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Dynamic bid pricing for an optimized resource utilization in small and medium sized enterprises

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Abstract

Sales revenues of small and medium-sized enterprises are subject to seasonal fluctuation. This leads often to overloaded or underutilized manufacturing resources. Either way, this results in revenue losses. Therefore, companies have to optimize their resource utilization. This paper describes a new methodology for a dynamic bid price system by using correlations of revenue management in production planning to level the resource utilization. The methodology supports especially small and medium-sized enterprises, which are often affected by additional work shifts across seasons. Furthermore, the proposed method points out dependencies between costs and capacity to avoid financial losses. The method has been developed and is being tested in collaboration with two small and medium-sized enterprises.

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Keywords: Production Planning; Manufacturing Resource Utilization; Dynamic Bid Price.

1. Introduction

In production, the economic success of companies is based on the highest possible utilization of manufacturing resources while maintaining flexibility and responsiveness to demand fluctuations. The majority of small and medium sized enterprises (SME) accepts the highest possible number of customer orders aiming to ensure a high production utilization. Commonly, a systematic evaluation of customer orders based on capacitive criteria (e.g. utilization of work stations) does not happen due to a lack of information and decision-making. Consequently, the production is overloaded, which causes overtime, quality problems, delays and the risk of economic losses. The fluctuating demand from customers forces manufacturers to plan available capacities under a dynamic demand over a long period. Capacities for regular customers or for the production of standard products must be kept available. At the same time, spontaneous orders and orders with a high proportion of own development as customized brackets, must also be included in capacity planning. Many manufacturing companies already provide information on resource utilization in manufacturing execution systems. Nevertheless, customer orders are not rejected even when manufacturing resources are fully utilized. Instead, the date of delivery is shifted depending on the order priority. In order to overcome this issue, this article presents a methodology for capacity-based production planning and control, which prognoses the long-term capacity of manufacturing resource as well as the short-term deviations, as shown in figure 1.

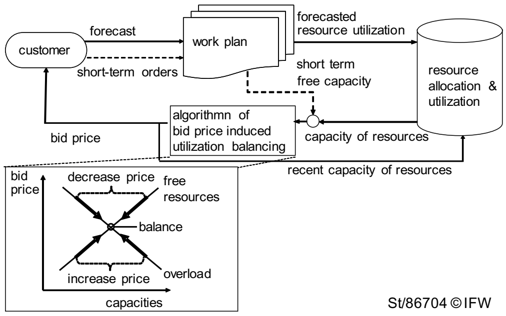

Fig. 1. Resource utilization equilibrium by bid prices.

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Within the method, the necessary capacities for a production order are determined based on the predicted demand. Furthermore, the current utilization (e.g. operating resources, machine hours) and a dynamic bid price are used to determine individual manufacturing costs for each customer order using a mathematic cost model. If a resource is busier than planned, the increased production costs must be taken into account by starting a new work shift or by switching machine classes. The dynamic bid price influences the demand and thus the resource utilization. The methodology has access to the scheduling, which enables the integration of relevant information on the current and the expected resource utilization. The method has been developed and is currently being tested at two SMEs.

2. State of the art of capacity planning and revenue management

Production planning and control (PPC) contains the planning of the production program, the material and the monitoring of all production stages. Production control on the one hand, includes functions that enable the execution of specific orders in terms of time, quantity, quality and cost. Production planning on the other hand, covers the activities that comprise the service creation process, e.g. the creating part list and the work plan in advance. Order release, capacity control, scheduling and order monitoring are the main tasks of production control. The order release sets the earliest starting time for processing at a particular work station. Within the scope of capacity control, the capacity requirement is matched with the capacity availability of every manufacturing resource. The order monitoring records and visualizes the progress of a production order with regard to the planned quantity, the completion date and the quality [1].

In PPC, methods like workload control (WLC), order review and release (ORR) or bottleneck load oriented release (BLOR) are main research targets as presented in [2]. The objective is to level order releases (input), work in progress and capacity adjustment (output) of manufacturing work stations or networks.

