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Optimal Work-In-Process control for a closed multistage production system with machine preference

Bacem Samet 1^a, Florent Couffin 2^a, Marc Zolghadri 3^a, Maher Barkallah 4^b, Mohamed Haddar 5^b

^aLaboratoire QUARTZ, Supméca, 3 Rue Fernand Hainaut, 93400 Saint-Ouen, France,
bacem.samet@supmeca.fr

^bLaboratoire de Recherche de Mécanique, Modélisation et Productique (LA2MP), ENIS, Route de Sokra km 4, Sfax 3038, Tunisie

Abstract – In this work, we expose a closed loop production system which have great similarity with the Kanban system as the Work In-Process (WIP) is constant (CONWIP). This system can suppose more than one machine in every stage with a limited capacity buffer. We consider also that there is a preference for a machine usage in each stage. We use a Closed Queueing Network (CQN) with a repetitive blocking mechanism to model this system. In a first place, we derive the routings to machines in the same stage when we have a preference for a machine on another. In a second place, we look for the optimal WIP to keep in this system by exploiting the Maximum Entropy Method (MEM) for the resolution of the CQN. We present some numerical results on a simple two stage production system which holds the same number of batches looping. Interesting perspectives for the development of the presented model are looked over.

Key words: closed loop production / conwip / closed queueing network / repetitive service-random destination / entropy maximisation.

1 Introduction

The production system is expected to respond to the customer demand. Competitiveness of the manufacturing system is held meeting the required quality, covering the quantity demanded and reducing the cost of production. Reducing the quantity of WIP contribute to cost reduction by virtue of suppressing the costs of keeping useless inventories. The production control system is a very important leverage that should be well chosen to meet these performances. The CONWIP, a pull production control system, is defined as a system maintaining constant the maximum amount of WIP[1]. It was first time defined in [2] to minimize the WIP in a single product flow shop subject to a given throughput level. This same purpose was also conducted in [3] and [4]. These aforementioned works are simulation based models. An analytical model approach [5] using a closed queueing network with unlimited queueing buffers was established for a Conwip flow shop single product system. The purpose of this study, which is the same of ours, is finding the optimal WIP responding to a certain throughput level. In this work, we propose a CQN model with limited buffering and blocking for a flow shop multistage production where the number of batch in the system remain constant. This closed loop production system can be ruled by a CONWIP control system since the quantity of WIP is the same. The remainder of this paper is organized as follows: in section 2, we describe the under scope type of production system. In section 3, we develop the CQN model for this system. In section 4, we present the approximate resolution approach based on EM. In section 5, numerical results are exposed for a simple case. Finally, some interesting future developments for this model are revealed.

2 The proposed production system

The production system is a multistage flow, supporting multiple machine in every stage. We study the case when there are an order of preference for the machines in the same stage. We take a closed loop system so the batches (WIP) circulating in the system remain the same. For instance in figure 1, we expose a two stage production system. In every stage, two parallel machines doing the same process and we presume a priority machine for processing the job (i.e. priority of using M1 rather than M2 in stage 1). If the priority machine will be fully occupied and when its buffer is overloaded, the jobs are redirected to the other machine. We suppose having an Unloading/Loading (U/L) process closing the cycle of production. We present a CQN model with a blocking mechanism for this production architecture class in the next section.

3 Closed queueing network model with RS-RD blocking

We model this system by a CQN with L jobs (which is the quantity of WIP). Since every machine suppose a limited capacity buffer space, the queueing system support a blocking mechanism defined as Repetitive Service-Random Destination (RS-RD). This blocking defines the mechanism of a job finished being served in a queue i and intending to enter a full buffer of a downstream queue j . In the RS-RD the job loopback to queue i to undergo a new service time and this dynamics is repeated until the job finds a free buffer space in a downstream queue to which it is routed.

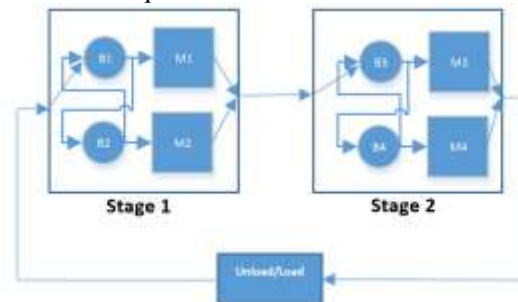


Figure 1. A closed queueing network for closed loop production system

Every machine is modeled by a single server node (M_i) (for example M1 and M2 in stage 1 in figure 1) with limited capacity buffering. We introduce in the upstream of every station a multi-server node (B_i) (for example B1 and B2 in stage 1) which will play the role of the router of the job when the buffer of the principle downstream machine is overloaded. The number of the servers in (B_i) and the buffering space is the same (equal to L) and its service time is taken very small compared to the service time of the machines. The service times of all the node have a general distribution which can be defined by a mean time (μ) and a squared coefficient of variation (sqv). This CQN have the underlying state space:

$$S = \{(n_1, \dots, n_M) : \sum_{i=1}^M n_i = L, 0 \leq n_i \leq L_i, \quad (1)$$

$$i = 1, \dots, M\}$$

With n_i is the number of jobs in the node i and L_i is the queueing capacity of the node i . The resolution of a queueing network is the establishment of the steady state probability of occurrence of this states. In the underlying section we describe the resolution approach.

