CONFERENCE ON PRODUCTION SYSTEMS AND LOGISTICS
CPSL 2020

1st Conference on Production Systems and Logistics

Tactical Production Planning for Customer Individual Products in Changeable Production Networks

Johannes be Isa[1], Thomas Zimmermann[2], Philipp Scherwitz[1], Gunther Reinhart[3]

[1] *Fraunhofer IGCV, Am Technologiezentrum 2, 86159 Augsburg, Germany*
[2]*BSH Home Appliances, Savinjska cesta 30, 3331 Nazarje, Slovenia*
[3]*Technical University of Munich, Boltzmannstraße 15, 85748 Garching bei München, Germany*

Abstract

The requirements of future production are characterized by increasing demand volatility as well as very short delivery times and high timeliness in the order-based production environment. Furthermore, the trend to customer individual products leads to additional production planning challenges. Therefore, to react fast to these market trends, changeable production networks is a key to success. This technical contribution describes a method for tactical production planning for customer individual products in changeable production networks. The design of the method contains three main process modules (1) order-capability-comparison, (2) capacity planning, and (3) order-specific network structure. Underlying the former described modules, a data model is necessary and introduced. Furthermore, the simulation of the applied system on a prototypical implementation at BSH Hausgeräte GmbH, the largest home appliances manufacturer in Europe, is shown and explained. Finally, limitations are discussed and an outlook into future work for the research field in production planning of production networks is given.

Keywords

Changeability; Mass Customization; Production networks; Production planning; Production as a Service

1. Introduction

During the last 30 years, a strong trend towards global production in networks has been recognized [1]. Already today, more than 80 % of the turnover of goods takes place in production networks [2]. Furthermore, the current business environment confronts the companies with high demand fluctuations and high competitive pressure [3]. In addition, saturated markets lead to an unbroken trend towards customer-specific products [4]. The production of these customer-individual products opposes the classical industrial approach of mass production [5]. In order not to produce these individualized products in a one-off production process, as it was the case in the traditional manufactory with high process costs, the research field of mass customization was created. In the area of mass customization, a distinction is often made between soft customization and hard customization [5]. Soft customization is characterized by comparatively simple adjustments to the sales product. Hard customization, on the other hand, represents a physical product individualization in production and for this reason; it places very high demands on changeability of production systems. Moreover, the market demands ever-shorter delivery times and high adherence to delivery dates [6]. These harsher conditions lead to higher complexity and increased requirements for future production [7]. Production networks, which have grown historically, tend to have rigid and inert structures [8]. Furthermore, the heterogeneous production capabilities are not taken into account and mapped in the production network. However, this mapping of the technical capabilities of each location at the production network level is necessary in order to make quick decisions for the acceptance of a customer-specific order. Another challenge is the capability-based production planning across locations [9]. This is necessary in order to avoid resource overbooking due to a lack of knowledge about existing production capabilities. Consequently, production planning based on capabilities in order-related production networks is required to break out of the existing rigid network structures. In order to meet these increased requirements and to master the complexity, it is necessary to apply new digital technologies [4]. The globally available internet as well as modern information and communication technologies (e.g. cloud approaches) make it possible to connect single production sites further to form integrated production networks [10]. According to the joint Fraunhofer IPA and Trovarit (software enterprise) study in 2017, the use of manufacturing execution systems to transform multiple single production sites to an integrated production network and thereby ensure deep networking of these locations at the production planning and control (PPC) level is increasing [11]. The PPS-Report 2017/2018, a regularly study concerning production planning and control, shows that more than 45 % of companies in Germany plan to change or implement major changes to their production planning systems within the next one to two years to boost higher network integration [12].

Integrated production networks offer a high potential to balance the demand volatility described above by intelligently distributing customer-specific orders over the whole network in a short and medium term perspective. After this brief introduction, the state-of-the-art of research will be considered. Subsequently, the method for tactical production planning of order-related production networks will be presented. In the fourth part, the prototypical implementation, which has been realized at a world-leading producer of household appliances, is described. The fifth part concludes this work with a summary and an outlook.

