European Journal of Operational Research 268 (2018) 243–254

Contents lists available at ScienceDirect

European Journal of Operational Research

journal homepage: www.elsevier.com/locate/ejor

Decision Support

A clearing function based bid-price approach to integrated order acceptance and release decisions

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ARTICLE INFO

Article history:
Received 1 August 2016
Accepted 5 January 2018
Available online 12 January 2018

Keywords:
Revenue management
Order acceptance
Stochastic demand
Stochastic production
Clearing functions

ABSTRACT

In this paper, we consider the order acceptance and order release decisions of a manufacturer facing order-specific demand. In contrast to previous literature, both demand and production are stochastic. We develop a novel bid-price-based revenue management approach to solve this decision problem. The production system is modeled using clearing functions to capture the non-linear inter-dependency of workload and lead times in stochastic production systems. In extant literature, a common approach to cope with variability in a production system is to introduce fixed, workload-independent lead times. We show in a numerical study that our newly developed approach based on clearing functions clearly outperforms this fixed lead time approach.

1. Introduction

In this paper, we develop a bid-price-based approach for the order acceptance and release decisions of a manufacturer facing stochastic demand in an order-driven, stochastic production system.

As an example of this setting, consider semiconductor back-end production. Fig. 1 depicts the production process of a typical semiconductor manufacturer, which comprises two stages: front-end and back-end production. In the front-end stage, the integrated circuits are produced on a raw wafer, which is a thin disc made of silicon. The finished wafers are stored in a die bank, which represents the system's customer order decoupling point. In the back-end production stage, the functional circuits are cut from the wafers and assembled into finished chips, based on customer-specific requirements. The finished chips then undergo final testing.

In this setting, the manufacturer must decide which incoming orders to accept, considering e.g., achievable margins, requested delivery times, available wafers, and available assembly and testing capacity. In addition, processing of accepted orders has to be scheduled. These are the sets of decisions that we consider in this paper. We describe a concrete example of such a production process in Section 6.5.

Several factors complicate this planning task (Mönch, Fowler, & Mason, 2013). Unforeseen machine down times result in stochastic cycle times; expensive machines are used at multiple stages of the production process and for different products, leading to significant, sequence-dependent set-up times; on some equipment, sets of jobs are processed simultaneously in batches. In addition, demand is characterized by industry-wide peaks (see Mönch, Uzsoy, & Fowler, 2018). Capacity expansions are not a feasible mitigation option because they are time consuming and require high capital investments. Outsourcing is also infeasible during peak periods because all factories are working at capacity.

Generalizing from this motivating example, the present paper addresses integrated order acceptance and release decisions of a manufacturer in a flexible job shop with stochastic effective processing times. Production is order specific, and demand is stochastic. Orders differ with respect to their contribution margin (for example due to different prices), lead time requirements, and capacity requirements. Available capacity is exogenous. For such heterogeneous orders, the manufacturer has to decide which orders (with order-specific contribution margin) to accept. The objective is to maximize the difference between the contribution margin from accepted orders and the sum of work-in-process (WIP) holding costs, finished good inventory (FGI) holding costs, and backlog costs.

We consider a planning problem with stochastic demand and processing times. For discrete probabilities, a stochastic dynamic program can be developed to find expectation-optimal solutions. However, the state space must contain all possible demand states

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https://doi.org/10.1016/j.ejor.2018.01.006
0377-2217/

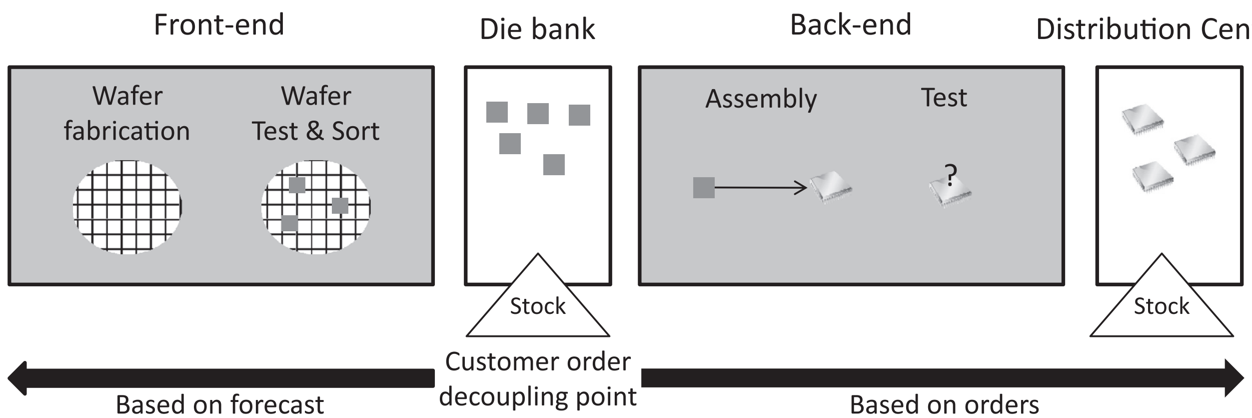

Fig. 1. Production process description of semiconductor manufacturing (cf. Guhlich, Fleischmann, & Stolletz, 2015).

