process time, virtual enterprise

1 INTRODUCTION

In order to cope with the new challenges of the customer purchase behavior like volatile demand, expectation of short delivery time and individualized products, the enterprises are forced to search for new sustainable solutions. Production within collaborative networks (CN) could be one of these solutions. CN consists of independent self-interested manufacturers at the same horizontal layer of supply networks. The collaboration provides a capability especially for small and medium size enterprises (SME) to react faster to the unexpected changes of customer needs and share capacity or demand.

In general, there are two types of coordination within CN, namely a centralized and a decentralized approach. The centralized coordination approach is often avoided by independent enterprises due to additional cost, central instruction etc. The decentral approach is more preferred and allows enterprises to make their own decisions and react faster and more efficiently to customer needs. [1]

Each enterprise, as a self-operative organization in a collaborative network, aims to achieve benefits. Normally, SME allocates a limited number of resources and competences. To increase their scope of action, an investment can be made. However, due to unpredictable market demand, the investment is closely connected with a high risk [1]. Expanding the capacity in case of exceeding demand or in return sharing of free capacity is, economically seen, an attractive procedure.

Enterprises aim to reduce cost to stay competitive. Additional expenditure for coordination activities contradict to the purpose of efficiency. Various methods like capacity market, virtual enterprise or extended enterprise are already researched and implemented by various authors [2]. However, the main critical factor of all these methods is the necessity of numerous arrangements to fulfill the order. Collaborative platforms for regional SME, based on the peer-to-peer thought, enable enterprises to produce their product to competitive conditions. By connecting ERP-Systems to the platform, enterprises enable sharing demand by capacity planning of manufacturing orders inside and outside of their own enterprises in the real time and to estimate costs. Indispensable requirement for this process is in addition to mutual trust an exact definition of process parameters.

Hence, in this paper, a specific case of collaboration of independent SME[1] with single item production is considered. Characteristic of the single item production is the lack of the exact information on machining time, process time etc. Therefore, the application of existing approaches like demand and capacity sharing protocol, collaborative capacity sharing protocol, multi-agent-system etc. is difficult ([3], [4], [1]). To cope with this problem, the applicability of the type representative method is suggested.

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[1] We assume that the participant of collaborative networks are both competitors and non-competitors.

The remainder of this paper is organized as follow. Section 2 gives a literature review of national and international studies of methods of external horizontal collaboration. The following section analyzes the new resulting requirements and proposes a model for decision about profitability of orders, which are manufactured using capacity of the virtual enterprise (VE). Furthermore, the application of factor *f* is suggested to consider features of SME in collaborative networks.

Ultimately, the conclusion will provide an insight of future proceedings on this topic.

2 LITERATURE REVIEW

2.1 Collaborative networks

In recent years, many studies have been carried out to find out how to support enterprises to adjust to the new and changing market requirements. Short product life cycle and rapid technology obsolescence get enterprises to reflect on two option for action:

- investment in new machines to expand their capacity and capability
- disclaim an investment, accept inability to meet demand and reduce customer satisfaction

To meet the challenge, a lot of research was carried out to find a suitable solution for different branches of industries. The main problems are the risks and the costs, enterprises have to take if they try to meet the challenge on their own, especially for small and medium sized enterprises. A way to avoid these problems is the organization of enterprises in CN.

Manufacturing in CN is based on the belief that by working together, the enterprises in the network can achieve results that could be not accomplished alone or to an acceptable price. A form of working together is e.g. an extended enterprise, a virtual enterprise and a virtual organization. An extended enterprise is a type of collaboration, where a dominant enterprise stretches its boundaries to its supplier. A virtual organization, as hypernym of virtual enterprise, is a collaboration, which is not limited to achieve profit. A VE is a temporary alliance of enterprises. It usually has no employees or resources and will be dissolved as soon as the customer demand is satisfied [2]. In the following, we limit our study only to collaboration types, which have equal rights and strives an economical profit.

By joining a VE, SME can profit of the broad spectrum of technologies and capacities in the VE and thereby compete with larger enterprises. It is also possible for competitors to be in the same VE. In addition, in case the demand of the same capacity is lower than the available capacity, enterprises, which produce different types of products or work in different branches, can turn into competitors regarding the same capacity.