2. State of the art

2.1 Production planning aspects

The configuration and coordination of production networks requires a wide variety of planning efforts due to the high degree of interdependence between the locations. In literature there are existing diverse approaches to structure the production planning aspects. According to Wittek et al. [13], the following four dimensions can be formed: (1) Planning tasks according to the company divisions e.g. procurement, production, sales; further along the (2) production system levels e.g. work station, cell, system, site, network; additionally according the hierarchical order of the (3) management level (strategic, tactical, operational) and the (4) planning horizon (long, medium and short-term) are common. The development of the Aachen PPC model contributed greatly to the understanding and classification of production planning especially on the network level [14]. Production planning, in turn, can be divided into three temporal areas. (1) Strategic production planning, which deals with long-term production issues, (2) operational production planning, which deals with short-term issues a few days before order release, and (3) tactical production planning, which is located in the medium term and lies between the strategic and operational time horizon [15]. The research concerning the medium term time horizon is relatively weakly developed compared to the two other temporal areas [16]. Tactical production planning is used to make decisions about the service areas, capacities and production organization in order to design an efficient production process. Based on the current market conditions described above, this tactical time horizon becomes more important [16]. The main focus in this work is therefore the fast and adaptive reconfiguration of networks to customer-specific products.

2.2 Classification of production networks

There are different definitions for production networks; the following one given by Röhrs [17] is technical but universally valid:

“A production network can be seen as a network where nodes adopt subtasks of a production process and maintain service exchange relations based on material and information flow.” [17]

In general, production networks can be classified and typologized at different levels. A common classification according to Rudberg and Olhager is into four classes: (1) cross-company networks, which describe several locations and several organizations, (2) internal networks, which describe several locations of one organization, (3) supply chain, which describes a location and several organizations serving this location, (4) factory, which describes one location of one single organization [18].

A further appropriate division into five categories of so-called phenotypes world factory, sequential or convergent, network structure, hub and spoke, local production plants takes place according to Abele et al. [12]. In addition, there are other classifications, but these should be more understood as extensions of those previously mentioned. The classification into different phenotypes is very common in the scientific literature but has the disadvantage of creating very rigid network structures as described above. Therefor the latest research linked to changeable, reconfigurable and fast scalable production networks can be found in the area of Production-as-a-Service which will be considered in this work [19, 20].

2.3 Production as a Service

The Production-as-a-Service approach has its origin in the information technology sector and is based on the idea of sharing temporarily unused resources. It can be seen as an adaptation of IT cloud approaches, Platform-as-a-Service, Infrastructure-as-a-Service and Software-as-a-Service to the operational technology sector [11]. Another term describing which is often used synonymously to describe the Production-as-a-Service approach is Cloud Manufacturing. An extensive investigation of this research area can be found in Siderska & Jadaan [21]. In general the approach of Production-as-a-Service is the focus on production capabilities rather than specific resources. This means further that the production planning in a Production-as-a-Serivce environment can be designed differently. A production process step can be interpreted as a micro service. This approach to the planning of production capabilities in an internal company network is further investigated in this paper. This leads to the two questions: (1) How does the mapping of these changeable production networks look like? (2) How can the data model of these networks be designed?

2.4 Customer individual products

In order to meet the rising customer requirements in the industrial sector, an attempt has been made in recent decades to meet these requirements with a wide variety of product variants [5]. In the meantime, however, it has become apparent that the management of these variants is a very complex and time-consuming task. In particular, keeping all variants in stock would go beyond storage locations and contradicts lean approaches. In order to reduce exactly these stock keeping units, many companies changed from the simple make-to-stock production approach to a combined make-to-stock and make-to-order approach [5, 10]. As mentioned above, there is also a trend towards customer-specific products in the private consumer sector due to the saturated markets. The general idea of mass customization was to produce individualized products to the time, process and cost of traditional mass production [22, 23].

The first step towards the customer-specific production described above is the reduction of batch size production and the determination of an appropriate customer decoupling point. This point separates production into a customer-related and customer-neutral control loop. The customer-related control cycle represents a direct link between the customer order and the production order. The customer-neutral control cycle represents production orders in prefabrication without direct reference to the customer [15]. The customer individual demand requires fast adaption of the production capabilities and capacity. In this work, mass customization is related to the hard customization approach and will be later applied by the developed method. Further this work contributes to the development of solutions at the network level to the challenges outlined.

