

Pre-requisites and added value based upon a comprehensive coordination of multi-product customer orders in MTO production networks

Ganzheitliche Koordination von Kundenaufträgen in MTO Produktionsnetzwerken: Voraussetzungen und Nutzen

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In a data- and information-driven enterprise, production planning and control becomes more and more important. Most enterprises invest in data collection and analytics systems within production. Production-related information is, however, already given and included within the customer order and entered by the sales department. The customer order may not only consist of one production order, but, especially in a B2B (Business to Business) environment, the customer order may include more than one production unit. Therefore, it may be advantageous to transmit the customer order information throughout the overall production planning and control process. In former studies, the so-called integrated planning developed concepts and algorithms to combine the production and transportation constraints within production planning. Increased customization and competition may resolve in new services and more efficient methods. Enterprises within machinery and plant engineering business face both trends. In this case, an adjustment of the operative production planning might be beneficial. A central operative production planning for the overall production network enables companies to offer special service to their customers (complete delivery) and to remain efficient (total costs of order scheduling). The concept will be presented and discussed within this article and focuses on MTO (make to order) manufacturers with an existing production network.

[Keywords: integrated planning, scheduling, production planning, customer order, MTO]

Die Produktionsplanung und -steuerung gewinnt in einem daten- und informationsgetriebenen Unternehmen zukünftig weiter an Bedeutung. Zahlreiche Unternehmen investieren in Datenbanktechnologien und

Data Analytics im Produktionsbereich. Viele produktionsrelevante Informationen sind jedoch bereits im Vertrieb und im Kundenauftrag verfügbar. Insbesondere zwischen Geschäftskunden (B2B) enthält ein Kundenauftrag häufig mehr als einen Produktionsauftrag. Deshalb könnte es vorteilhaft sein, wenn die Kundenauftragsinformation über den gesamten Prozess der operativen Produktionsplanung und -steuerung verfügbar wäre. Bisherige Studien zur integrierten Planung stellten Konzepte und Algorithmen zur Einbeziehung von Transportrestriktionen in der Produktionsplanung vor. Die ansteigende Individualisierung und der internationale Wettbewerb motivieren die Hersteller zum Angebot zusätzlicher Services und zur Anwendung effizienterer Methoden. Die Unternehmen im Bereich des Maschinen- und Anlagenbaus verfolgen beide Richtungen. Dabei kann die Einbeziehung der operativen Produktionsplanung von Vorteil sein. Eine zentrale operative Produktionsplanung für den gesamten Produktionsverbund ermöglicht es, im Kundenauftrag verankerte zusätzliche Serviceleistungen (wie beispielsweise die Komplettlieferung) abzuwickeln und die Effizienz bei der Auftragsplanung beizubehalten. Das dahinterliegende Konzept wird in diesem Beitrag vorgestellt und diskutiert. Es bezieht sich in erster Linie auf Auftragsfertiger mit einem bestehenden Produktionsnetzwerk.

[Schlüsselwörter: Integrierte Planung, Einplanung, Produktionsplanung, Kundenauftrag, Auftragsfertiger]

1 INTRODUCTION

Mechanical Engineering Industry companies are widely spread within Germany and so is the scope of their production. The corresponding Mechanical Engineering Industry Association (VDMA) represent more than 22 different industry sectors from foundry machinery to agricultural engineer-

ing. [Vdm15, p. 19] The different sectors also have some characteristics in common. Most companies within this industry produce in a MtO (Make to Order) B2B environment and follow a product differentiation strategy. In an MtO business environment the provision of supply chain quality measures is important. Due to special regulations, the distribution of the products is more expensive in relation to other products. In addition, the customers frequently order more than one product at the same time. To reduce their efforts regarding the on-site set-up of the machines, customers request the opportunity to receive more than one product at the same time. Previously this service was often coordinated and provided by the sales organization. The products were ordered in the different production plants and provided to a distribution hub. At the distribution hub, the products were stored upon completion and transported afterwards to the customer's site. The following research discusses the opportunity to insert the customers' requirements regarding the type of delivery into the production planning process. This paper describes the process, system and organization of such an added function into the production planning process within a production network.

