

January 01, 2000

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Recommended Citation

Gupta, Surendra M. and Nakashima, Kenichi, "Analysis of a just-in-time production system with supplier kanbans" (2000). . Paper 20.
<http://hdl.handle.net/2047/d10013738>

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Bibliographic Information

Nakashima, K. and Gupta, S. M., "Analysis of a Just-in-Time Production System with Supplier Kanbans", *Proceedings of the 2000 Annual Meeting of the Northeast Decision Sciences Institute*, Atlantic City, New Jersey, March 22-24, pp. 221-223, 2000.

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ANALYSIS OF A JUST-IN-TIME PRODUCTION SYSTEM WITH SUPPLIER KANBANS

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ABSTRACT

In this paper, we introduce a generalized stochastic Petri net (GSPN) to model a single-process, single-product, Just-In-Time (JIT) manufacturing facility with a supplier kanban system for multiple vendors. Its properties are investigated and the effects of the vendors' activities on the system are discussed using ANOVA.

INTRODUCTION

Just-In-Time (JIT) manufacturing has been successfully implemented in numerous companies worldwide during the past two decades. JIT manufacturing is a philosophy based on eliminating waste, reducing manufacturing cost, and promoting total quality control. The primary objective of JIT is to produce the right quantity of product in the right place at the right time, while maintaining minimal work-in-process and minimal stock of completed work. In JIT systems, little or no finished product is kept in stock. Instead, the product is manufactured in response to a specific demand. Control of JIT systems is maintained using kanbans (Japanese for "cards"). Various kinds of kanbans are used to control the flow of entities in the system. A kanban used to control supplies from a vendor is called the supplier kanban [12].

Modeling and analysis of JIT under realistic assumptions present a number of challenges, including the ability to: conduct both qualitative and quantitative analysis of the system, and model control policies. These challenges are due, in part, to station interdependence, blocking and starvation due to limited buffer spaces, and the necessity of modeling both material and kanban flows. The two dominant approaches to modeling JIT systems are analytic methods and simulation. While analytic methods provide closed-form solutions, they make limiting assumptions for processing times and demands, and are subject to state-space explosion. As a result, simulation is often the methodology of choice for modeling JIT systems [5, 6, 7, 8, 9, 10]. While simulation can be used to model the system precisely, it does not, by itself, allow the determination of any qualitative properties regarding the system design (such as deadlock).

Petri nets (PNs) have recently emerged as a promising approach for modeling manufacturing systems [1, 2, 3, 4, 11, 13, 14, 18, 19]. One of the advantages of PNs is that the same PN model can be analyzed to determine

qualitative properties of the system and directly simulated to determine quantitative properties. PNs are a graphical and mathematical modeling technique developed in the early 1960s [17] to model concurrent computer system operations. Since then, they have been extended and applied to a wide variety of systems [13, 15]. PNs are useful for modeling systems that can be characterized as concurrent, asynchronous, distributed, parallel, non-deterministic, and/or stochastic, and in which operations share multiple resources.

In this paper, we describe and develop a generalized stochastic Petri net (GSPN) model of a single-process single-product, manufacturing facility with limited capacity, which varies stochastically. A supplier kanban system for multiple vendors is used as the management system for ordering the parts in the system. We consider a scenario with two vendors and obtain numerical results using the GSPN model and discuss the effect of vendors' activities on the system.

A JIT PRODUCTION SYSTEM

The just-in-time (JIT) system is designed to make manufacturing organizations operate efficiently. The JIT production system uses two kinds of kanbans, viz., a production-ordering kanban and a withdrawal kanban, to control the production and withdrawal quantities at each station [12]. A withdrawal kanban can operate in one of two kinds of environments, viz., withdrawal of a constant quantity, but variable cycle time or withdrawal of a variable quantity, but constant cycle time. The withdrawal kanban used between stations usually operates in the former type of environment while withdrawal kanban used for making withdrawals from a vendor (also known as the supplier kanban) operates in the latter type of environment. Ohno et al. [16] studied a JIT production system with production-ordering and supplier kanbans and derived its stability condition and the number of kanbans that minimized the expected cost per period. However, the authors only considered a single supplier.