The comprehensive consideration and consolidation of the areas of mass customization, tactical production planning and changeable production networks will be discussed and deepened in the next sections of this paper.

3. Tactical production planning of changeable order-based production networks

In order to convey the setting of this work, the production network is depicted in Figure 1. An exemplary network with six distributed production sites of a European company is shown.

Furthermore, a simplified aggregated capacity utilization profile can be seen for each site. This profile also shows the flexibility corridor, which illustrates the frequently available possibility of scaling to compensate for minor demand fluctuations in single production areas or locations [24]. The constant aim of the companies is to find an operating point within this corridor in order to produce cost-efficiently. In the exemplary network representation, supply relationships already exist in some locations, represented by the dashed lines (logistics link) in Figure 1. This representation is well suited to visualize locations with over- or underutilization. For example, locations A, C and E show an underutilization. The utilization rate is below the lower bound of the flexibility corridor. This means existing resources are not used efficiently because there are not enough orders available at that time. Locations B and F are overloaded and therefore cannot provide all orders at the desired delivery time. In this simple example, however, a snapshot of a particular planning period is given. Under certain circumstances, it may also be the case that the capacity utilization of a location can look completely different at another planning period.

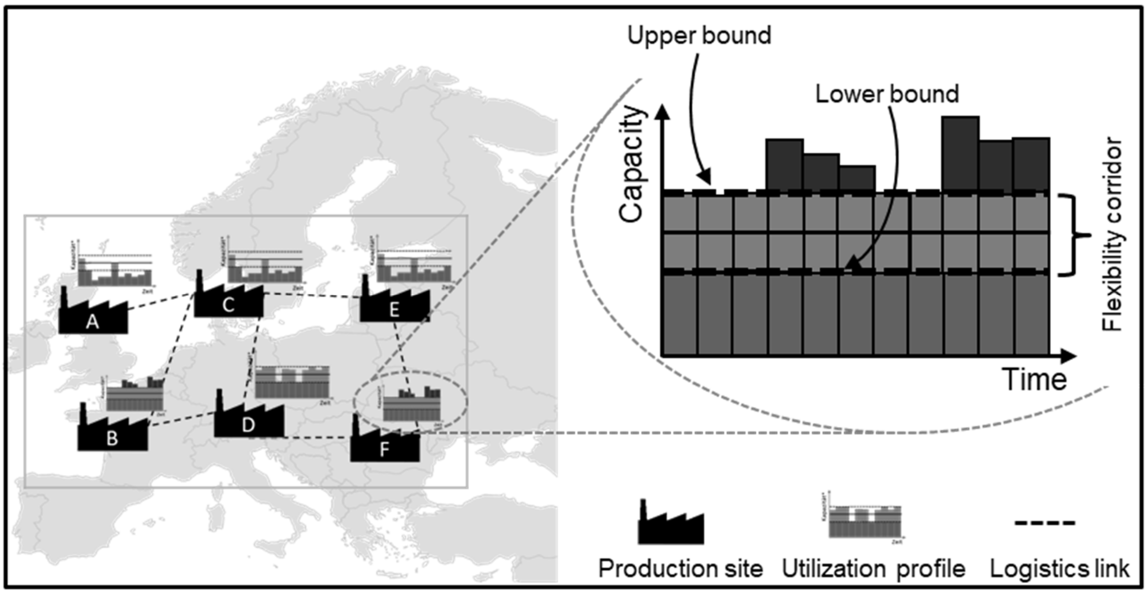


Figure 1: Exemplary production network and utilization profile

Both states described above should be avoided. The state of underutilization is by far the more critical problem, since high losses are usually caused in this state due to fix costs of workforce and production systems. In a state of overload, unrealised profits often result. This capacity utilization problem is caused by the difficulty to balance the supply and demand of capacity. Production sites around the world have to face this challenge.

