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Optimal work order release for make-to-order job shops with customer order lead-time costs, tardiness costs and work-in-process costs

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ABSTRACT

Work order release mainly has been studied with regard to its impact on throughput, throughput time and work-in-process. In this research, we investigate work order release from an economic perspective. We study the situations where there are costs associated with the length of the customer order lead-time, the order tardiness and the work-in-process on the shop floor. Our research aims at minimizing the sum of these three costs. We derive expressions for the optimal value for the maximum number of orders that is allowed to be in process. Numerical analysis of a job shop model is used to investigate the reduction in total costs that results from optimally controlling the work-in-process as compared to the total costs under immediate release of arriving orders. The results show that cost reductions can be substantial for small shops, and for high ratios of work-in-process costs to lead-time costs.

1. Introduction

Controlled work order release has been widely advocated as an approach to control production order throughput times at a predetermined level (Bertrand and Wortmann, 1981; Bechte, 1988; Spearman et al., 1989; Kingsman, 2000). For an overview of research of work order release we refer to Cigolini et al. (1998). Theoretical studies of queuing models of production systems reveal that for the same throughput under workload control, modeled with a closed network queueing system, the average and the standard deviation of the production order throughput times are smaller than under uncontrolled workload, modeled with an open network queueing system (Spearman et al., 1989). For instance, at a utilization rate of about 90% the average shop throughput time decreases with about 20%. A general assumption in these analyses is that the order-processing rate is independent of the workload in the system. For workload-dependent processing rates, controlled work order release can be a necessary condition for having a stable production system (Bertrand and van Ooijen, 2002).

In this paper, we consider systems with workload independent processing rates. For such systems the above-mentioned benefits of workload control can only be fully realized if the production system is embedded in a market that can generate a new customer order each time a production order is completed. It will be clear that this is a rather strong assumption that will not be valid for many production situations. Generally, customer orders are placed under long-term contracts, or after a negotiation process where the customer can choose from a number of suppliers, making the customer order arrival process stochastic on the short term. As a result, the production system best can be modeled as an open queueing network with a stochastic order arrival process. Applying workload control in an open queueing network leads to a shop floor throughput time that is stochastically smaller than

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without workload control. However, the total order throughput time, including the time after arrival and before release to the shop, is stochastically larger than without workload control (Van Ooijen, 1996). Only if work order release also takes into account detailed information about the shop status, making it not just a workload control system but also providing detailed scheduling, the total order throughput time using controlled work order release can be shorter than without workload control (Van Ooijen, 1996; Land and Gaalman, 1998; Kingsman and Hendry, 2002; Land, 2004; Henrich et al., 2004a, b).

In this paper, we study work order release based on the total number of orders in the job shop. We consider make-to-order job shop production systems that use a constant customer order lead-time in their market and that experience a linear penalty on customer order lead-time, a linear penalty on customer order tardiness and a linear penalty on work-in-process. Penalties on customer order lead-times may be due to the sales effort needed to attract orders being dependent on lead-times, or to sales prices being dependent on lead-time. Penalties on customer order tardiness may be due to contracts implying a reduction in sales price as function of order tardiness. Penalties on work-in-process may be related to cost of capital needed to finance work-in-process (raw materials and value added) and costs of storage of work-in-process. In this paper, we investigate the cost effectiveness of controlled work order release for this type of production situation. The problem setting and the model that we use to analyze the problem are presented in Section 2. In Section 3, we show that there exists a finite optimal value for the maximum number of orders on the shop floor and we use numerical analysis to determine the optimal values of the maximum number of orders on the shop floor, for different shop sizes, different shop utilizations and different ratios of work-in-process costs to lead-time-related costs. We also calculate for each of these settings the decrease in average total costs as compared to the average total costs under immediate release and give a discussion of the results. Conclusions are given in Section 4.

2. Problem setting and modeling assumptions

We study the impact of controlled work order release on the sum of work-in-process carrying costs, customer order lead-time costs and customer order tardiness costs, for production systems that can be modeled as open queueing network systems with a stationary stochastic order arrival process and stationary stochastic order processing times. Arriving customer orders are immediately released to the shop floor if the work-in-process, expressed in number of orders at the shop floor, is smaller than a critical value, N; otherwise, the orders are placed in a release queue. If work-in-process drops below the critical level, the first order in the release queue is released to the shop floor.

To investigate the effects of controlled work order release on the sum of work-in-process costs, lead-time costs and tardiness costs, we study an idealized job shop model. This is a versatile model that captures the main characteristics of job-shop-like production systems, while still allowing for analytical or numerical analysis using Markov theory or queueing theory. The idealized job shop model is versatile in that it can capture situations with large differences in orders, where there can be small orders, only requiring one or two operations, but also large orders, requiring very many operations, or where there can be operations with small processing times and operations with very large processing times. In the ideal job shop this is modeled with a geometric distribution of number of operations per order and exponential processing times. Geometrically distributed number of operations per job also captures the randomizing effect of product reject and yield losses on routing length, and exponential processing times also capture the randomizing effect of machine breakdowns on processing time (effective mean process time, see Hopp and Spearman (2001)).

The idealized job shop model is also versatile in that it captures situations with high variations in order inter-arrival times, where a period during which many orders arrive can be followed by a period during which few orders arrive. In the ideal job shop this is modeled with an exponential order interarrival time.

Our shop model is characterized as follows:

- The shop consists of M work centers, each containing one machine that is uninterrupted available for processing.
- Orders arrive according to a Poisson process with arrival rate λ.
- An arriving order is processed according to a routing along the work centers that is generated by choosing with equal probability one of the work centers for its first operation, and after processing of an operation choosing with equal probability one of the other work centers or completion of the order. Thus, the average number of operations in an order is equal to M and the number of operations is geometrically distributed.
- Operations on all work centers have exponentially distributed processing times with rate μ.

Our model assumes that the system operates in a steady state. For the question that we investigate in this research this is a reasonable assumption. Job shops typically produce components that are supplied to the capital equipment building industry. This industry does not face yearly seasonality in demand but works in markets with business cycles with a period length of 5–6 years (see Anderson and Fine, 1999). On this time scale the shops can adapt their capacity such that capacity utilization can be considered to be constant over a year, the period length that is relevant for the control issue studied in this paper, being the control of orders to be released to the shop floor.

The economic setting is characterized as follows:

- Since our order release rule implies that orders are released from the release queue to the shop in order of