The machinery and plant engineering sector counts with 226 Billion EUR in 2017 to the most important industries within Germany. [Vdm18, p. 5] Its companies focus more than other production companies on product innovation/ technology, quality and customization. [Kin07, p. 4]

Next to product related measures, short delivery times and delivery reliability is amongst the key factors (see also figure 1).

Delivery reliability is one of the key performance indicators for supply chain quality. [Erl10, p. 21] The key question in this regard is: "How to establish a central control measurement and function for supply chain quality within a production network?" The control function shall reflect the requirements of the MTO business environments. As customer orders are the leading items within an MTO environment, the complete customer orders shall be monitored in order to measure and evaluate the supply chain quality and delivery reliability.

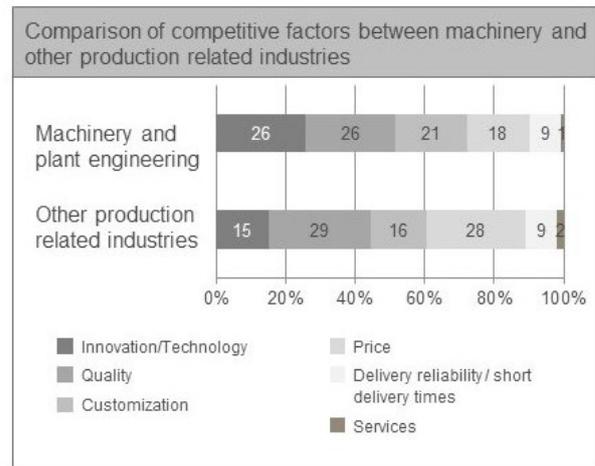


Figure 1. Competition factors [Kin07, p. 3]

2 INITIAL SITUATION

The customer order in a B2B environment may consist of more than one product or component. Due to the production diversity, the products may not be produced at the same production facility or even location. Therefore, the order lead times may differ. If the customer requires a

package delivery (which we all know from e-commerce), the completion and commissioning must be controlled and handled manually via a special process. Figure 2 shows an example of how often customers within the mechanical engineering industry place multi-product customer orders.

Customer order structure	Share of orders	Share of volume
Customer order (Product type: 1 Amount: 1)	68,8 %	34,9 %
Customer order (Product type: 1 Amount: >1)	16,6 %	29,1 %
Customer order (Product type: >1 Amount: >1)	3,3 %	9,6 %
Cross-plant customer order (Product type: >1 Amount: >1)	11,3 %	26,4 %
Total	100 %	100 %

Figure 2. Customer order composition

Figure 2 illustrates that the number of customer orders with one product counts for most of the order entries ($\approx 69\%$). In relation to the total quantity this amount of customer orders reflects only $\approx 35\%$ of the ordered prod-

ucts. Most of the numbers of units ($\approx 65\%$) come along with customer orders consisting of more than one product. The product can also vary. It can be differentiated between a single product type customer order or a multi-

product type customer order. The shown data in Figure 2 has been collected during the case study.

What are the special requirements for an order management or production planning process that reflects the coordination of so-called multi-product customer orders? To understand this in more detail, the comprehensive customer order process with all its main processes is briefly described.

