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Applying work flow control in make-to-order job shops

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ABSTRACT

This paper considers work flow control within a make-to-order job shop, which in this presentation differs from either a just-in-time (JIT) or make-to-inventory system because finished goods due dates are externally determined and early delivery of finished goods is prohibited. In particular, this paper considers the cross-effects of both choice of work flow control method and queue discipline at each work center. An experimental approach, using discrete event simulation, evaluates a five work center job shop with independent, randomly selected process sequences and process times over an experimental matrix of four work flow controls (uncontrolled, Kanban, CONWIP, and POLCA) and three queuing disciplines (first come first serve, shortest operation processing time, and earliest operation due date).

Statistically significant comparisons demonstrate that while shop inventory (partially complete orders) is reduced through work flow control, the total inventory of pending, incomplete, and held finished goods orders increases. Further, the choice of queue discipline is far more significant than the choice of work flow control method.

This paper contributes a detailed performance analysis of a relatively new work flow control method, "paired overlapping loops of cards" or POLCA. Additionally, this paper explains "lockup," a previously unreported terminal system blocking behavior. A management method to prevent occurrence of lockup is provided.

1. Introduction

The innovative aspect of the paper is the study of the cross-effects of choice of work flow control and priority rule (queue discipline) in make-to-order environments where early shipment is prohibited. In this paper we evaluate the interaction of work in progress (WIP) limits and work priorities, together referred to as "flow control," within a simulated sample of a randomly routed make-to-order job shop. We pay particular attention to a relatively new control system called Paired Overlapping Loops of Cards (POLCA) and to a new failure phenomenon we call "lockup" that occurs when Kanban or POLCA are implemented in a make-to-order (MTO) job shop. Although occasionally job shops are reflexively referred to as "push" systems, this shop enforces a fixed upper limit on WIP, and thus following the definitions of Hopp and Spearman (2004), this shop is a "pull" make-to-order system.

Since the publication of *Toyota Production System* by Monden (1983), the notions of JIT and work flow control have had a profound influence on U.S. manufacturers' approach to production planning and control. The JIT approach calls for synchronizing all the steps of production to run at the same pace, mitigating the need for buffering between production steps. The result of implementing this approach has been reported in many cases to be hugely successful in reducing manufacturing inventory. A central element of the Toyota manufacturing control system is Kanban.

Kanban was originally conceived for systems with little product variety, i.e., product is homogeneous or commodity-like. Production processes in these systems are dedicated to repeatedly performing the same operation to the same production SKU. Rather than dealing with delivery dates for individual customer orders, it is the production rate or throughput rate that is the key concern. The focus then is on watching for and eliminating bottlenecks in the production process, with the assumption that any increase in production capacity automatically generates more throughput (and revenue). On the other hand, for MTO systems this assumption that capacity automatically generates more throughput does not hold. For make-to-order systems, it is the satisfaction of externally-generated individual customer orders that drives revenue. According to Stevenson et al. (2005), make-to-order manufacturing has its own special set of requirements for production planning and control including:

1. A method for negotiating or setting job due dates
2. A job entry/release stage and a method to determine the appropriate job entry or release time
3. A control scheme to manage the intersecting and conflicting routes of highly customized products with variable shop routings

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Because there are multiple product or job types with variable routes, WIP control cannot be evaluated in isolation from the method of setting priorities at work centers. Frequently, multiple jobs will possess the requisite authority for processing at a particular machine, but the sequence in which they are processed will have a significant effect on the resulting system performance. Consequently, we evaluate each WIP control method across a set of well-known priority dispatching procedures.

The scientific literature is rife with simulation-based experimental studies of priority dispatching rules for production scheduling. Various studies have been conducted to compare dispatching procedures under various shop environments. Typical performance measures for comparison are order tardiness and inventory. No studies that we know consider the performance of shops when priority rules operate under a regime of work flow control. For comprehensive reviews of dispatching rule performance see Blackstone et al. (1982) or the more recent work of Sarin et al. (2011).

On the other hand, simulation-based experimental studies comparing the performance of work flow control procedures for make-to-order shops are few; a recent related study of work flow procedures in make-to-order production was conducted by Germs and Riezebos (2010). In that study the authors compare the performance of CONWIP, m-CONWIP, and POLCA in a make-to-order environment when the performance measure is mean flow time. As Germs and Riezebos write, "Pull systems focusing on throughput time control and applicable in situations with high variety and customization are scarce." Our focus here is to extend the work of Germs and Riezebos in a number of important ways. First, we consider the interaction of work flow control procedures with choice of priority dispatching rule. Second, we consider an enlarged system view of flow time whereby orders are not permitted to leave until the customer-specified due date. Finally, in addition to flow time performance we measure system performance in terms of adherence to customer-defined due dates.