The initial goal is therefore the optimal allocation of orders to the production resources in the production network of a company and the automated derivation of recommendations for action. In order to solve this problem, a methodological approach is required.

The following research questions were derived:

1) How should the data model for production planning for order-related production networks be designed?
2) How can the technical order capability comparison be mapped at the production network level?
3) How does tactical capacity planning take place in order-related production networks?
4) How can a cost-minimal network structure and the corresponding network allocation plan be set up?

The following sections attempt to further specify these research questions and present new approaches to solving them.

3.1 Data model

The aim of the data model is to illustrate the information requirements for tactical production planning of changeable production networks. The graphical modelling language Unified Modelling Language (UML) was used to specify and visualize the requirements see Figure 2. The data model supports the developed method and is divided into four submodels: order model, product model, logistics model and network model. The order model is used to describe the order specifications e.g. quantity and delivery date. To ensure data transferability, standards such as DIN 6789 were taken into account [25]. The product model defines the technical and geometrical information as well as the bill of material and the bill of processes. The logistics model serves to characterizes the supply relationships, the means of transport and the costs incurred by the respective use. The network model is the most comprehensive one and is structuring, assembly as well as manufacturing capabilities according to DIN 8580 [26]. Furthermore, the network model depicts the locations, production systems and their capabilities as well as the site-related production costs. The capacity offered and the respective capacity utilization for each capability are also defined in this model. As a result, all four submodels together represent the overall data model and provide the information basis for the following method.

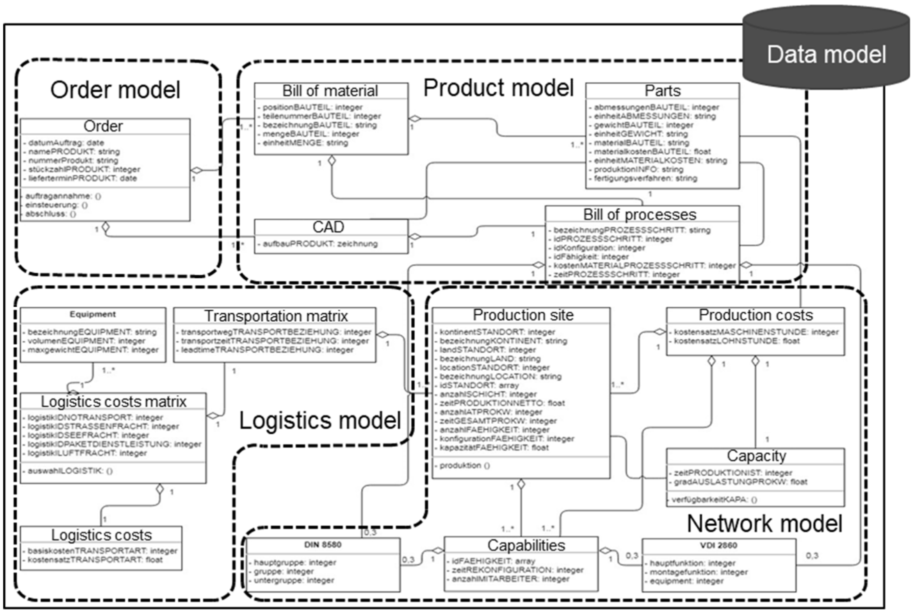
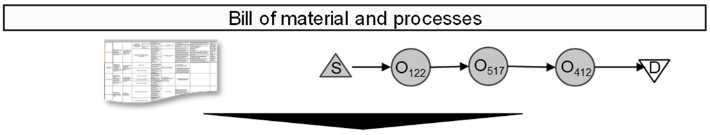


Figure 2: Overview of the data model and the four submodels for changeable production networks

3.2 Order-capability-comparison

The first method component of the order-capability-comparison aims to match the order requirements per process step with the existing technical capabilities of the individual production sites in the network. First a completeness check and an analysis of the order data is fulfilled. In the second step, the bill of materials and the bill of processes, which are available in the product model, are extracted. In the third step, every single process step is compared with the capabilities portfolio of the individual sites. An order capability matrix maps the necessary process steps on the one hand and the technically capable locations on the other. As a result of this method step a solution space is created. For this purpose, binary variables are used to indicate whether a technological capability is available at the production site (1) or not (0). Figure 3 shows a basic example considering three operations. The process starts with the source (S), followed by operations O122 Injection Molding, O517 Labeling and O412 Assembly and finally the sink (D).