The customer order process [Kuh02, p. 152] consist of “all tasks to plan, control and monitor information, material and financial flows which are linked to the fulfillment of customer orders”. If an enterprise follows the MTO-strategy, the customer order initiates the customer order process [Hei, p. 76]. The production strategy is also linked to the production planning and control. The general goals of the production planning and control is the achievement of the following Key Performance Indicators (KPI):

- High delivery reliability
- Low inventory
- Short cycle and delivery times
- High utilization of resources

The customer order process combines the core processes of a production company: sales & operations planning, production planning & control and the material requirement process. Figure 3 gives an overview of the different process owners, processes and their linkages. The sales and operations planning process covers demand and capacity planning for the entire markets and plants. The

customer orders enter the system through the sales system and fill the production order slots according to production strategy and its accompanied restrictions. In accordance to the planned and current demand the material is ordered, produced and delivered to the production site. The production orders will be scheduled and sequenced individually. There is no consideration of coordination or interdependency between production orders. [Dic14, p. 374] The production control accompanies the production of the product and monitors the progress. After completion of the product, the planned and scheduled distribution process begins. The products can be delivered to the customer. [Wag07, p. 13-19], [Her09, p. 2]

The information within the customer order regarding the type and delivery option is currently not considered in the subsequent production planning. The production planning of each production unit schedules and controls a production order. Whether the production order belongs to a multi-product customer order or not - is not considered. The question arises how a customer order process can include and consider the provided information in the customer order? Can this lead to an increased customer satisfaction and delivery reliability? Which changes in terms of processes, systems and organization are required and what is the benefit? In the past, research was especially focused on the inclusion of logistics and transportation requirements within the production planning in order to increase efficiency, e. g. the project InTerTrans [<http://www.in-ter-trans.eu/index.html>]. The following paper does not refer primarily to the logistics and transportation restrictions but to the information within the sales order. In the following, a target system will be described in order to reflect the information of the sales order in a production network to increase the efficiency of the operation system.

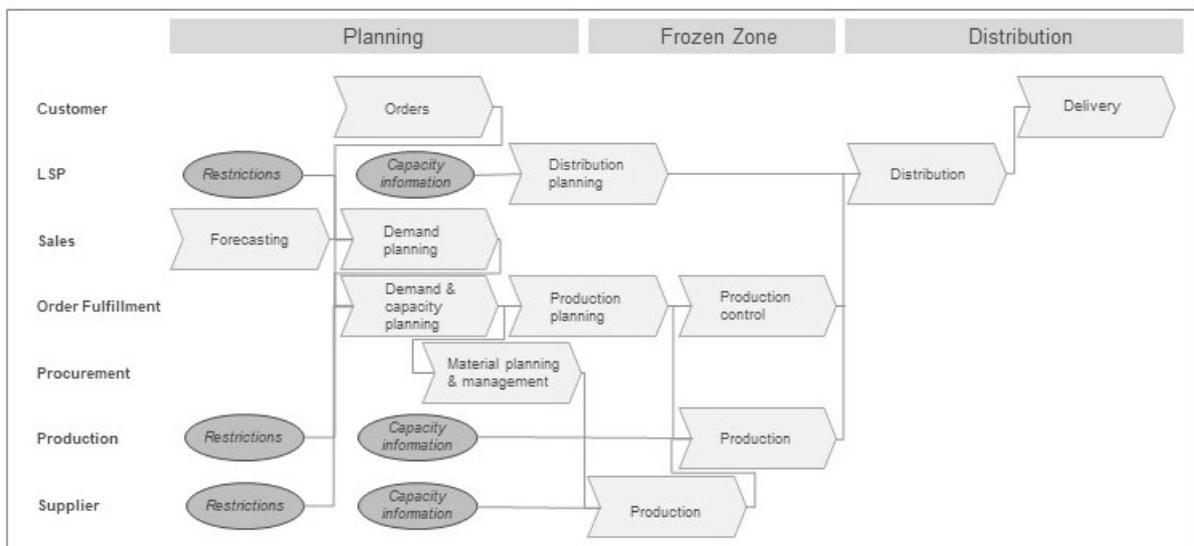


Figure 3. Customer order process [Her09, p. 2]

3 PRODUCTION PLANNING

In the MTO production the information about the customer is important. The sales department has the most interaction with the customer, independent from the sales channel. The question therefore is, which information about the customer is also relevant for production and how can this information be used in order to increase both: customer satisfaction and production efficiency. According to the data mentioned before, this paper focuses on the coordinated production and delivery of customer orders in a production network, if it is required by the customer.