However, according to a study of five collaborating German SME the most significant problems in the VE is the capacity and resource planning as well as enterprise resource planning systems (ERP-Systems) which are not applicable in VE [5]. Nevertheless, enterprise collaborations are an attractive strategy to minimize the impact of dynamic market behavior. They act on the assumption that when a customer order cannot be fulfilled by the own local capacity the enterprise can share customer demand with collaborating enterprises in the network [3]. In case of sufficient capacities by a partner in the network, both, the customer and the partner, can profit. Therefor a demand and capacity sharing protocol is designed to support enterprises in the collaboration networks to find a profitable decision.

However, the researches assume existing reliable information to the amount of necessary capacity [3]. In the following, an overview of some research regarding collaboration of enterprises is presented.

The optimal strategy regarding capacity sharing among competitors depending on the time of the price setting is researched by [6]. It concludes that an ex-ante negotiated contract price is more preferred by enterprises with capacity shortage and high buyer loyalty. However, the type of enterprise is not specified in this research [6].

An overview of studies that have already investigated on the enterprise collaboration is presented by [7]. In this paper, the lack of research work on real time execution and control aspects of collaboration at the same level is emphasized. The paper closes the gap between planning and execution and optimizes the collaboration decision by developing a Task Administration Protocol (TAP). TAP is developed for real-time execution of generated plans and should be able to handle dynamic and unforeseen situations. The workflow can be described in three steps: prioritize, choose the best resource for the task and control. However, every task needs to be described by quantity, due date and processing time [7].

A lack of studies, which addresses capacity sharing in independent plants, was found out by [1]. [1] develops Multi-Agent Architecture to support the collaborative network by capacity sharing in independent plants. Therefore, each plant in the CN consists of two Agents, a requiring capacity agent (RCA) and a capacity offering agent (COA). By detecting a lack of available resources, the RCA transmits a proposal by the mediator agent to the COA. If the proposal is accepted by the COA, the RCA updates its capacity. Otherwise, the negotiation is repeated [1].

The research by [8] considers more process related organization than horizontal coordination at the same level of the supply chain. It develops the competence-cell-based networking approach to connect single competence cells to a non-hierarchal order-related supply chain especially for regional enterprises [8].

The approach of integrated capacity market to match the demand and excess of resources is presented by [9]. The approach consists of a four-integration level system. Beginning by a simple search of the suitable resources, the system allows an integration in the company-owned ERP-System. It realizes the unavailable amount of needed capacity and searches for appropriate exceed in the CN.

All of the approaches described above are based on having information platforms. An efficient allocation of excess and unavailable capacity is one of the most important topics for all sharing platforms. Digital technologies, particularly internet-based platforms, enable to offer the necessary capacity at the right time. Peer-to-Peer frameworks allow registered enterprises to offer demand by using online-platform, web-portal or web-based network solution. [10]

However, during the research of the collaboration process and the development of decision models, the knowledge of capacity was assumed. This assumption makes the inapplicability of the methods, which were introduced before, for single item manufacturer obvious. The chapter shows the need of investigation for an approach to simplify a participation of a single item product manufacturer on CN. This need will be focused in chapter 3.

2.2 Enterprise resource planning

An ERP-System is a software solution for supporting the business-management process. According to [11], an ERP-System is designed as "… a large, integrated system handling business processes and data storage for a significant number of business units and business functions". Conventional ERP-Systems are built on a single database and require data standards as well as process standards. Consequently, the application of ERP-Systems can primarily benefit information flow, timelines of information and reduce the cost of information sharing.

Changes of customer needs, behavior and trends of the market influences not only manufacturing products but also indirectly the business process together with the systems, like ERP-Systems, supporting it. Especially the access to different data bases and comparing of various types of information can be a new challenge in inter-company collaboration.

Since enterprises have to adapt to changing demands and trends, the ERP-Systems have to develop as well. A summary of the crucial trends for the ERP-Systems is given by [12]. Because most of the ERP research is focused mainly on the improvement of ERP-Systems within the enterprise, it is discussed how an ERP-System has to be designed to overcome new requirements and to be applicable in cross-plant organization and in VE in the next step. An ERP II-System is described as an uprating of an ERP-System, consisting of add-on-modules like advanced planning and scheduling, supply chain management etc., which can facilitate an inter-organizational collaboration. Afterward the ERP II-System is compared to the requirements of a VE to describe necessaries for further development.

