



Production, Manufacturing and Logistics

The optimal control of just-in-time-based production and distribution systems and performance comparisons with optimized pull systems

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ARTICLE INFO

Article history:

Received 29 September 2010

Accepted 4 March 2011

Available online 9 March 2011

Keywords:

Production

JIT-based production and distribution system

Optimal control

New neuro-dynamic programming algorithm

New algorithm for optimizing pull systems

Numerical comparisons of optimized pull systems with near optimal control

ABSTRACT

In just-in-time (JIT) production systems, there is both input stock in the form of parts and output stock in the form of product at each stage. These activities are controlled by production-ordering and withdrawal kanbans. This paper discusses a discrete-time optimal control problem in a multistage JIT-based production and distribution system with stochastic demand and capacity, developed to minimize the expected total cost per unit of time. The problem can be formulated as an undiscounted Markov decision process (UMDP); however, the curse of dimensionality makes it very difficult to find an exact solution. The author proposes a new neuro-dynamic programming (NDP) algorithm, the simulation-based modified policy iteration method (SBMPIM), to solve the optimal control problem. The existing NDP algorithms and SBMPIM are numerically compared with a traditional UMDP algorithm for a single-stage JIT production system. It is shown that all NDP algorithms except the SBMPIM fail to converge to an optimal control.

Additionally, a new algorithm for finding the optimal parameters of pull systems is proposed. Numerical comparisons between near-optimal controls computed using the SBMPIM and optimized pull systems are conducted for three-stage JIT-based production and distribution systems. UMDPs with 42 million states are solved using the SBMPIM. The pull systems discussed are the kanban, base stock, CONWIP, hybrid and extended kanban.

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1. Introduction

Just-in-time (JIT) production systems are popular as an effective means of manufacturing management, and have been successfully implemented in many factories around the world. As noted in literature by Sugimori et al. (1977), Ohno (1988), Monden (1993) and others, JIT production systems require both input stock in the form of parts and output stock in the form of products at each stage. To maintain these systems, two kinds of kanbans (i.e., production-ordering kanban and withdrawal kanban) are used as tools to control the production and withdrawal quantities at each stage, respectively (Monden, 1993). Although numerous research papers have already discussed JIT production systems, almost all of the theoretical papers focus on only one stock between adjacent stages or one kind of kanban. Due to length limitations, only Kumar and Panneerselvam (2007) and New (2007) are cited here. This paper discusses the discrete-time optimal control of a JIT-based multistage production and distribution system that determines the production and withdrawal quantities at each stage without using kanbans (Fig. 1).

One of the main objectives of this paper is to propose a new algorithm, the simulation-based modified policy iteration method (SBMPIM), of neuro-dynamic programming (NDP) (Bertsekas and Tsitsiklis, 1996) for solving the discrete-time optimal control problem. The other objectives include proposing the simulation-based optimal setting (SBOS) algorithm, a new algorithm for finding the optimal parameters of pull systems, and conducting numerical comparisons between near optimal control computed using the SBMPIM and pull systems with optimal parameters computed using the SBOS algorithm. The pull systems discussed include the kanban, base stock, CONWIP, hybrid (Bonvik et al., 1997) and extended kanban. These are developments of Ohno et al. (2003) and Ohno and Ito (2004), written in Japanese.

The optimal control problem of the JIT-based production and distribution system with stochastic capacity and demand can be formulated as an undiscounted Markov decision process (UMDP), the solution of which gives an optimal production and ordering policy. Puterman (1994) summarized all the algorithms of the Markov decision processes (MDPs) such as the value iteration method (VIM), policy iteration method (PIM), modified policy iteration method (MPIM) and linear programming. Ohno and Ichiki (1987) showed the relative

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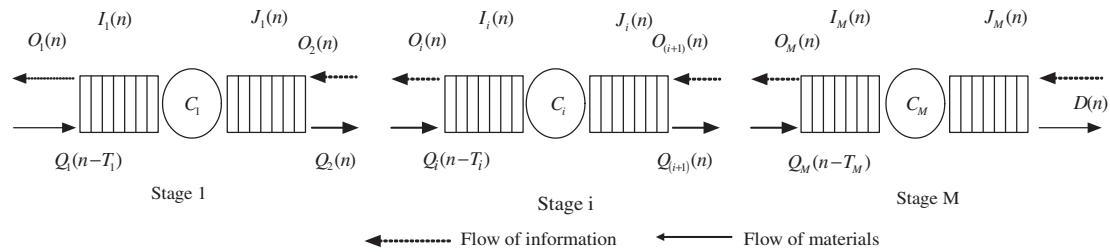


Fig. 1. A M -stage JIT-based production and distribution system.

efficiency of the MPIM for a large-scale problem. However, the curse of dimensionality makes it very difficult to find an exact solution for a large-scale MDP. This is because the state space of the MDP grows exponentially in the number of state variables.

