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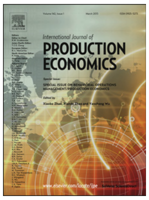

Make-to-stock policies for a multistage serial system under a make-to-order production environment

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ABSTRACT

Production control policies for a make-to-order manufacturing system composed of several stages under uncertain demand are considered. Conducting order-specific operations at each stage can produce a variety of final products from the same raw material. The production quantity per period at a stage depends on the workload. To shorten lead times, it is permitted to start production at upstream stages without confirmed orders, hold semi-finished items within the system as make-to-stock, and then match orders to these items under the constraints of specifications and quantities. Eight make-to-stock policies are prepared by combining buffer selection rules, matching acceptance rules, and make-to-stock replenishment rules. Their performance is evaluated via computer simulation. In the case of relatively limited capacity, aggressively matching orders to make-to-stock items are preferable in terms of the average lateness of orders and the average inventory level of the make-to-stock items. A policy that loads carefully to avoid undesirable processing delay by calculating the workload and considers the planned order quantities explicitly obtain better results under increased production capacity.

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1. Introduction

Severe worldwide competition is compelling make-to-order companies to shorten lead times without sacrificing quality and cost competitiveness. There are several approaches to reduce lead times, from the operational level (e.g., introducing advanced production scheduling), to the tactical or strategic level. Starting production without confirmed orders is an example of the latter approach. Make-to-forecast production, as discussed by Meredith and Akinc (2007) and Akinc and Meredith (2006), initiates production from the upstream stage by forecasting or anticipating orders based on the past data. Any incompatibility of the semi-finished products with the received orders is resolved by a later replacement of inappropriate parts with the requested parts at a downstream stage. This strategy generally incurs additional costs for these modifications, but achieves shorter lead times by starting the production in advance. This approach is tailored for make-to-order companies producing expensive and diverse assembled products, such as a large-scale machining center.

In the kind of make-to-order production environment discussed in the present paper, the final products are typically raw materials delivered to another industry. Therefore it is practically impossible to later modify the finished products to reflect the specifications of the newly arrived orders. The steel industry, which produces several kinds of steels from common materials, i.e., a few-to-many industry (Denton et al., 2003), fits well with the assumed production environment. Many papers have discussed production planning and scheduling problems in the steel industry, and it seems that one of the items most focused on is the *slab*. The slab is a semi-finished product produced from a continuous caster, and the same slab can potentially satisfy various customer orders. Therefore, one major research direction is to find the best allocation of orders to slabs by modeling this problem as an extension of bin-packing, cutting-stock, knapsack, or other relevant combinatorial problems. Kalagnanam et al. (2000), for example, explore the problem of matching orders with existing surplus slab inventory. Surplus inventory is caused by order cancelations, quality reasons, or restrictions on machines or operations. At the first step of production planning, trying to satisfy orders from surplus inventory is quite logical. The matching problem is formulated as a multiple knapsack problem with color constraints, and a network-flow-based heuristic is successfully applied to a steel plant. Some other stimulating problem situations and solution procedures within this direction are illustrated in Huegler and Hartman (2007), Dawande et al. (2004), and Balakrishnan and Geunes (2003). The present paper also investigates a kind of surplus inventory matching problem, but under the different assumption

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that the surplus inventory is a decision term to shorten lead times. Kerkkänen (2007) and Denton et al. (2003) state that some integrated steel mills are shifting or planning to shift from a pure make-to-order system towards a hybrid make-to-stock, make-to-order system in order to improve their responsiveness to market demand. As slabs are the least differentiated semi-finished products, they have more flexibility for satisfying incoming orders. In addition, matching orders to slabs reduce delivery lead times roughly by half (Denton et al., 2003). Denton et al. (2003) develop a tool for deciding which slabs to produce for make-to-stock, and Denton and Gupta (2004) propose a two-stage stochastic integer programming model to find semi-finished products for make-to-stock, and their target inventory levels. However, handling other semi-finished products such as hot band jointly remains as a continuing research issue.

The present paper is motivated by interview research, and guided by related published papers. A multistage serial system is considered. Final products are produced based on the orders received from customers, and all products need processing at all stages in turn. The production time at each stage is significant, and therefore the sum of production times over all stages may be longer than the requested lead time from a customer. To shorten the lead time, it is a reasonable idea to start production in advance, hold semi-finished items within the system as make-to-stock, and then match arriving orders to these items if it is possible. Under uncertain order arrival conditions, however, the decisions regarding quantity and timing of the make-to-stock items and order matching are crucial. In addition, it has often been mentioned that the output rate of a stage depends on the level of congestion or workload of the stage. By taking this mechanism into account, eight make-to-stock policies are proposed and examined in the present paper.