Customer inquiry and job entry stages are a sub objective of WLC research. As mentioned in [2], the LUMS approach deals with the decision-making problem in an early stage of the manufacturing process. Starting with a customer request, the manufacturer has to decide whether the order is accepted or rejected. Furthermore, in this stage the delivery date and the bid price have to be determined. Kingsman [3] refers to an "analytical model of dynamic capacity planning at the stage of customer inquiry" by using the flexible capacity of single work stations. In this case, capacity is an output rate of PPC. Moreover, Kingsman transferred the methodology of single work stations to shop floor networks, which shows the decision-making problem in orders requiring processing on work stations. By controlling the order release, the observance to delivery dates is managed. Main part of managing order releases is a job pool, which includes all accepted orders. In addition, Kingsman explained the planning problem of bidding and order acceptance. The capacity of each work station in future is defined as the main decision variable. Kingsman emphasis the importance of the delivery date and the price in this early stage of the manufacturing process. Nevertheless, only the delivery dates are taken into account, because the companies try to keep the price as low as possible [3]. In [4] an "overall decision support system for dealing with inquiries" is developed. It is divided in three modules: the estimation module, the capacity planning module and the marketing module. The estimation of the bid price is mainly influenced by a database of past prices and won bids. Regarding to [2], the main research target in PPC is the order release. At this time, the order is already priced and the price communicated to the customer without considering the future resource utilization.

According to VDI Guideline 2234 [5], the quotation calculation can be divided into the preliminary costing, the accompanying costing (intermediate costing) and the post-calculation. The availability of information on calculation-relevant data increases with the production progress, when accurate information on the production and preparation of the work as well as the exact descriptions of the product and the required processing times are available over time [5]. The calculation methods can be divided into expert estimates as well as parametric, analog and analytical calculations. Basic descriptions and general conditions of these procedures can be found in [6, 7]. The lower and upper boundary of the price are determined by the total cost of production and the customer's willingness to pay for the product, respectively neglecting strategical reasons for lower prices [8]. The challenge of bid price calculation is to determine costs of the product development and the production process quickly and at an early stage, although the necessary calculation basis is often incomplete [6].

Within the service sector, enterprises (e.g. aviation industry, car sharing, hotels [8, 9]) already sell free capacities at a time-dependent price using revenue management (RM) approaches. If the current demand exceeds or underruns the expected demand, the price increases or decreases and thus regulates the demand [10]. It refers to a price-quantity control. Quantitative methods are used to quantify the assumption or rejection of uncertain, chronologically distributed demand of different values. The aim is to use the inflexible available capacity in a limited time as efficiently as possible [8]. Within the framework of the RM, a heterogeneous demand behavior represents a major application requirement [11]. A consequence of the heterogeneity is that the demand for the available capacities in a period is not constant and uncertain. The capacity control is a stochastically dynamic decision-making problem. If a company accepts an order, it will decide whether the order is accepted or rejected, even if the order is still available. At the time of the decision, future incoming orders are uncertain [8]. Instead of appointed prices for capacity units, dynamic pricing is increasingly known, as a revolution in RM [12]. As mentioned in [12] dynamic pricing alters the opportunity to bring RM from stable business environments to real-time competition.

For the service sector, e.g. in ticket sales, converted systems are commercially available (for example, ISO software systems: Skyfly Revenue, Lufthansa systems). With respect to their complexity, these systems cannot be transferred to the manufacturing sector without adapting to SME needs. A large number of resources have to be taken into account in production. In addition, RM's mathematical models refer to a short-term period and inflexible capacities [8].

A price-capacity-control is based on four components: the market segmentation, the price differentiation, the forecast and the fixing of quotas [13]. Previous concepts e.g. from Spengler [14], Hintsches [15] or Volling [16] in RM for production are based on a rejection of orders and a fixed capacity. However, in case of SME a rejection of orders should be avoided if possible. Instead of rejecting orders, the capacities are increased to satisfy the demand. Further, the decision variables for order acceptance are the contribution margin of a product and the opportunity costs. In typical SME one-piece-manufacturing a product is made usually only once. Therefore, the contribution margin is not known in pricing. In SME often a close customer relationship is common. Hence, this method assumes a strategic dependency of market partners. The contribution margin is not exclusively the decision criterion for order releases.

Time series forecasts are often used for price and sales prediction [17, 18]. In RM, future demands have to be determined in accordance with the customer classification and the available capacity, for instance the number of seats for a flight leg [8]. The most common methods are linear regression, exponential smoothing, Holt-Winters and ARIMA. The ARIMA has been proven the best method for long-term forecasts [19].

3. Methodology of dynamic bid prices

This paper presents an approach that enables balancing manufacturing resource utilization automatically by adapting a dynamic bid price in accordance with the forecasted demand. Furthermore, enterprise revenues are increased, since financial losses by overloads are avoided. The objective is to integrate a capacity factor to preliminary costing, which rewards customers, when they order in underutilized periods. Orders leading to overloads are penalized with higher prices. This dynamic bid price influences the demand and thus the resource utilization by combining alternative delivery date and variable bid prices.