4 Analytical resolution of the CQN

We exploit the MEM for solving such a CQN. This method seek to attribute the same chances of occurrence for every state respecting normalization and some marginal constraints [6]. The Entropy

function (eq.2) is maximized subject to the related constraints. We refer to [6] for the details of this resolution.

$$H_p(\bar{n}) = -\sum_{\bar{n}} p(\bar{n}) \log p(\bar{n}) \quad (2)$$

The Lagrange multipliers resolution method gives a product form solution of the CQN. This product form establishment allows facilitation to the network resolution. The probability of a state of the network can then be calculated through the marginal probability of the queues in isolation.

The resolution of the CQN go through two main stages. The first stage is about the resolution of the pseudo-open network corresponding to the CQN. It's an open network of queues with no arrival nor departure of jobs and it has the same parameters (service time and routings) of the CQN. The network is decomposed to deduce the mean time and the squared coefficient of variation (General Distribution) of both the service times and the inter-arrival times in the nodes. The MEM is applied then individually to these queues. The second phase of resolution consist of injecting the ME solution for individual queues deduced from the first phase to the CQN. An iterative convolution algorithm is used to find marginal probabilities of the CQN. And finally, a correction of several parameters (Lagrange coefficients of the pseudo-open network) is done to insure that the throughputs respect the flow balance equations (eq.3).

$$X_i = \sum_{j=1}^M \alpha_{ji} X_j, \quad i \in \{1, \dots, M\} \quad (3)$$

With X_i the expected throughput of node i and α_{ij} the routing probability from node i to node j .

The outputs of this resolution are probabilities of the states (of the set S). We seek as output the throughput of the production system which is the throughput of the Unloading/Loading machine. Other performance indicators can also be calculated (mean response time, mean number of jobs in a station...).

5 Numerical results

In this section, the system presented in the queueing model in figure 1 is evaluated. The service times are generally distributed with rates and squared coefficient of variation indicated in table 1. Buffer capacity of M_1 , M_2 , M_3 and M_4 is respectively 9,14,9 and 14. From the resolution, we sketch firstly the throughput of the system which is the throughput of the (Unload/Load) process. And secondly, we exploit the steady state blocking probability entering to M_1 which can give information about the proportion of jobs that should be routed for every machine in the stage 1.

Table 1. Service Time parameters

Nodes	General Distribution	
	Rate of the service time	sqv
M1, M3	0.5	1
M2, M4	0.4	1
B1, B2, B3, B4	60	1
Unload/Loading	60	1

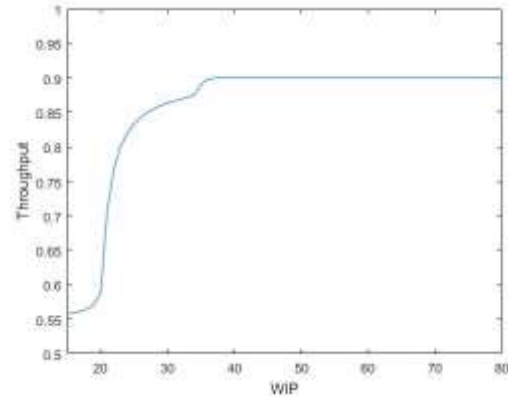


Figure 2. Throughput evolution

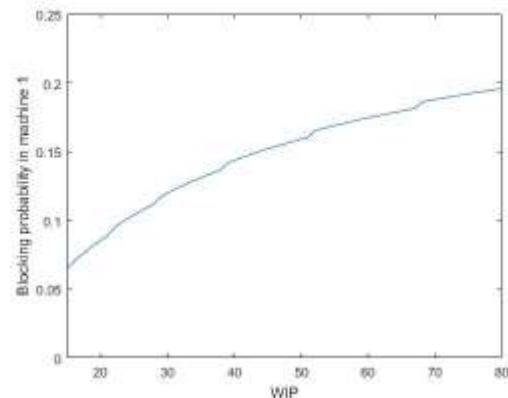


Figure 3. Blocking probability in M_1 regarding the WIP

In figure 2, we present the evolution of the throughput of the system as the circulating WIP increases. To have a maximum throughput equal to 0.9 (job/h) it's sufficient to keep 35 jobs in the network. From figure 3, the amount of jobs that can be blocked trying to enter M_1 is deduced. We know that 12% of jobs entering to M_1 (when the WIP=35) are blocked so with such buffer size of M_1 it's advised to rout only 88% of jobs to M_1 and the rest to M_2 . The same reasoning can be conducted to machines of stage 2.

6 Conclusion

A simple multi-stage CONWIP flow shop production system for a single product is modeled by a closed queueing network supposing RS-RD

blocking mechanism. This model gives insights of the system dynamics and performance analysis regarding control and design changes are possible. The underlying queueing framework was exploited to look for the routings to machines when a preference for a machine use is present in a stage. The optimal number of WIP is sketched regarding a target throughput or the maximum reachable throughput.

The generalization to a multiproduct closed system is interesting as a further development for more general cases. Introducing the batch processing, breakdown delays for the service and set-up delays between different products workloads. Another perspective is to add the fork/join nodes in the network for more generalization to study assembly lines.

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