A potential solution can be defined as next level of ERP – VE requirements planning system, ERP III. The ERP III-System is defined as a "flexible, powerful information system incorporating web-based technology which enables enterprises to offer increasing degrees of connectivity, collaboration and dynamism through increased functional scope and scalability”. The possibilities of using this ERP-System within the VE are an important topic of current researches. [12]

3 DECISION MAKING USING TYPE REPRESENTATIVE APPROACH

3.1 Type representative method

Type representative (TR) is a virtual object, which summarizes and integrates almost all characteristics of a group of products. The TR method is used for products, which are in the development stage and have consequently no reliable information. The method combines all characteristics including their impacts e.g. on the process and integrates them into a TR.

Generally, there are two types of TR – real and fictitious type representative. Real TR is an existent product, which comprises all characteristics of a group completely. Fictitious TR is a product that does not exist in the product group. It is built of all characteristics regarding to the product group. Fictitious TR can be built by complementing a real product with missing characteristics or by compiling a new virtual object.

Characteristics could be constructive, technological, organizationally. The TR method reduces the amount of information and simplifies the planning system. [13] [14]

3.2 Planning view

The following investigation considers production of products in small quantities and assumes that for the manufacturing of a product more than three manufacturing process m ($m \geq 3$) are needed. The assumption is necessary to present a manufacturing step with restricted start and end date, which has to be manufactured on machines of the VE.

We consider only orders, which have previously not been manufactured with the same parameters and characteristics. In addition, product development is not a topic of the following analysis as well as benefits of implemented scheduling strategy (backward, forward, etc.).

An established process for production planning consists of four successive steps: machine scheduling, definition of start and end time depending on the implemented scheduling strategy, sequence planning and material requirement planning.

Acting on the assumption that development and work preparation including determination of necessary production steps and suitable technologies have already been finished, we start investigating the production planning process. The first step is machine scheduling, the assignment of required manufacturing processes to the available machine groups depending on their types. If the enterprise possesses several machines of the same type, free capacity of every machine has to be considered separately. Afterward, the required amount of capacity has to be determined. For this purpose, following practices can be used:

- the enterprise has unambiguous information about machine capability and can simulate needed processing time
- the enterprise has reliable data of last orders available and can forecast needed processing time

Application of the first practice requires availability of machine specifications. This is essential to simulate a processing time. It is not to be expected that all SME have appropriate simulation software tools and participants of VE disclose all specifications. This is why we do not amplify the first practice.

The second practice is based on the collection of predefined information like geometrical characteristics, complexity or material of manufactured products and classifies it into representative types. That means that a new product p with special geometrical dimensions doesn’t have processing time yet. Following the representative types approach, needed data can be deduced using previous times by considering relevant dependences. It is to be expected, that the precision of the type representative grows with the number of collected data. In addition, generation of fictitious type representatives for new virtual object by uncovering of dependence and correlating of data is possible.

The application of this approach allows enterprises an improvement of push production, since products are often transported directly to the next machine after finishing a process step without considering the scheduling and waiting times before.

Estimation of process time t_p allows not only the scheduling of production process and consideration of finishing times, but also the identification of bottlenecks. This knowledge of start and end times of orders facilitates sequence planning at the machine in order to reduce potential bottlenecks. These bottlenecks are the reason why customer orders can not be completed timely without prior adjustments.

The enterprise is forced to investigate a new delivery date or to expand its own capacity. The extension can be carried out by investing in new machines, especially at permanent capacity overload, or by making use of free capacity in the VE. As a part of a VE within a collaborative network, enterprise can use a foreign unutilized machine capacity for a defined period.

As we defined at the beginning, the number of manufacturing processes is larger or equal to three. Based on product parameters, the type representative approach provides expected process times. Scheduling, on the base of available machines and delivery data, has already been finished. In case of lack of available capacity to fulfill a complete process step, there are two options. First, the order can be split and manufactured on the own and foreign machine, or second, the entire order can be manufactured merely by foreign machines. However, decision on whether to split the order depends not only on the available offer of free capacity by enterprises in the VE but also on the cost of foreign manufacturing, which will be discussed in the next chapter.