Order-capability-comparison

	O_{122}		O_{517}		O_{412}	
	TC	CA	TC	CA	TC	CA
[124] Prag	1		1		0	
[131] Ljubljana	1		1		1	
[147] München	0		1		1	
[162] Barcelona	0		0		1	
[632] Istanbul	1		0		0	

TC: technological capability, CA: capacitive availability

Figure 3: Order-capability matrix for three linked operations

3.3 Capacity planning

The second module of the method is the production capacity planning on network level. The aim here is to determine the capacity plan for the solution space. The results from the previous method step will be enriched with further information regarding the production site capacity. The goal is a solution space that brings together technically capable and capacitively available locations in a comprehensive matrix. The lower section in Figure 4 displays an example of the solution space in a matrix structure with the three required process steps and the respective available locations.

The capacity planning on a tactical period is required to determine the capacity availability of the individual processes. It differs from operational planning, which is focused at detailed sequence planning. Tactical planning is done a few weeks before the start of production, so an initial rough estimation is appropriate. However, in order to deal with these order-specific requests, a new approach to capacity analysis is required. Up to now, planning in practice has usually been based on finite capacity, but often also on infinite capacity. However, the problem described above requires a dynamic capacity supply and, accordingly, dynamic capacity planning [27].

To accomplish this, an analogy was created from the yield management of airline operations. Airlines use an overbooking rate to maximize the utilization of their aircraft fleets. This means, for example, that 88 flight tickets are sold for a flight with 80 physically available seats. The reason for this overbooking rate is that, based on the airline's previous experience, e.g. around 10 % of passengers do not board their flights. This means that according to the 10 % no show rate 80 passengers can still board their plane. This allows the airline to achieve a very high load factor and thus to operate economically [28]. A knowledge transfer linked to this overbooking Airline approach can also be created in the production environment. Production orders, however, have more diverse characteristics than standardized seats in an aircraft. Therefore, the airline approach is only transferable under certain restrictions. In addition to the usual fixed production capacity limit, this requires a nonphysical capacity limit. The term virtual capacity limit is well fitted to describe this dynamic approach and create a plannable capacity unit [27]. This virtual capacity limit thus allows an overbooking of the physical capacity. However, it is different from planning against infinite capacity. The virtual capacity limit is designed dynamically and therefore does not represent a fixed amount. This dynamic approach allows a fast response to a change in the order behaviour. Rather, this figure depends on the time or planning period, demand volatility, and the order probability based on historical data [27].

The virtual capacity limit, see Figure 4, is used to compare the capacity requirements and the available capacity of each capability in the planning horizon for each individual process step. Also for the capacity availability binary variables are modelled. The result of this method module are pre-selected suitable locations, which have both the technical capability and the capacity availability for each process step. This pre-selection of suitable locations thus forms the solution space for the next method module.

3.4 Order-specific network structure

In the last method module, the order-specific network structure and the corresponding production plan are created. For this purpose, the dimension of costs details the previously defined solution space. Both production and logistics costs are considered. Each technological capability of a location has specific production costs. These are qualitatively represented in Figure 5. A non-linear course and a minimum are recognizable here. However, usually step costs are also represented in such cost curves. In this study, an idealized curve progression of the costs is depicted. In the final solution space, two locations - Prague and Ljubljana - are technically and capacitively suitable for the injection molding process. For each of these locations, a cost curve is shown in Figure 5.