Firstly, the information about a “coordinated multi-product customer order” must be collated by the sales department and inserted into the customer order. It can be analyzed whether the customer is also willing to pay for this additional service. Instead of the manual coordination of the fulfillment of the customer order, the additional information can be used for a central operational production planning based upon the production program planning.

3.1 PRODUCTION PROGRAM PLANNING

The production program planning is proceeded for all final products at one production unit. The production programme has two major tasks [Gue, p. 163-164]:

1. Creation of decentralized production programmes for a multi-period time horizon
2. Coordination of production segments

The production program planning can be solved as a linear optimization model. The goal is to “minimize relevant production, storage and resource dependent costs under the fulfilment of delivery constraints. [Gue, p. 163] It is therefore possible to model the production program planning with linear programming or an equivalent heuristic approach.

The production program is the core product of the operational production planning function. With the creation of a future-oriented production program is this function at the interface between forecast based and order-based planning. [Vol09, p. 62]

3.2 CUSTOMER ORDER FLOW

The customer order flow is shown in figure 4. It reflects the flow from the sales units until its release as a production order within a production unit.

The sales units’ issue and edit continuously customer orders. These will be checked and released as sales orders to the production units. The sales orders are assigned to the production units individually. The linkage between customer order and sales order is not provided to all pro-

duction units. In the case of a single product customer order this linkage is not relevant. In the before mentioned multi-product customer order with a complete delivery to the customer, the information is crucial. The pure customer desired delivery date is not enough.

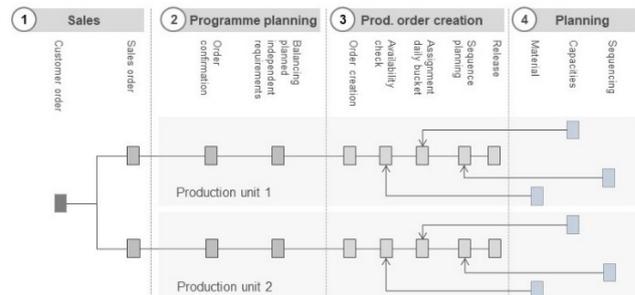


Figure 4. Scheduling of a multi-product customer order [Ebe16, S. 51]

The production units receive the orders and review the capacity and constraint situation. After the validation, the order center of the production unit sends an order confirmation with a preliminary delivery date to the corresponding sales unit. The order enters the work list for production. [Ebe16, p. 50; Boy07, p. 769]

In the next phase, the production order will be created and released. After the determination of the possible order start and order finish dates, the material availability and capacity requirement will be calculated. If required, this will run several times. [Dic14, p.374].

Finally, the order will be scheduled into a production period. In general, there are two procedures: The order selection process and the master production scheduling (MPS). The order selection chooses production orders out of the order list for the following production period. The MPS, however, assigns all production orders to production periods. In this case, it can be ensured that all orders are considered, and no unforeseen bottlenecks occur. This might be also the case in the order selection procedure. Due to the selection process, difficult and constraint related orders can be postponed by the procedure until the latest starting date has arrived. If this applies to many orders within the work list, the work list orders cannot be released to production orders without production losses. [Doe13, p. 52-54]

As mentioned before, the linkage between the multi-product customer orders and the later production orders or sequence numbers is interrupted with the transmission of the sales orders to the production units. Therefore, there is so far neither process- nor organization-wise the opportunity to coordinate the production and supply of multi-product customer orders within production planning.