At this point it is essential to consider, that manufacturing within the VE can also be carried out on other types of machines with different capabilities. Consequently, t_p has to be corrected by a factor $f_{j,z}$, which relates to an enterprise j and machine z. If an enterprise possesses another technology or production process to fulfill the manufacturing step, these machines can also be considered. Deviation between the process time t_p needed by enterprise for its own production and t_p* of foreign enterprise within the VE has to be considered by scheduling the order.

The process time t_p* is calculated by multiplying the original process time t_p with the correction factor $f_{j,z}$ (eq. (1)).

$$t_p^* = t_p \cdot f_{j,z} \tag{1}$$

Based on collected data, $f_{j,z}$ can be determined using type representative approach. It consists of two parts: predictable and unpredictable part. The first one, predictable part, is the time directly needed to execute the manufacturing step. The second one, unpredictable part, includes for example the set-up time, which is highly connected to the manufacturing sequence on a given day.

Fig. 1 presents exemplary the planning process in the form of a bar chart. Filled bars symbolize used capacity, while blank bars symbolize free capacity. The process times for each manufacturing step $t_{p,m}$ are shown as a colored dashed rectangular square in the corresponding machines. For easier understanding we use abbreviation $E_{j,m,z}$. E stands for the enterprise, j numbers the enterprise, m describes the manufacturing step and z the machine.

Enterprise E_1 has already finished all development, work preparation and is at point of time d_0. To accomplish the product p, the work preparation defined the three manufacturing steps m. Regarding technology feasibility, each of these steps can be operated by E_1. Using type representative approach, the processing time t_p for every machine of E_1 can be deduced. As determined at the beginning, we don't discuss benefits of scheduling strategy (backward, forward) and use backward scheduling exemplary. Starting at delivery day d_3 we compare available process time $d_3 - d_2$ with the needed process time $t_{p,3}$. If the available process time is larger or equal to the needed process time, manufacturing step 3 with the duration of $t_{p,3}$ can be scheduled (marked green). d_2 describes a point in time, when the capacity of machine 3 (z = 3) is available at the earliest. At machine 2 (z = 2) manufacturing step 2 has to be operated. The period $t_{p,2}$ is obviously bigger than available processing time on manufacturing step 2 and can not be scheduled (marked red). Thus, we have to consider two options:

- Order can be split
- Order can not be split

Order splitting depends highly on the product and has to be considered primarily from an economical point of view. However, the proceeding is independent on the splitting. Therefore, we omit scheduling $t_{p,2}$ and look at $t_{p,1}$ to determine d_1. Machine 1 has free capacity for a period of time bigger than $t_{p,1}$, so we scheduled m_1 on machine

1 as early as possible and get d_1. d_1 describes the point in time, when manufacturing step 1 is finished and manufacturing step 2 can be started.

At this point, we look to the offer of the VE to check whether p can be manufactured on time using foreign capacity. Two enterprises E_2 and E_3 provide free capacity between d_2 and d_1. As mentioned before, each enterprise possesses primarily different machines with various specifications. Therefore, we have to multiply $t_{p,2}$ by factor $f_{j,z}$. If the needed process time is smaller than the available process time, we can start with the next step, economic consideration (eq. (2)).