Manufacturing of a product involves using several different kinds of parts. Many of these parts are obtained from outside vendors. This adds a layer of complexity to the already challenging problem of managing the logistics of the production operation. It is important to efficiently control the ordering of parts from the outside vendors as their lead times tend to be relatively long (compared to the

internal lead times) due to, among other things, the geographical distances of outside vendors from the production facility. Since the production of a product often requires interaction with multiple vendors, it is crucial to develop a coordinated supplier management system for the entire operation to work efficiently.

A supplier management system with multiple vendors involves ordering different types of parts from different vendors and using their own supplier kanbans. The number of kanbans attributed to a given part represents the maximum number of units of that part available in stock for the use in production. Once the number of kanbans is agreed upon, the system performs automatically.

SUPPLIER KANBAN SYSTEM MODEL

Let us consider a supplier kanban system with two vendors. The generalized stochastic Petri net model of the system is shown in Figure 1. The number of tokens in their respective places represents the number of parts, products and demand. Directed arrows denote the flow of the tokens. The inter-arrival time of demand, processing time and the various lead times are independently and identically distributed according to the exponential distribution with their respective mean rates. Note that we consider the variability on lead times in this model.

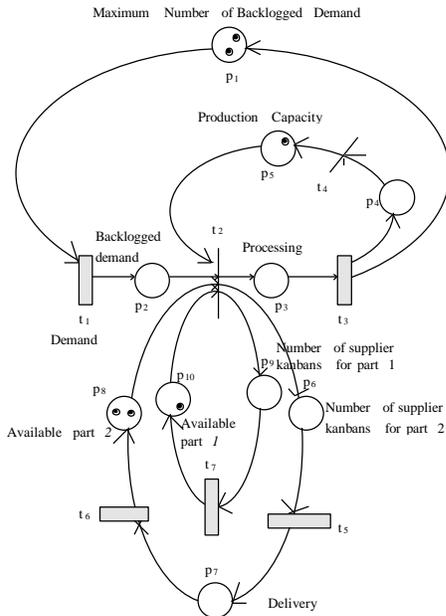


Figure 1. The GSPN model for two vendors.

The notations in Figure 1 are as follows:

- t_1 generating demand
- t_2 starting production
- t_3 processing
- t_4 production capacity variability
- t_5 ordering of part 2
- t_6 delivery of part 2
- t_7 delivery of parts 1
- p_1 maximum backlogged demand
- p_2 backlogged demand
- p_3 processing
- p_4 available production capacity
- p_5 production capacity
- p_6 number of order for vendor 2
- p_7 delivery for parts 2
- p_8 available parts 2
- p_9 number of order for vendor 1
- p_{10} available parts 1

In addition, T_i represents the firing rate of transition t_i .

ANALYSIS OF VARIANCE

We investigate the properties of the supplier kanban system by varying firing rates and using continuous time Markov chain. The initial marking is set as follows:

$$M_0 = (2000100201).$$

Based on the initial condition, there are 56 possible states of the process. We can calculate the steady state distribution of the each state in the system and obtain the expected backlog under various conditions. For the purpose of illustration, we chose two factors in the system, viz., T_5 and T_6 (note that $1/T_5$ is the mean order lead-time and $1/T_6$ is the mean delivery lead-time). Each of these two factors has two levels, viz., 1.0 and 1.5. All other firing rates are held at 1.0s. We performed the analysis of variance (ANOVA) on the expected backlog in fulfilling the demand for part 2 in the system as shown in Table 1.

Table 1: Analysis of Variance on backlogged demand

Factor	S	f	V	F
T_5	0.01141	1	0.01141	1041.83*
T_6	0.00305	1	0.00305	278.606*
e	0.00596	1	0.00001	-
Sum	0.02875	3		

From Table 1, it is clear that both T_5 and T_6 are statistically significant. This means that the system performance is sensitive to changes in ordering and delivery times for part 2.

Similar analysis on other factors can give further insight on the performance of the system. For example, it can be shown that for the same demand rate, more parts are needed as the processing rate increases; or frequent delivery of part 1 reduces expected backlog; etc.

SUMMARY

In this paper, we considered a JIT production system with multiple vendors controlled by supplier kanbans. A two-vendor model using the generalized stochastic Petri net was developed. We investigated the system performance using the analysis of variance.

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