4 TARGET CONCEPT

The operative production programme planning is the interface between forecast based, tactical planning and the customer order entry. The customer orders will be transferred into production orders within the remaining production process. [Vol09, p. 62]

In the target concept, the customer order hands-over additional information from the sales department in terms of the delivery of multi-product customer orders. This information will be used in the creation of a central production programme concerning all major restrictions. The central production programme can issue and schedule orders in daily buckets. The daily buckets of production orders will be sequenced afterwards.

4.1 TARGET FUNCTION

The result of the production programme planning is the creation of a future oriented production programme which lasts for several time periods and can be conducted by the production. [Bis99, p. 19] The creation of a production programme is a linear planning problem [Gue05, p. 159] consisting of a target function and constraints. The problem can either be solved via an optimization or a heuristic approach. The basic target function consists of:

1. Costs for early and late production
2. Inventory costs

The target function for the central production programme has further components. The additional components are:

3. Costs for coordination of customer orders
4. Costs for continuous planning

The costs for the coordination of customer orders are linked to the multi-product customer orders with complete delivery. If parts of these production orders are produced in advance, these products would receive an inventory cost penalty until the last item of the customer order is produced.

In the case of continuous planning, an update of the production schedule will be created for every time period. Previous production orders will leave the scheduling process and new orders will enter. [Pin10, p. 433] In this case, part of the multi-product customer order can be scheduled in a previous period whereby the rest remain in the planning process. Without any linkage, the already scheduled part will be “forgotten” for the remaining items of the customer order. The costs for continuous planning increase the costs for the remaining items for each time period in which a part of the multi-product customer order is already scheduled.

Both additional features of the target function (coordination costs and continuous planning costs) increase the costs, if the items of the multi-product customer orders are in different production stages. This provides an incentive to the mathematical model to keep these items timewise together, even if the production will take place at different sites.

4.2 CONCEPT MODEL

The following figure 5 shows the concept model of a central operational production planning model. It consists of three different phases:

1. Data tables from different sources and production units
2. Collating, validating and editing of provided information
3. Creation of a complete and comprehensive daily production program based on orders

In the following, the different phases are described.

The customer orders with all relevant data will be submitted. These data will also contain the characteristics symbol for multi-product customer orders with complete delivery. In addition, more information for the central operational production planning is required as the assignment of products to production lines according to product type or sales market.

The production units will also provide the current and updated supplier and production constraints which are relevant for the capacity adjustment planning. The production planning is based upon the shift and plant calendar.

The information from different data sources is collated and analyzed within the data model. If the data is valid, the multi-product customer orders will be split. In parallel, the possible combinations for the scheduling of multi-product customer orders with complete delivery will be created and submitted to the mathematical model.

The outcome of phase 2 is a complete order list that contains the linkage between single order and single product to the customer order information.

In phase 3, the orders will be scheduled according to the target function and constraints on the supplier and production level. The orders will be assigned to a daily production program for each production unit. The central daily production program for the short-term period is valid for all production units and is the optimal program on a production network and customer order perspective.

The evaluation of this hypothesis will be discussed based upon a case study in a subsequent paper.