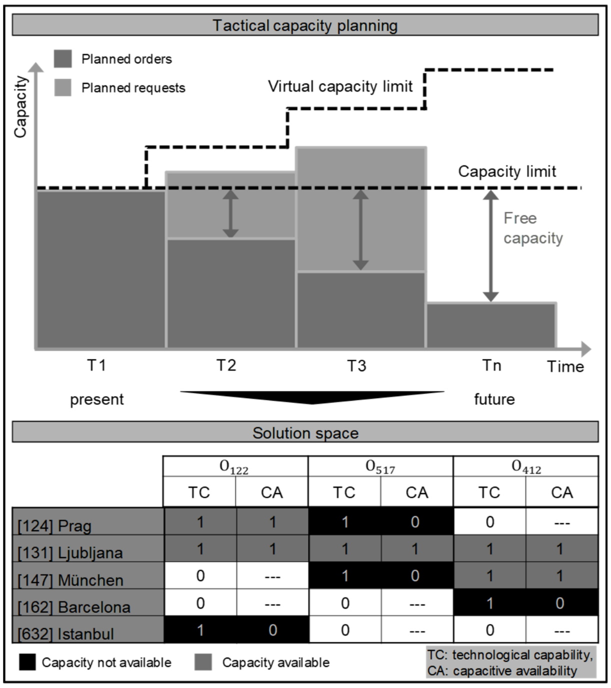


Figure 4: Virtual capacity limit and solution space

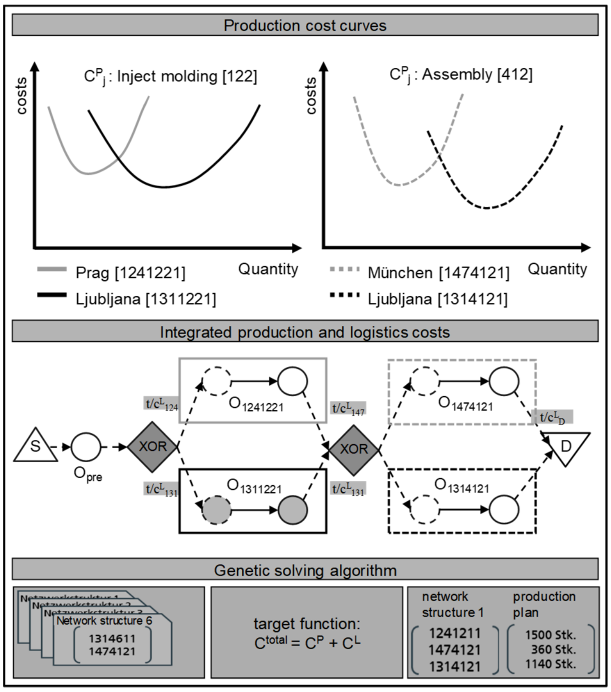


Figure 5: Integration of production and logistics costs

Each of these cost curves in Figure 5 (grey and black, representing a production site) show a local minimum for a certain production quantity. The local optimum of this idealized curve shape for one particular process step is relatively easy to calculate. The search for the global minimum, on the other hand, becomes complex when all the necessary process steps are taken into account.

Next to production costs also logistics costs always play an important role within the overall costs of production networks. Therefore, matrixes for each mode of transport were developed in the data model. This information is taken into account in this method module for the integrated consideration of production and logistics costs. The lower part of Figure 5 shows a process variant graph according to Käschel et al. [29]. This was extended by logistics operations, which are essential for the integrated time and overall cost consideration. In this simplified example two processes, injection molding and assembly are considered. Both processes can be manufactured at two locations. The “exclusive or gate” (XOR) allows one process step of an order to be distributed to several locations. This process variant graph approach supports the modelling of an order splitting. The order splitting in turn allows companies to accept large-volume customer-specific orders that a single location could not handle in terms of capacity. The most-economic network structure and the corresponding production plan, including the order splitting, are determined in the last step by applying a solving algorithm. Due to the high degree of complexity of such a problem and the modesty of an approximate solution in the area of medium-term production planning, a heuristic procedure was chosen to solve the problem [30].

4. Prototypical implementation at a large household appliances manufacturer

A prototypical implementation was tested on the production network at BSH (former Bosch-Siemens Hausgeräte GmbH) a leading manufacturer of home appliances.

In the initial situation, as with many companies, there was a rigid assignment of products or product families to production sites. The Industrial Engineering Department by means of a forecast, which was designed on historical production figures, created the offered dimension and capacity for future production figures.