As shown in figure 2, the vertical process chain of the approach represents the order handling process, which is mainly influenced by the enterprise resource planning system (ERP). The output is a bid price according to a specific date of delivery. The horizontal flow of information represents the process of future production planning based on the manufacturing execution system (MES). Both contain four methods:

- classification of customers (1), chapter 3.1,
- long-term forecast of resource utilization (2), chapter 3.2,
- determination of future capacity of customer classes (3), chapter 3.3,
- bid price calculation (4), chapter 3.4.

The horizontal flow of information starts with an evaluation of the past resource utilization. On this data basis, a prediction model forecasts the future resource utilization. After forecasting the future resource utilization, the level of utilization is separated by the customer classes depending on their utilized capacity on each work station. Thus, an expected period within the business year of high and low resource utilization divided by the customer classes is created. This provides several decision supports: The decision for the

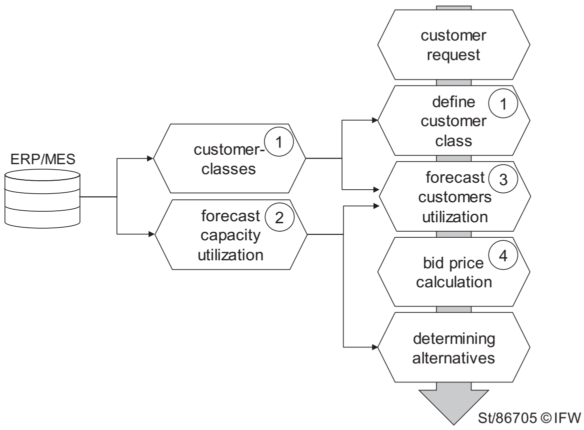

Fig. 2. Process chain of the methodology.

alternative date of delivery by pointing out the periods with unused capacity. Moreover, the busy time as a variable of decision for increasing bid price. At last the expected resource utilization by customer class for assigning incoming orders. The end of the horizontal flow of information is the transition to short-term production scheduling. These marginal conditions are not considered in this paper.

The vertical process chain starts with an inquiry from a customer with a desired date of delivery. The first step is to determine the customer class and the estimated work plan with processing time on each utilized work station. The next step is to examine the future resource utilization for the determined customer class at the required date of delivery. Next, the method assess if the order should be accepted by making a comparison between required capacity and forecasted utilization and calculates the bid price for the requested date of delivery. Hence, an alternative date of delivery and an alternative bid price are determined. The difference between the bid price for the requested date of delivery and the alternative bid price should be within the price elasticity.

The main difference to RM is the expandable capacity by using additional workforce or different machine classes. The demand is uncertain, but in case of forecasting customer classes' demand, the uncertainty is reduced. The transition to the next work shift represents a new approach in RM. In RM, the classification is influenced by the periods before the event. The closer the utilization of the service or the product, the more expensive the service or the products are. Moreover, the opportunity costs are an appropriate variable for decision making in RM.

In opposite to Kingsman's "overall decision support system for dealing with enquiries" in workload control, the proposed methodology accesses a longer forecast period for production planning. Instead of a job pool, as mentioned in [4], a customer class depending forecast is required. Despite the lack of information at the early stage of bid price calculation, an appropriate forecast of future demand enables controlling the resource utilization by the price.

3.1. Customer classification

The classification of customers divides the customers in three groups: strategic customers (A customers), temporary customers (B customers) and spontaneous customers (C customers). Each class represents a level in fulfillment of the producer made demands. The classification criteria are temporal and determined by economic aspects, such as turnover rate, required production period and the amount of order-specific profits. This subdivision of the customers allows analyzing the customer portfolio and carries out a group of similar customer orders. Class A has the highest capacitive priority, since it is a recurring source of income to cover fixed costs. However, C customers have a higher willingness to pay than long-term A customers due to their short-term demand.

First, an analysis of revenues, frequency of orders and willingness to pay of the different customers is carried out (hard factors). Second, less quantifiable aspects like status of partnership or multiplying effects for sales are analyzed (soft factors). The weighting of hard and soft factors has to be defined by a "use-value benefit analysis" for each company individually. The classification of customers depends on the production strategy. For example, engineer-to-order products are different to build-to-stock products in case of price elasticity and repetition rate.