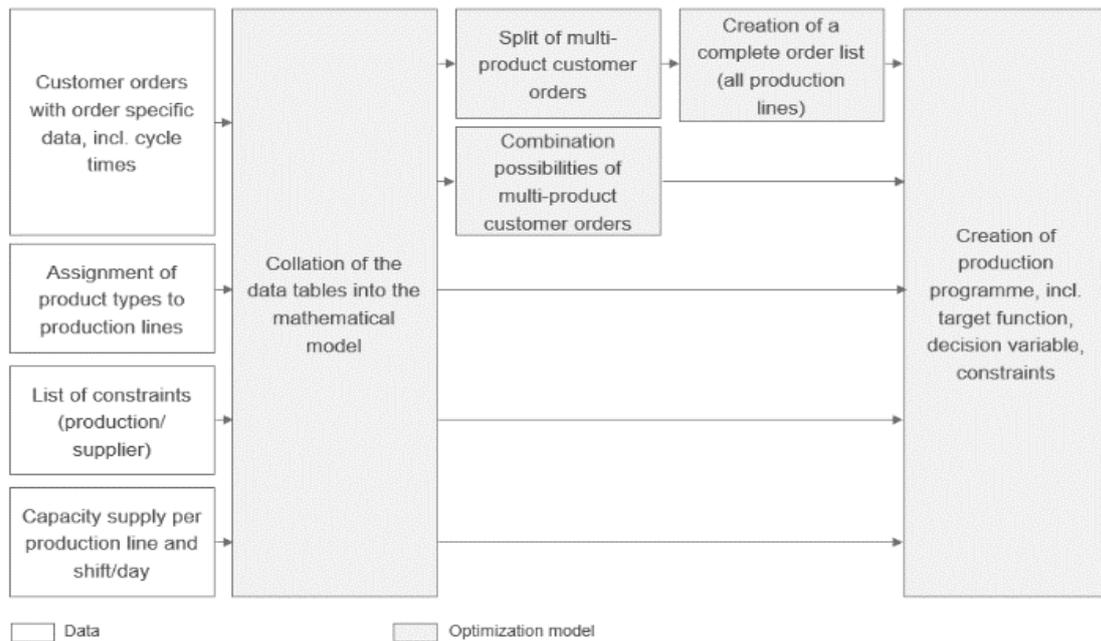


Figure 5. Concept model

4.3 ADJUSTMENT OF CUSTOMER ORDER FLOW

As shown in figure 4: *Scheduling of a multi-product customer order*, the multi-product customer order is split into two sales orders which are proceed into the further planning and execution process. In order to change the order flow, the sales orders shall be sent to a central customer order center and operational production planning team.

The central customer order team evaluates the order related data and releases the sales order to operational production planning. The order confirmation is sent to the correspondent sales department. The order appears in the working list of the operational production planning and can be assigned according to the given constraints.

In the first place, the defined production program can be reviewed by the local team. The local team can acknowledge or deny the central production program due to unknown restrictions or events. In this case, the central production program will re-run.

It needs to be considered that the rolling horizon of the central production program makes a difference in the order flow process. If the rolling horizon of the orders is about one working week, the central and local processes might have more time compared to a daily updated production schedule. Otherwise, the amount of calculation is shorter and the updates of sales orders faster – if the order delivery by sales is proceed daily, too.

The final production program is released to each entity of the production network. The order sequencing finalizes the scheduling process. After the release of the pro-

duction orders, production control takes over in order to achieve the provided plan.

5 SUMMARY AND OUTLOOK

Real time data transmission and cloud solutions enable the execution processes to collect and analyze more data in the operations environment. Next to execution processes, this data can also be used for production planning. Big Data can therefore also be used for an adjustment of operational production planning.

Several trends occur at the same time and accumulate themselves to a possible new procedure:

1. Production network: Machinery and assembly lines become more flexible and can produce different types of products. The production may also take place at different locations.
2. MTO: The customization of products increases, and the customers require increased services, e. g. complete deliveries of customer orders to decrease the on-site efforts.
3. Big Data analytics and cloud computing enable the planning departments to act centrally. Data are available and the computing times decrease tremendously.
4. Workforce: Many companies, especially SMEs (small and medium sized enterprises) suffer of specialists. The opportunity to centralize special functions might be supportive.

It still needs to be proven that a centralized created production program is more efficient than a local one. In addition, the role of multi-product customer orders varies between companies. The centralized operational production program enables, however, the coordination of multi-product customer orders and presents an overview of the condition of the production network. Not only in the execution function of every single unit, but also on the planning side. Various benefits may arise out of this transparency regarding standard processes, constraint management, throughput and delivery reliability.

Further research is required in order to evaluate the additional value of a centralized operational production planning. The above-mentioned trends and benefits can also accelerate the process towards centralization.

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