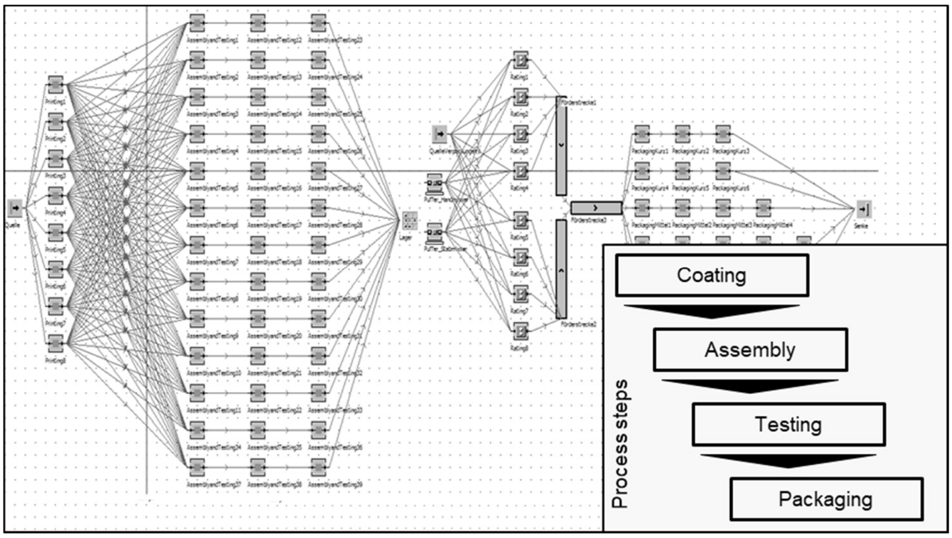


Figure 6: Future production structure & concerning process steps (PlantSimulation)

The major challenge here lies in the strong volatility in demand within a few weeks. To tackle this challenge, the production processes of two different kitchen appliances and a cumulative production number of over 5 million units per year were analyzed. To simulate the individual customer platform over 220 individual products based on the two different kitchen appliances were ordered. For each of the individual product five process steps were examined in detail: coating, assembly, testing, marking and finally packaging of the finished product. The technical capabilities required to successfully complete the production step were analyzed. Different variants with different process times and individual test mechanisms had to be considered. Furthermore, the provision of correct and sufficient material in all production areas must be ensured during planning. Within the industrial project, the prototype implementation could be validated by running a material flow simulation. The result is a uniformly high utilization of the individual production areas, which enables more cost-efficient production. The network approach can be interpreted in the prototypical implementation by the eight production systems distributed within the site.

5. Conclusion

Nowadays, a very high proportion of value creation takes place in production networks. However, these networks have mostly grown historically and have rigid structures. This work has scientifically described the relevance and potential of networked and, in particular, changeable production networks. Furthermore, a methodological approach was described for the tactical production planning of customer-specific products in changeable production networks. This consists of three method modules (1) order-capability-comparison, (2) capacity planning, (3) order-specific network structure, all of which were presented in this publication. Finally, the prototypical implementation of a part of the method in an industrial project in the field of household appliances production was briefly discussed.

Further topics were to be scientifically examined in the context of fast changeable production networks:

- Is it possible to expand to changeable cross-company production networks?
- How does the qualification and evaluation of production sites take place in order to participate in a changeable production network?
- How can social aspects be introduced in rapidly changeable production networks and how can their compliance be verified?
- How can high resource efficiency and environmental protection in changeable production networks be evaluated, ensured and rewarded?