$$t_{p,2} \cdot f_{j,z} \leq d_2 - d_1 \tag{2}$$

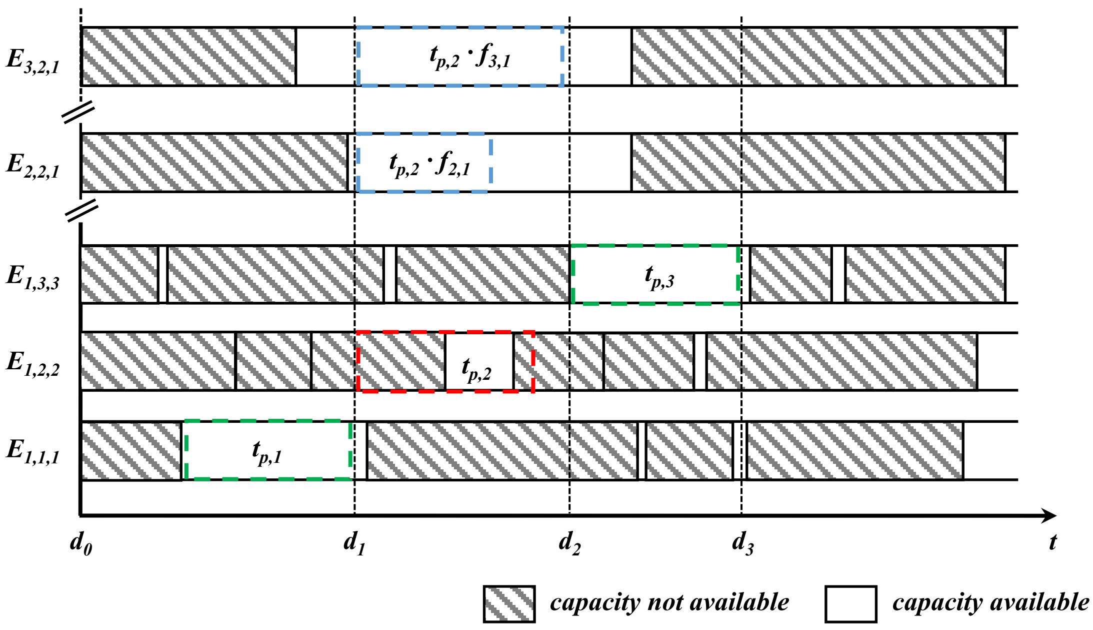

Fig. 1: Production planning process in a CN

3.3 Economic view

The principle of profitability means that every enterprise strives to increase their profit. To achieve this goal, the difference between product costs $(A_p + H_p)$ and sale price S_p, which customers are willing to accept, has to be maximized (eq. (3)). Product costs consists of A_p, which accumulates during pre-production, and production cost H_p. Consequently, every enterprise tries to reduce material and process cost for their products. Process costs result among other things from the time the machine is occupied while manufacturing the respective product.

$$\max(S_p - (A_p + H_p)) \tag{3}$$

If the entire manufacturing process is carried out in the own enterprise, scheduling focuses only on machine scheduling and material requirement planning. If the needed capacity exceeds the own available capacity, the difference of capacity has to be estimated. Demanding resources from a VE causes manufacturing cost $c_{j,p}$ and logistic cost $k_{j,p}$.

Both type of costs need to be known before the enterprise can calculate H_p (eq. (4)) and enter into negotiations with the customer.

$k_{j,p}$ can be spitted into cost for transport, packaging, insurance and other accrued cost. We assume that, based on product characteristics like dimension, weight, value and sensitivity of environment impacts, these costs can be calculated using costing tables. Manufacturing costs are composed of required machine time, employees in addition to expended material and cost for managing n (eq. (5)). Cost for expended material w is case-related and depends on the individual enterprise within the VE, if each enterprise has its own arrangements with their supplier. Consequently, the material costs are not considered as well as costs for managing accrues e.g. for license fee for software etc.

It is more important to analyze the costs for machine and employees. These costs can vary widely within the enterprises of the VE. $g_{j,z}$ includes costs for employees, which depend on qualification as well as regional features and costs for machines, which depends on amortization rate, wear cost etc. $g_{j,z}$ is determined by each enterprise independently and won't be influenced by the order. Consequently, $g_{j,z}$ can be assumed as fixed cost.[2]

Following the previous explanation, the person[3], in charge of acceptance or rejection, orders under the customer defined condition and has to check economical and organizational restrictions before. If the enterprise can dispatch the order by using own and foreign capacity for all needed manufacturing processes M, financial benefit (3)has to be estimated. The following equation can be consulted to support the estimation of financial benefit.

$$H_p = \sum_{m=1}^{M} (c_{m,j,p} + k_{m,j,p}) \quad (m \in [1, M];\ M \in \mathbb{N}^+) \tag{4}$$

$$c_{m,j,p} = g_{j,z} \cdot t_{p,m} \cdot f_{j,z} + n_r + w \quad (n \geq 0;\ f_{j,z} > 0;\ j, z \in \mathbb{N}^+) \tag{5}$$

4 CONCLUSION

In this paper, we have presented an approach to simplify the decision making process of SME within a VE, regarding to feasibility and economic benefits. It is focused on the manufacturing of single items.

To handle the unpredictable parameters in single item production we have suggested the use of type representative method, which is commonly applied in factory planning. The method can be used to categorize influencing factors of every enterprise in the VE. Based result, the factor *f* as the type representative of external influencing factor can be estimated and the processing time can be corrected. Consequently, the enterprise can calculate its profit more reliable.