(backlogged orders) and production states (status of each machine and of each accepted order). Solving a stochastic dynamic program is computationally intractable already for much simpler problems, where only demand is stochastic and production is deterministic (Petrick, Steinhardt, Gönsch, & Klein, 2012).

Instead of modeling the production system via a stochastic dynamic program, we develop a heuristic solution approach by combining bid-price-based revenue management (RM) with order release planning based on clearing functions *(CFs)*. Bid-price approaches approximate the value function with a linear function and are commonly used in RM-based order acceptance – in assemble-to-order (ATO) production systems (e.g. Gao, Xu, & Ball, 2012 and Guhlich, Fleischmann, & Stolletz, 2015), and make-to-order (MTO) production systems (see e.g. Hintsches, Spengler, Volling, Wittek, & Priegnitz, 2010; Chevalier, Lamas, Lu, & Mlinar, 2015; Guhlich, Fleischmann, Mönch, & Stolletz, 2015, and the references therein).

In the existing literature, linear programming *(LP)* models with fixed lead times are used to model the production system. This is justified in deterministic production systems. However, in systems with stochastic influences, such as in the semiconductor setting discussed above, lead times depend non-linearly on the workload. CFs provide a means to capture this relationship. Specifically, CFs model the maximum output of a machine group as a non-linear function of the workload over a given period of time. CF-based LPs have been successfully applied to order release decisions in production systems with stochastic influences, e.g., in the semiconductor industry (cf. Asmundsson, Rardin, & Uzsoy, 2006; Kacar, Mönch, & Uzsoy, 2013). In the present paper, we integrate this approach into order acceptance planning, which is novel. Specifically, we use CFs to derive bid prices, reflecting opportunity costs of capacity usage.

Summarizing, our main contributions in this paper are as follows:

1. We consider integrated order acceptance and release decisions in a stochastic production environment with stochastic, order-specific demand. This problem has not yet been studied in the literature.
2. We propose a novel bid price approach using CFs to measure the opportunity costs of production capacity.
3. In a numerical study, we show that the proposed approach significantly outperforms approaches that address variability in production systems by modeling fixed, workload-independent waiting times, which is a common practice in order release planning (Missbauer & Uzsoy, 2011).

From a managerial point of view, order acceptance decisions have to trade off incremental contribution margins against opportunity costs of resource consumption. In real-life production systems, assessing opportunity costs is challenging because orders require multiple resources and throughput times depend non-linearly on the workload, due to stochastic influences. Furthermore, opportunity costs vary over time and therefore depend on future order release decisions. In this paper, we present a method that can handle these complicating factors and thereby supports managers in making appropriate order acceptance decisions. The numerical study demonstrate, that especially for a high uncertainty in processing times and many production stages, this revenue management approach consistently outperforms approaches based on exogenous lead times as applied in real-world industrial settings. Therefore, it is worth spending additional effort for determining the shape of respective clearing functions for each machine group.

This paper is organized as follows. In Section 2, we review the related literature. In Section 3, we formally define the addressed problem. In Section 4, the derivation of CFs is discussed. The bid-price-based RM approach is developed in Section 5. In Section 6, a numerical study evaluates the performance of the presented approach. In Section 7, we outline our conclusion and provide possible avenues for further research.

2. Literature review

In this paper, we develop a novel demand fulfillment approach based on ideas of bid-price-based RM in order-driven manufacturing and of CF-based production planning. Therefore, we review literature from these streams. In addition, related literature on admission control and stochastic scheduling is discussed.

2.1. Bid-price-based RM approaches for order-driven production

Spengler, Rehkopf, and Volling (2007) use a multi-dimensional knapsack formulation to compute bid prices in a deterministic MTO production environment in which all orders are routed via the same path. No scheduling decisions are made because only one start date is available for each order. Hintsches et al. (2010) also consider a deterministic MTO production system, using a production planning LP that assumes fixed lead times to compute bid prices. In the current paper, we also use a production planning LP to derive bid prices. Volling, Eren Akyol, Wittek, and Spengler (2012) use neural networks to update bid prices. Capacity is given by a single bottleneck resource with deterministic capacity requirements. Guhlich, Fleischmann, Mönch, and Stolletz (2015) address online order acceptance and release planning in a deterministic multi-stage no-wait production system, using a production planning LP to compute bid prices. In this paper, the authors also analyze their RM approach in a model of a semiconductor backend factory. However, they assume deterministic cycle times. Guhlich, Fleischmann, and Stolletz (2015) develop a bid-price-based RM