References

[1] E. Abele, U. Näher, J. Kluge, Handbuch Globale Produktion, Hanser, (2006)

[2] UNCTAD 2018, World Investment Report 2018, Investment and new industrial policies, United nations publication, 26, (2018)

[3] E. Abele, G. Reinhart, Zukunft der Produktion. Herausforderungen, Forschungsfelder, Chancen. Hanser, Carl. Verlag, (2011)

[4] G. Reinhart, Handbuch Industrie 4.0. Geschäftsmodelle, Prozesse, Technik. Hanser, (2017)

[5] F. Piller, M.M. Tseng, The customer centric enterprise, Advances in mass customization and personalization, Springer, (2003)

[6] G. Lanza, S. Peters, Integrated capacity planning over highly volatile horizons, CIRP, 61, (2012)

[7] H.A. ElMaraghy, Changeable and Reconfigurable Manufacturing Systems, Springer, (2009)

[8] J. Hochdörffer, Integrierte Produktionsallokations-strategie und Konfigurationssequenz in globalen Produktionsnetzwerken, Shaker Verlag, (2018)

[9] E. Abele, T. Meyer, U. Näher, G. Strube, R. Sykes, Global Production: A Handbook for Strategy and Implementation, Springer-Verlag, (2008

[10] U. Rauschecker, M. Stöhr, Using Manufacturing Service Descriptions for flexible Integration of Production Facilities to Manufacturing Clouds, Proceedings Int. Con. on Engineering, Technology and Innovation, 18, (2012)

[11] H.H. Wiendahl, A. Kluth, R. Kipp, Marktspiegel Business Software – MES – Fertigungssteuerung 2017/2018, Trovarit AG, 6, (2017)

[12] P. Nyhuis, PPS-Report 2017/2018. Studienergebnisse, PZH-Verlag, (2018)

[13] K. Wittek, T. Volling, S. Spengler, F.W. Grundlach, Tactical Planning in Flexible Production Networks in the Automotive Industry, In Operations Research Proceedings, Springer, (2011)

[14] G. Schuh, V. Stich, Produktionsplanung und -steuerung 1, Springer Vieweg, 4, (2012)

[15] P. Schönsleben, Changeability of strategic and tactical production concepts, CIRP Annals, 58, (2009)

[16] S. Thomas, Produktionsnetzwerksysteme – Ein Weg zu effizienten Produktionsnetzwerken, Dissertation Universität St. Gallen, (2013)

[17] A. Röhrs, Produktionsmanagement in Produktionsnetzwerken, Lang Verlag, (2003)

[18] M. Rudberger, J. Ohlhager, Manufacturing networks and supply chains. An operations strategy perspective, Omega, 31, (2003)

[19] Y. Koren, The Global Manufacturing Revolution: Product-Process-Business Integration and Reconfigurable Systems, John Wiley & Sons, (2010)

[20] J. Váncza, L. Monostori, D. Lutters, S.R. Kumara, M. Tseng, P. Valckenaers, H. Van Brussel, Cooperative and responsive manufacturing enterprises, CIRP Annals, 60, (2011)

[21] J. Siderska, K.S. Jadaan, Cloud Manufacturing: a service-oriented manufacturing paradigm. A review paper. Engineering Management in Production and Services 10, (2018)

[22] S.M. Davis, From "future perfect": Mass Customizing, Planning Review, 17, (1989)

[23] B.J. Pine, Making mass customization happen: Strategies for the new competitive realities, Planning Review, 21, (1993)

[24] H.P. Wiendahl, H.A. ElMaragy, P. Nyhuis, M.F. Zäh, H.H. Wiendahl, N. Duffie, M. Brieke, Changeable Manufacturing – Classification, Design and Operation, CIRP Annals, 56, (2007)

[25] DIN 6789, Dokumentationssystematik, Beuth, (2013)

[26] DIN 8580, Fertigungsverfahren, Beuth, (2003)

[27] J. Atug, A. Hees, M. Wagner, S. Braunreuther, G. Reinhart, Production Planning for Customer Innovated Products, IEEE - IEEM, (2016)

[28] J. Subramanian, S. Stidham, C.J. Lautenbacher, Airline Yield Management with Overbooking, Cancellations, and No-Shows, Operations Research and the Management Sciences, Transportation Science, 33, (1999)

[29] J. Käschel, S. Häckel, S. Lemke, Genetische Algorithmen für die Fertigungsteuerung mit Prozessvarianten, Springer Gabler, (2014)

[30] J. be Isa, H. Epha, S. Braunreuther, G. Reinhart, Management of Reconfigurable Production Networks in Order-Based Production, AMPS, (2018)