In following researches, we will identify which kind of factors are relevant to create a type representative for the single item production. This research will be conducted based on a concrete range of products, which is manufactured by a medium sized enterprise within the VE by comparing the scatter of predicted and actual process time.

Current ERP-Systems are based on part lists and process sheets. A significant part of the process sheets are the parameters, which correlate with the number of products which belong to a specific type representative. The most important parameter in the decision model for manufacturing within the VE is the processing time, which must be corrected by the factor *f (*eq. (5)*)*. For this purpose, we will collect, analyze and classify data which belongs to the investigated range of products. The classification will be conducted based on the type representative method on the basis of enterprise, machine etc. The precision of *f* will be verified by comparing expected and actual costs for using capacities in the VE.

Finally, it could be interesting to investigate the possibility of integrating the suggested method into an ERP III – System.

2 Authors take into consideration the fact of reduction of amortization rate by improving of degree of capacity utilization. Nonetheless costs for machines are fixed costs because they do not connect with t_p directly.

3 Decision making process can also be fulfilled automatically by a ERP-System

5 APPENDIX

Abbreviation

CN	Collaborative Network
ERP	Enterprise Ressource Planning
SME	Small and Medium Enterprise
TR	Type representative
VE	Virtual Enterprise

Symbol

A	Pre-production cost
c	Cost
d	Date
E	Enterprise
f	Factor
g	Fee for using capacity
H	Production cost
j	Number of Enterprise
k	Logistic costs
m	Manufacturing process
n	Fee for using network
p	Product
S	Sale Prise
t	Time
w	Material
z	Machine

6 REFERENCES

[1] P. Renna and P. Argoneto, "Capacity sharing in a network of independent factories: A cooprative game theory approach", *Robotics and Computer-Integrated Manufacturing*, pp. 405 - 417, 2011.

[2] L. Camarinha-Matos and H. Afsarmanesh, "Collaborative networks: a new scientific discipline", *Journal of Intelligent Manufacturing* , pp. 439 - 452, 2005.

[3] Sang Won Yoon and Shimon Nof, "Demand and capacity sharing decisions and protocols in collaborative network of enterprise", *Decision Support Systems* , pp. 442 - 450, 2010.

[4] Hyesung Seok and Shimon Nof, "Collaborative capacity sharing among manufacturers on the same supply network horizontal layer for sustainable and balanced returns", *International Journal of Production Research*, pp. 1622 - 1643, 2014.

[5] Frank Wagner, Jochen Eichert, and Roman Schirra, "Management of virtual enterprises: a case study of german rapid prototyping smes", in *Processes and Foundations for Virtual Organizations*.: springer science+business media, 2004, pp. 493 - 500.

[6] Liang Guo and Xiaole Wu, "Capacity Sharing between Competitors", 2016.

[7] Mohsen Moghaddam and Shimon Nof, "Real-time optimization and control machnisms for collaborative demand and capacity sharing", *Production Economics*, pp. 495 - 506, 2016.

[8] E. Müller, S. Horbach, J. Ackermann, J. Schütze, and H. Baum, "production system planning in competence-cellbased networks", *Internation Journal of Production Research*, pp. 3989–4009, 2006.

[9] Yilmaz Uygun, *Integrierte Kapazitätsbörse*. Dortmund: Praxiswissen (Fabrikorganisation), 2012.

[10] Reiner Clement and Dirk Schreiber, *Internet-Ökonomie*. Berlin Heidelberg: Springer, 2016.

[11] Thomas F. Gattiker and Dale L. Goofhue, HICSS '00 Proceedings of the 33rd Hawaii International Conference on System Sciences , Januar 04 - 07, 2000.

[12] YI Wan and Ben Clegg, "Enterprise Management and ERP Development: Case Study of Zoomlion Using the Dynamic Enterprise Reference Grid", in *Enterprise Information Systems*.: Springer-Verlag, 2010, pp. 191 - 198.

[13] Michael Schenk, Siegfried Wirth, and Egon Müller, *Factory Planning Manual*. Berlin Heidelberg: Springer, 2010.

[14] Kurt W. Helbing, *Handbuch Fabrikprojektierung*. Heidelberg Dordrecht London New York: Springer, 2010.

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