3.2. Forecast of resource utilization

In the following chapter, the method of forecasting the resource utilization is presented using data sets from two SME. Both data sets contain production information from the last three years. The first SME produces parts for aerospace industry and is characterized by a make-to-order production in small lot sizes and 29 work stations. The second SME is a manufacturer of clamping technologies with build-to-stock and make-to-order products including in-house development and 64 work stations. The analysis of the reported working hours shows that bottleneck stations are characterized by a resource utilization of almost 100 percent over the entire three years. The data quality is an important factor for the quality of time series forecasting. The bottleneck determines the resource utilization for the bid price calculation. The work station with the highest resource utilization determines additional work shifts. According to data quality, a set of past data minimally affected by human failures has to be determined for forecasting future resource utilization. The recent utilization contains the sum of all delayed orders in a month, which is calculated by subtracting the date of the delivery note from the first known requested delivery date from the customer. Common time series forecasts as ARIMA, Holt Winters, exponential smoothing and moving average have been analyzed. Time series forecast by moving average showed the best results in terms of mean squared error (MSE) and mean absolute percentage error (MAPE), as presented in table 1. The moving average and the exponential smoothing consider a trend for the next period. However, they do not support monthly prediction in a one-year period. As shown in chapter 2, the ARIMA supports forecasts in a larger horizon of time. Using the software "gretl" in combination with the "X-13-ARIMA" algorithm by the Free Software Foundation, a forecast for the next year on a monthly base were made.

Table 1. MSE and MAPE of time series forecasts

Forecast methods	MSE	MAPE (%)
exponential smoothing	327	16
moving average	149	11
ARIMA	333	17
Holt Winters	300	14

The forecasted values of the sum of delayed orders show the expected months of high or low resource utilization. The deviation of the sum of delayed orders and the real resource utilization in the past determines the capacity limit.

3.3. Future capacity of customer classes

Subsequently, the specific demand curves of the customer classes, based on the first method (forecasting resource utilization) in chapter 3.2, are transferred in the selected forecast models, shown in figure 3. By dividing the past data set in training data and test data, a cross validation can be made. The ARIMA tested with four month in 2016 results in a MSE of 472 and a MAPE from about 20 percent. By using only four month for testing, the measures of MSE and MAPE causes in the high influence of error in the third month of testing data. Without considering this error, a MSE of 41 and a MAPE of 4 percent can be reached. The introduction of a capacity limit to the predicted data enables an activator for bid price decision. The fuzziness of capacity forecast is used to introduce an overbooking system to avoid losses in production flow due to underutilization in total.

As shown in figure 3, the predicted resource utilization in January/February and September/October 2016 exceeds the capacity limit. In these periods, an increased bid price for C customers has to be defined. If the predicted resource utilization exceeds the capacity limit, every inquiry from C customers (C_I) has to be checked in order to decide whether a work station is overloaded ($C_T > 100$) or not. Therefore, the future workload on each work station has to be predicted as a function of customer A and B (C_{A+B}). By adding the inquiry capacity, the total allocated capacity of the work stations is known. In contrast to this, periods with low resource utilization are used to determine the alternative date of delivery. As shown in figure 3, a period from May to August 2016 is predicted to be underutilized.

An order confirmation leads the system to fill the forecasted orders with real orders. The forecasted orders act like virtual orders. These virtual orders can be filled up until the limit of capacity is reached. In a customer dependent definite period of time to manufacturing start, the forecasted virtual orders are eliminated and the real resource utilization is known. At this time, two results are possible, overload or short-term capacity. Short-term capacity can be used to produce stock equipment or to deal with short-term demands. For overloads the C capacity orders will be delayed. Thus, A and B orders will get former C order's capacity.

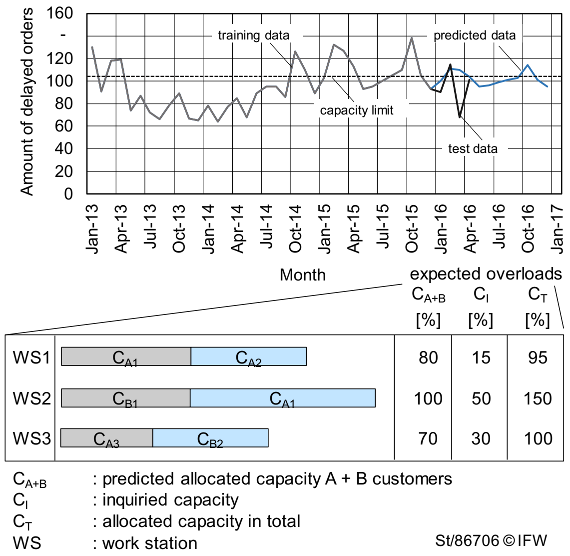

Fig. 3. Future demand curves.