The present paper is organized as follows: in Section 2, the assumptions, system models, and performance measures are described. Make-to-stock policies by combining rules are described in Section 3, and their performance is investigated in Section 4 via computational simulation. The present paper closes by summarizing the findings and mentioning issues for further research in Section 5.

2. Production environment

2.1. Assumptions

1. The system has N stages in series, as shown in Fig. 1. Stage 1 is the most upstream stage, and stage N the most downstream stage. All items visit these stages in this order and finished products from stage N are delivered to customers.
2. There are two types of buffers BO^i and BS^i at the downstream side of stage i, except for stage N. Buffer BO^i is dedicated to items already matched to orders. This means that BO^i holds make-to-order items. On the other hand, buffer BS^i is for make-to-stock items, i.e., items without confirmed orders. Unlimited space is available for these buffers. At the downstream side of stage N, only a buffer for make-to-order items, BO^N, is available.
3. Order specifications from customers are wide ranging, but it is possible to satisfy all of them from the same raw material supplied to stage 1. Each stage conducts a specific operation to satisfy one of the requested specifications. For example, stage 1 rolls down raw material to a specific value of thickness; stage 2 adjusts items' width, and so on, as shown in Fig. 2. No two stages do the same type of operation.
4. Let T^i be the number of variants of a specification prepared at stage i, and every potential order requests one variant from among them. Therefore, it is possible to process an item in a make-to-stock manner by selecting one variant from the set of possible variants $\{1,\ldots,T^i\}$ at stage $i \in \{1,\ldots,N-1\}$. For example, thickness 1 for item #1, thickness 2 for item #2, and so on at stage 1. All potential orders from customers request one of them in terms of thickness. It is also assumed that the specifications handled by stages i and j are independent. For example, regardless of the thickness specified at stage 1, stage 2 can adjust the width of each arriving item.
5. It is practically impossible or managerially unacceptable to make final products in a make-to-stock manner because of an extensive range of order specifications and the difficulty in forecasting orders. Therefore, make-to-stock production at stage N is not acceptable and there is no buffer for make-to-stock items at the downstream side of stage N. On the other hand, the completion of the production of make-to-order items before their due date is allowed.
6. The time horizon is divided into discrete time periods with the same length. New orders arrive at the beginning of each period. The order information has four terms: (1) order specifications, (2) due date, (3) time period that the order quantity will be fixed, and (4) current planned or estimated order quantity. The last term means that when an order arrives, it generally contains the planned quantity, not a fixed quantity. In addition, this value may vary over time until the order is fixed. An order is considered as fixed when the period reaches the time point so that the quantity of the order is fixed. Initially all new orders are treated as unfixed. This type of order arrival can be found in companies that often accept orders from customers with long-term business. By knowing the planned quantity in advance, it may be possible to start production before orders are fixed. However, the uncertainty of quantity is problematic. Producing less is meaningless for shortening the lead time, while producing more creates surplus items.
7. The production capacity at a stage is constant over time and each item requires the same amount of capacity regardless of the order specification at that stage. The setup operations are negligible, and the production activities do not produce

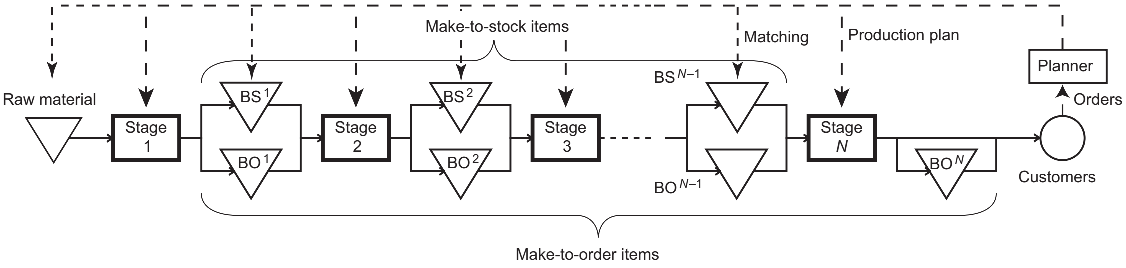

Fig. 1. Multistage serial production system.

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