In the following section, we review the principles of the WIP control schemes Kanban, CONWIP, and POLCA and demonstrate how we implement them in a pure job shop make-to-order production model. We describe our experimental five machine job shop configuration in Section 3 and its implementation in commercial simulation software in Section 4. A significant failure scenario for Kanban or POLCA flow control in this job shop, called "lockup," is explained in Section 5, and we describe the modification we made to the WIP control scheme to avoid it. Section 6 provides our results and a discussion of them. Finally, we conclude in Section 7 with suggestions for future research.

2. Flow control approaches

There is a great deal of scientific literature dealing with models for coordinating and controlling the flow of work in manufacturing systems. Much of the earlier literature deals with applying flow control for products that are homogeneous, produced in serial or linear routings, and that are made to stock. See Liberopoulos and Dallery (2000) for a unifying framework and review of the literature covering flow control mechanisms for such single product multi-stage manufacturing systems. Baynat et al. (2002) provide a similar review of control systems for the case of multi-products and identical serial routings.

We consider in this experiment three approaches to WIP limits that have been presented in the production management literature: Kanban (Monden, 1983), CONWIP (Spearman et al., 1990), and POLCA or "Paired-cell Overlapping Loops of Cards with Authorization" (Suri, 1998). Each of these is a token system of cards for enforcing limits on work-in-process (WIP) in a shop. Together, these systems address three fundamental levels of WIP control:

1. Control of WIP associated with a single work center (Kanban)
2. Cumulative control of WIP across the whole shop (CONWIP)
3. Control of WIP associated with a given route between two work centers (POLCA)

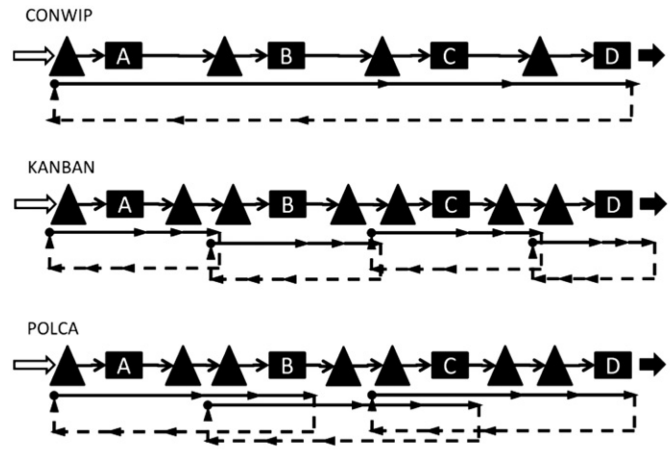

Fig. 1. Control card flows within a simplified shop for CONWIP, Kanban, and POLCA.

Stevenson et al. (2005) provide a discussion of the general properties of these three approaches and a subjective comparison and evaluation of their applicability to make-to-order systems. However, to date there have been no reports of controlled experiments that compare the performance of the three methods in an MTO environment. For each of these systems, the number of cards, a system parameter, determines the upper limit on the level of WIP allowed in the shop. The structure of these shop control systems is compared in Fig. 1 for what might be a smaller sector of a larger make-to-order job shop. It is common to organize such shops into a set of work centers or stages whereby each stage is comprised of one or more machines.[1] Adapting CONWIP to the make-to-order environment is straight-forward. As shown in Fig. 1, CONWIP cards circulate with the same job through the entire shop; once the shop completes a job k, it sends that job's card to the shop gateway authorizing the entry of another job to the shop. Adapting Kanban to this shop requires further modifications which are described next.

2.1. Kanban implementation in this experiment

The typical description of Kanban assumes a homogeneous product in a linear, make-to-inventory setting. In that setting, WIP accumulates downstream of work centers and is replenished by sending free cards back to the upstream side to signal new work to begin. However, in an MTO setting WIP accumulates upstream of work centers as it is ordered by customers and is held downstream only as finished goods in the case that a job is completed ahead of schedule. Further, while cards provide the "authority to exist" within the WIP limit, they do not provide guidance on the priority of competing jobs possessing cards at the same work center.

[1] See Liberopoulos and Dallery (2000) for a more detailed discussion of why organizing such shops into stages is desirable.