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A two-stage bid-price control for make-to-order revenue management

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ABSTRACT

Capacity control implementations in make-to-order (MTO) revenue management typically are based on bid-prices, which are used to approximate the opportunity cost of accepting a customer request. However, in the face of stochastic demand, this approximation becomes less accurate and the performance of bid-prices may deteriorate. To address this problem, we examine the informational dynamics inherent in MTO capacity control problems and propose a two-stage capacity control approach based on bid-price updates. Updating is realized with neural networks, which are applied to adjust the selection criteria during the booking period with respect to online demand information. Not only is the resulting contribution margin positively influenced by the update, but also the downside risk of performing worse than a naive first-come-first-served policy. Results from computational experiments show that the proposed approach dominates traditional revenue management methods like randomized linear programming with and without resolving in expected contribution margin as well as in risk.

1. Introduction

Companies, which use make-to-order (MTO) order fulfillment strategies, face the problem of accepting or rejecting dynamically arriving customized orders that are unique to the customer. In checking customer orders against limited capacities, available-to-promise (ATP) approaches provide support for this decision situation. ATP concepts are widely implemented in industry and are available in commercial tools for planning and scheduling. However, ATP fails to provide decision support when demand exceeds capacity. In such a situation, companies have to decide which orders to accept and which orders to reject in order to maximize profits. Customer requests should therefore be evaluated with respect to the opportunity costs of their acceptance. In assessing the order's utilization of bottleneck capacity, revenue management approaches satisfy this requirement and can thus be used to complement ATP [1,2]. The associated business function is referred to as capacity control.

Within the last years there is an increasing emphasis on incorporating capacity control concepts into the order acceptance process of MTO companies. For medium term capacity allocation decisions, approaches based on expected marginal revenue analysis have been successfully applied [3]. For short term sales, bid-price approaches are amongst the most popular instruments [4]. The most important reason for their popularity in MTO revenue management is that bid-price based approaches neither require customer requests to be standardized in terms of capacity requirements nor to arrive in a predetermined sequence, both of which holds true for MTO production. A threshold price, the bid-price, is computed for each bottleneck resource. This price reflects the opportunity cost of consuming one unit of capacity. Orders are accepted, if the associated revenue exceeds the opportunity cost of their specific resource requirements. Details on bid-price approaches and other revenue management methods can be found in [5,6].

The determination of opportunity costs requires knowledge on the optimal allocation of capacity. This allocation can be determined using mathematical programming based on the forecast on the demand to come. However, forecasting demand in MTO settings is challenging. This is on the one hand due to the variety of the product offering, which easily comprises several thousands of configurable products and on the other hand due to the volatility of demand, which is more pronounced than in mass markets. To account for this uncertainty, bid-prices may be re-computed with respect to previously accepted orders and current demand information [7,8]. While this procedure is widely employed in service industries where transactions are highly standardized (e.g. one seat on a flight connection), there are limitations with respect to MTO settings. Firstly, sales management commonly requires simple ways to track

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the acceptance decisions of the sales personal [9]. In many cases the sales performance is assessed with respect to a reference price. If bid-prices are used as reference prices, they should not be changed frequently not to cause serious dynamics into the sales organization. Secondly, MTO sales are usually not executed online. Customers are requesting for an offer and are confirming this offer after a consideration phase. If bid-prices are updated in between, consistency issues appear. Despite volatile demand it is consequently not surprising that MTO revenue management approaches focus on the application of static bid-prices, which are not changed throughout the booking period [10]. Accordingly, consistency issues arise. If the real demand deviates from the forecast, the application of the (wrong) static bid-price results in inferior order acceptance decisions.

To account for this drawback of static bid-prices, we introduce a two-stage procedure, which combines anticipative with reactive elements. Demand information is collected within the first stage, using a static basis bid-price which is set in anticipation of future demand. In the second stage, the bid-price is updated, in response to new demand information. Limiting the number of updates allows for the transparent and stable coordination of the sales organization, which in contrast to purely static approaches still incorporates current demand data. Compared to reactive re-computation, planning nervousness is reduced, since updates are deferred until sufficient demand information is available. At the same time, the future flexibility to change the bid-price is explicitly considered, when determining the basis bid-price.