In this approach, the dynamic bid price will only influence the C customers. B customers will get a new date of delivery, if the A customers' resource utilization is higher than the predicted utilization. The results of this chapter are divided for the future resource utilization into customer classes, the future resource utilization of each work station and future overloads by inquiring C customer orders.

3.4. Determination of bid prices

The calculation of bid prices depends on the price functions of every work station. The sum of these price functions determines the bid price of the inquiry. In figure 3, the work stations 1 and 2 are overloaded by C customers inquiries, which leads to different prices for each work station.

Costs that can be influenced are variable costs. It is common to calculate product prices by multiplying the price per piece by the number of items. Another possibility is to multiply the time of production by a cost rate. In this approach, it is necessary to take the date of manufacturing into account as an indicator for the capacity. There are three levels for a work shift change. The first section determines the normal price at a moderate level of utilization between points 1 and 2 in figure 4. To an individual point of resource utilization in the first work shift, it is necessary to differ in cost calculation. From point 2 on, the second section begins. Hence, every order demand has to be checked, if the assumed workload is dealing with the free capacity on each work station the order needs to go through.

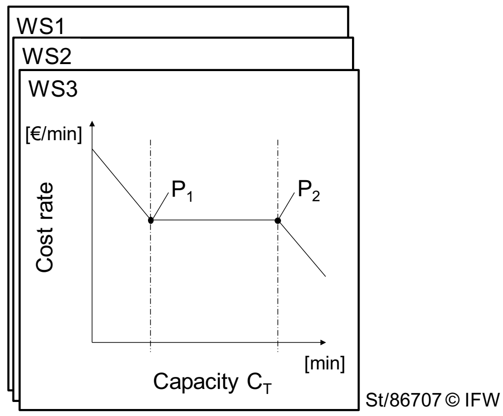

Fig. 4. Three sections of bid price calculation.

By having enough capacity, the order can be accepted with a lower price. If there is not enough remaining capacity, the third section on the left side of point 1 is entered. This section represents the beginning of a new work shift. The price will be determined by the probability of filling the next work shift and the amount of used capacity as shown in figure 4. For this decision, the following assumptions are made:

- only one open offer for one delivery date,
- no capacity enlargement on weekend work,
- each offer can only be in one section,
- the sum of all planned orders must be less than the maximum capacity minus availability.

Depending on the bottleneck work station, the calculated bid price should induce the customer to choose another date of delivery. This leads to a balanced resource utilization and avoids overloads. In case of accepting the increased bid price, the customer pays the higher effort of the manufacturer to organizing additional shifts, changing machines or rescheduling the working sequence.

4. Summary and Outlook

In SME a systematic evaluation of customer orders based on capacitive criteria is not executed because of a lack of information and decision-making. Therefore, the objective is to integrate a capacity factor in preliminary costing, which induces customers to order in underutilized periods or pay a higher amount, due to overloads caused by their order. The presented method takes into account the current and future utilization of the manufacturing resources. Capacity-based production planning and control enables the company to control the production utilization by a dynamic bid price, balancing the utilization of resources and a more precise offer calculation. The aim is to minimize the workload on the production staff by means of urgent orders and increase the motivation as well as the delivery deadline on a sustained basis. This method depends on cost functions for each work station, because of changing bottlenecks at different resource utilizations in time. Moreover, a time series forecast for real demands of SME has to be investigated. Depending on shown results, an ARIMA forecasting provides the best feasibility for long time forecasts. However, further improvements are possible. A classification of customers depends on the enterprise's business model and the product strategy. Therefore, the classes of customers have to be adjusted individually. The quality of reported working hours in company data acquisition has high influence on analysis of past data. Therefore, a high data quality is required for implementation of the proposed method.

In the next step, the cost functions of every work station will be developed. Furthermore, the impact of different cost functions on the bid price calculation and resource utilization needs to be determined. Variables of different bid prices and the point of transition for the range of the bid prices (highest to medium to low) will be identified. Moreover, a fit between business model and cost function has to be made. In case of bid prices, the influence of the upper price boundaries on the customer to accept the alternative date of delivery needs to be investigated.

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