In recent years, several algorithms in the field of reinforcement learning (Sutton and Barto, 1998) or NDP have been developed to overcome the curse of dimensionality. NDP utilizes learning algorithms, simulation and a neural network in the framework of MDPs to compute an approximate optimal control policy for large-scale problems. Das et al. (1999) proposed the semi-Markov average reward technique (SMART) algorithm for solving undiscounted semi-Markov decision processes including UMDPs and applied it to a maintenance problem. Moreover, He et al. (2000) proposed the simulation-based policy iteration (SBPI) algorithm and applied it to an inventory problem. However, Ohno et al. (2003) showed that it is not possible to apply these NDP algorithms to find an optimal policy for single-stage JIT-based production systems that the MPIM could solve. Accordingly, they proposed the first version of the SBMPIM, which was capable of finding the optimal policy. Gosavi (2003), Chang et al. (2007) and Powell (2007) are cited as recent books in this area of research.

Buzacott and Shanthikumar (1992, 1993) introduced a general approach using production authorization cards (i.e., PAC system), which included many traditional control systems such as kanban, base stock and CONWIP along with appropriate parameter choices. Ohno and Nakashima (1995) compared kanban control utilizing the optimal numbers of two kinds of kanbans, at which time an attempt was made to compute the optimal production and ordering policy for a single-stage JIT-based production system utilizing the PIM. The results showed that the kanban ordering quantities were not optimal, even for a single-stage system. Frein et al. (1995) investigated the design of parameters for a generalized kanban system. Duri et al. (2000) and Zipkin (2000) provided qualitative and quantitative comparisons of kanban, base stock and generalized kanban systems. Karaesmen and Dallery (2000) made numerical comparisons of pull systems that were optimally adjusted by the value iteration algorithm with optimal control policies computed using the VIM for two-stage production systems. Dallery and Liberopoulos (2000) proposed an extended kanban system, which was a combination of the kanban and base stock systems. Liberopoulos and Dallery (2000) devised queueing network models with synchronization stations as a unified framework for pull systems such as kanban, base stock, and generalized and extended kanbans. Bollon et al. (2004) developed a unified formulation based on the (min, +) algebra of these pull systems, and identified conditions under which the generalized kanban and extended kanban systems were equivalent. Ohno and Ito (2004) extended the first version of the SBMPIM so that it could solve three-stage production systems, and made numerical comparisons between near optimal controls computed using the SBMPIM and pull systems, such as kanban, base stock, CONWIP and hybrid, with optimal parameters. All of the aforementioned papers on pull systems except those of the author discuss continuous-time production systems. This paper focuses on discrete-time production and distribution systems, where the differences between generalized kanban control and extended kanban control are not clear. However, the extended kanban control system discussed here still refers to a hybrid of kanban and base stock systems.

In Ohno and Ito (2004), the optimal parameters of the pull systems were computed by exhaustively enumerating the expected average cost per period as estimated by simulation. However, several authors have already proposed simulation-based optimization algorithms for pull systems. Hurrión (1997) and Panaiyiotou and Cassandras (1999) applied a neural network metamodel and finite perturbation analysis techniques, respectively, to kanban systems. Gaury et al. (2000) proposed an evolutionary approach for selecting the optimal configuration of kanban, CONWIP and hybrid systems. Alabas et al. (2000, 2002) compared three simulation-based optimization algorithms using a genetic algorithm, simulated annealing and tabu search to find an optimal setting for kanban systems. Their conclusion was that tabu search is the best among the three. Shahabudeen et al. (2002, 2003) also proposed a simulation-based optimization algorithm using simulated annealing to find an optimal setting for kanban systems. Recently, Koulouriotis et al. (2010) proposed a simulation-based optimization algorithm using genetic algorithms to find optimal settings for pull systems such as base stock, kanban, CONWIP, hybrid and extended kanban. In this paper, utilizing the SBOS and tabu search, and applying a multistage structure to find optimal settings for the parameters of five pull systems are proposed.

The paper is organized as follows. In Section 2, the author explains a JIT-based multistage production and distribution system with stochastic demand and capacity, which is formulated as an UMDP to solve the problem of optimal discrete-time control. In Section 3, the SBMPIM in Ohno and Ito (2004) is extended so that it can solve production and distribution systems with three or more stages. In Section 4, the kanban, base stock, CONWIP, hybrid and extended kanban systems for a JIT-based multistage discrete-time production and distribution system are formulated. In Section 5, the author proposes a new algorithm (i.e., SBOS) for determining the optimal parameter settings of these pull systems. Finally, in Section 6, numerical comparisons of the MPIM, SBMPIM and NDP algorithms such as the SMART, SBPI and λ -SMART (Gosavi et al., 2002) are made for a single-stage JIT-based production system. Then numerical comparisons are shown between the near optimal controls for three-stage production and distribution systems computed utilizing the SBMPIM and those pull systems with optimal parameters computed utilizing the SBOS.

2. The JIT-based production and distribution system

The JIT production system requires both input stock in the form of parts and output stock in the form of product at each stage. It is controlled utilizing the production-ordering kanban circulating through the stage and the withdrawal kanban circulating between adjacent stages. The movement of kanbans is illustrated, for example, in pp. 21–22 of Monden, 1993. Here, the intention is to provide optimal

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