Int. J. Production Economics 120 (2009) 418–429

Contents lists available at ScienceDirect

Int. J. Production Economics

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

Defining inventory control points in multiproduct stochastic pull systems

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ARTICLE INFO

Article history:
Received 25 April 2007
Accepted 27 November 2008
Available online 20 January 2009

Keywords:
Kanban
Pull control
Buffers
Inventory

ABSTRACT

Multistage pull production systems have been widely implemented in recent years and constitute a significant aspect of lean manufacturing. One of the important considerations in such systems is identifying the control points, i.e. where in the multistage sequence to locate the output buffers. Allowable container/batch sizes, optimal inventory levels, and ability of systems to automatically adjust to stochastic demand depend on the location of these control points yet the issue of optimal location has not been widely addressed. This paper considers a multiproduct pull setting where part types compete with each other for common production resources. In this environment it is important to consider factors such as lead time variability and to include the corresponding queuing aspects into the model. Each workstation is modeled as a GI/G/1 queue. Waiting times spent by parts at workstations are approximated using a decomposition/recomposition algorithm. Necessary and sufficient conditions are provided for the optimality of a single control point. Conditions under which multiple control points are optimal are investigated along with the impact of product mix and utilization parameters on the number of control points. Analytical model results are validated by simulation.

1. Introduction

Extensive research has been carried out on pull control-based production systems as one aspect of lean manufacturing. However, the majority of this research has concentrated on determining the number of kanbans, with lesser emphasis placed on container sizes and product sequence in a just-in-time (JIT) shop. Askin and Krishnan (2006) developed conditions ensuring the optimality of a single buffer in a multistage pull system producing a single product type with known service times and deterministic lead times. However, while the issue of locating safety stock in multiechelon push production planning systems has been examined by several authors, little attention has been paid to the problem of locating buffers in a stochastic pull production system operating within a facility.

In this paper, the multiproduct, stochastic, pull environment is modeled. Service times and demand interarrival times are assumed to be random. Products flow in a serial manner through all stages, i.e. product merge/split issues are not considered. Because different product types may be present in the manufacturing system at a given time, the products compete with each other for the limited machine resources. This results in an increase in the mean and variance of production lead time at each stage as compared to single product models. The increase is due to the additional time spent by each part waiting for service. In serial systems, it is not necessary to implement controlled inventory buffers at all workstations. These

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0925-5273/$ - see front matter
doi:10.1016/j.ijpe.2008.11.020

controlled inventory buffers are referred to as control points in this study. We define a *control section* as the sequence of workstations between two control points. Within control sections, a push philosophy is incorporated. Once production is authorized by the removal of a container of parts from the control section's output buffer, a replenishment order is released to the first workstation in the control section. These orders then have authorization to flow through each stage of the control section until again reaching the output buffer, i.e. they are pushed through without waiting for a customer request. Each control section therefore operates as a CONstant Work In Process (CONWIP, Spearman et al., 1990) system. The objective of this paper is to determine where inventory buffers should be located in serial systems operating with demand-based pull control. A related question concerns determining the conditions under which it is optimal to use a CONWIP strategy with a single end-of-line inventory buffer. Thus the problem addressed may be viewed as determining the appropriate span for a CONWIP control system. We note that systems such as mixed model assembly lines operate as multiproduct serial systems with a single control section. A secondary consideration concerns determining the number of kanbans and container sizes that should be used in specific conditions. The system is modeled as a collection of GI/G/1 queues and the waiting times are approximated by a decomposition/recomposition technique modeled after Shantikumar and Buzacott (1981).

In the next section we review the relevant literature. A more formal problem statement is provided in Section 3 along with a solution methodology. Computational results are described in Section 4. Results are summarized and conclusions stated in Section 5.

2. Literature review

While there has not been much research done on determining safety stock locations in pull production systems, a substantial amount of research has gone into determining the size and location of safety stock inventory under other production control strategies. Inderfurth (1991) provides a technique for determining safety stock distribution in serial and divergent production/distribution systems operating under base stock policies. The paper assumes 100% reliable workstations. Inderfurth and Minner (1998) look at divergent systems with normally distributed demands where each stage follows a base-stock policy. Inderfurth (1994) contains a review of relevant research in this area. The paper is a survey on concepts and specific approaches for determining safety stocks in divergent inventory systems as a measure of protection against risk. Graves and Willems (2000) develop an approach to optimize the inventory levels in a deterministic supply chain that uses a base-stock policy with periodic review and guaranteed service times. Simpson (1958) provides a technique to optimize in-process inventory levels for a base stock system with random demand. van Houtum et al. (1996) also review relevant research on stochastic multistage systems where a periodic review base-stock policy is used. Magnanti et al. (2005) show that adding a set of redundant constraints and iteratively refining the approximation speed up the time required on a commercial solver to solve moderately sized safety stock placement problems in acyclic supply chain networks. Minner (2001) analyzes the problem of safety stock placement in reverse supply chains with the integration of internal and external product return and reuse. Using a simulation model, Simon and Whybark (1999) conclude that variance reduction is an effective approach to counteract the effects of uncertainty and model mix fluctuations in manufacturing cells. The tradeoff between variability and buffer inventory is further explored in the analytical models we present in this paper.

Most research into kanban systems has emphasized the choice of the number of kanbans to use in such systems. Monden (1983) suggests the following model:

$$k_i = \left\lceil \frac{\tau_i \cdot D_i(1+l)}{n_i} \right\rceil$$

where k_i is the number of kanbans for part type i, τ_i the total lead time, D_i the demand rate and n_i the container size. l is a safety factor, introduced to counter variability. The container size associated with each part type can be determined using the EOQ expression:

$$n_i = \sqrt{\frac{2a_iD_i}{h_i}}$$

where a_i is the setup cost and h_i is the holding cost per unit for product i. Schonberger and Schniederjans (1984) suggest that the EOQ model may be inappropriate for the JIT manufacturing environment. They claim that reductions in setup time and a proper value of holding costs will result in an optimal batch size of one. The value of setup time reduction is discussed in papers by Spence and Porteus (1987) and Hahn et al. (1988).

Davis and Stubitz (1987) determined the number of kanbans at each station using simulation and response surface techniques. Philipoom et al. (1987) showed experimentally that the lead time demand distribution constitutes a major determinant of the number of kanbans needed. Stochastic analytical models with discrete time periods (Deleersnyer et al., 1989) and continuous time (Mitra and Mitrani, 1990; Wang and Wang, 1990; Askin et al., 1993) for determining the number of kanbans needed have also been presented. Tayur (1993) shows that for a fixed number of kanbans, a single buffer maximizes throughput and proposes a heuristic for kanban allocation with multiple cells. Pettersen and Segerstedt (2009) confirm these results via simulation and reinforce the notion that extra kanbans should be located at the final production stage. Recently, Satyam and Krishnamurthy (2007) proposed a two-moment decomposition for performance evaluation of multiproduct CONWIP systems. Extended kanban systems (Dallery and Liberopoulos, 2000) that blend kanban and traditional base stock or CONWIP approaches have also been proposed for environments where demand rates vary over time. Our problem differs from previous studies in that we assume