Capacity control models which combine anticipative (static) elements with reactive (dynamic) ones are becoming increasingly popular. The underlying problem can be formulated as a dynamic and stochastic knapsack model. Exact solution approaches to this model are based on stochastic dynamic programming and have been studied by Talluri and van Ryzin [11] and Kleywegt and Papastavrou [12]. However, these approaches become computational intractable, when practical problem sizes are considered [8,13]. To cope with the computational burden, several heuristic approaches have been proposed. These can be classified into two classes according to the frequency bid-prices are updated [14]. The frequency ranges from request-based updates, which allows for the continuous adoption of the bid-prices with each customer request, to time-based approaches, restricting updates to one or multiple points in predefined intervals.

The most accurate approximation of the MTO capacity control problem is based on request-based updates. A heuristic approach based on simulation optimization, entitled self-adjusting bid-prices, has been introduced by Klein [7]. To account for forecasting errors, linear functions are applied, which continuously adjust the bid-prices with respect to the total capacity booked and the expected booking or the elapsed time, respectively. However, the approach is computationally intensive, even if the bid-price updates are limited to linear functions.

To reduce complexity, time-based adjustments are proposed in the literature which limit bid-price updates to predefined points in time. In [4] a concept of dynamic bid-prices on the basis of dynamic programming is developed. Instead of static values, a time trajectory of bid-prices is computed in advance. Bid-price updates are defined purely anticipative dependent on the time elapsed. Current demand information is not taken into account. In another group of papers, formulations based on multi-stage stochastic optimization are used [15,16]. Multi-stage approaches can significantly outperform static ones. The computational burden, however, imposes tight boundaries on real-world applications. To address this issue, Chen and Homem-de-Mello [17] present an approximation to the multi-stage formulation, solving a sequence of two-stage problems with simple recourse.

The major barrier to the implementation of the latter approaches in MTO settings arises from the fact that bid-prices are updated frequently. By limiting the updates to a single change, two-stage approaches better comply with the requirements of MTO-production as mentioned above. Additionally, the complexity is reduced, allowing for MTO capacity control problems of relevant size to be solved. The basic idea is to fix one part of the decision variables (bid-price of the first stage) before the actual realization of uncertain parameters (demand) occurs. The variables are adjusted after the random event (demand) becomes well predictable. Two-stage approaches have been proposed by e.g. De Boer et al. [18] and Higle and Sen [19]. The computational burden of incorporating exact information on the distribution of uncertain demand parameters is still challenging such that approximations become necessary [20]. This in particular holds true, if other than idealized demand distributions have to be considered. In this case, typically sampling methods are used to construct scenario trees [16]. In the case of MTO manufacturing, both demand volume (number of orders) and demand structure (contribution margin and capacity requirements of the orders) are uncertain. To define a certain state in the state space, multiple parameters are necessary. The resulting scenario trees are thus subject to the well known curse of dimensionality. The approach developed in this paper is likewise based on sampled demand data. However, we omit the generation of scenario trees and present a search procedure to determine the basis bid-prices. This procedure is based on demand scenarios in order to approximate the underlying stochastic process. Accordingly, demand variability can easily be incorporated. To determine bid-price updates, we apply techniques from artificial intelligence, namely neural networks.

The objective of this paper is to develop a revenue management approach, which provides decision support in order acceptance for the specific needs of MTO companies. We focus on spot market sales, which are placed on short notice and on a nonrecurring basis [21] and assume a single bottleneck resource. The proposed approach differentiates itself from the literature on MTO revenue management by updating the selection criteria at a predefined point in the booking period. As opposed to other re-computation approaches, the updating option is explicitly considered when computing the bid-price for the initial stage. The most important feature is that we use neural networks to compute the update. In doing so, we are able to incorporate both the non-linear characteristics of bid-prices and multiple inputs signals to characterize demand. The contribution of this paper is threefold: (1) description and analysis of information dynamics and its impact on the capacity control policies of MTO companies, (2) development of a new two-stage bid-price policy for capacity control, (3) evaluation of the performance of the developed policy with respect to expected contribution margin and risk. The organization of the paper is as follows. In Section 2, we introduce the problem setting, including information dynamics, which lays the motivation for our approach. In Section 3, we present our conceptual approach, which distinguishes an offline and an online phase. Neural networks are implemented to adjust the selection criteria after the offline phase. In Section 4, results from a computational study are provided. This study reflects the main characteristics of real-world MTO production in the steel industry. Section 5 concludes the paper with an outlook on future research issues.

2. Order acceptance in MTO-production

2.1. Problem setting

We consider the order acceptance problem of a company which uses a MTO order fulfillment strategy and faces excess demand. The company operates a single bottleneck resource, e.g. capital intensive machinery. Spot market sales are considered