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A KANBAN CONTROL MECHANISM FOR A MULTI-ECHELON INVENTORY SYSTEM WITH RETURNS

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ABSTRACT

In this paper, we present a two-stage kanban control model to study a two-echelon hybrid inventory system with disposals. We then express the expected cost function for the inventory system in terms of the performance measures obtained from the analysis of the kanban model. Finally, we present the results of a series of experiments that are conducted to measure the impact of the kanban sizes on the expected total cost of the system.

INTRODUCTION

Recent regulations aimed towards protecting the environmental resources have brought the issue of the reuse of products at the forefront of production and planning. Many companies are involved in retrieving used products where they repair, refurbish and upgrade the products in order to sell them for profit. Production systems of this type use both the returned products as well as new items as raw materials for the products they produce. Since traditional inventory models do not take returns into account, they are not suitable to address such systems. Therefore, new inventory models are needed to minimize total inventory costs.

Most of the models developed so far modify classical inventory techniques with control policies such as (s, S) or (s, Q) . In general, the return and demand processes are assumed to be mutually independent. A single echelon inventory system with this assumption was first modeled using an $M/M/1/N$ queue by Heyman [4]. The objective was to determine the optimal keep level N that minimized the total inventory cost. The model did not consider any lead times. A latter paper by Muckstadt and Isaac [10] considered lead times but ignored the disposal activity, when exploring a continuous (Q, r) policy inventory model. The results obtained from the single-echelon model were then applied to a multi-echelon model. Laan *et al.* [7] added the disposal option to the single-echelon model in [10]. Their study included a comparison between inventory policies with and without disposal which showed that disposal is a necessary action for cost minimization. Korugan and Gupta considered a two-echelon inventory system with disposals using an open queueing network model with finite buffers [5]. Laan *et al.* [9] showed that the pull control strategy was more cost effective than the push control strategy for inventory systems with return flows. Laan *et al.* [6] compared several inventory control policies with disposal option and showed that a four-parameter control policy was optimal. A further study by Laan and Salomon [8] verified these results while adding the disposal option to the

earlier model. A more detailed overview of such systems is given by Salomon *et al.* [12] and Gungor and Gupta [3].

In this paper, we consider a two-echelon supply system that satisfies customer demands through direct sales and allows returns. The returned items are first collected by the retailers at their *recoverable item inventory* (r) and then sent to the warehouse to be remanufactured. At the warehouse, the returned items are kept in the *remanufacturable item inventory* (rm) until they are remanufactured. After the remanufacturing process, the items are assumed to be restored into 'as good as new' condition and placed in the *serviceable item inventory* (s) to satisfy the demand from customers. The return rate is assumed to be smaller than the demand rate. The difference is produced at the facility.

As both demand and return rates are probabilistic, there is a chance that the recoverable item inventory exceeds the predefined limit. In an effort to control such an instance, we allow returned items to be disposed off from the recoverable item inventory at a fixed disposal cost per disposed item. For this study, we assume that the disposals take place only at the lower echelon. In addition to the disposals, we also allow a predefined amount of unsatisfied demand to be backordered. When this amount is exceeded, we assume that the unsatisfied demand is lost.

In the next section, we introduce a two-stage kanban control mechanism with extra buffers for returned products and backordered demand in order to model the inventory system. In the following section, we give the necessary performance measures of the kanban model and define an average total cost function with respect to them. Following that, we measure the effect of the kanban sizes on the average total cost of the system for different costs and arrival and service rates. Finally, we conclude our work by analyzing the results obtained in the previous section.

MODEL DESCRIPTION

We consider a two-echelon inventory system with N retailers and one warehouse as described above, where the demands and returns occur independently of each other and are Poisson distributed with rates l and g_i , (for retailer i , $i = 1, L, N$), respectively. In order to simplify the model, we assume, without loss of generality, that there exists only one retailer that receives returns with rate $g = \sum_{i=1}^N g_i$. We further assume that only one item is transported at a time and the transportation times are exponentially distributed with rate m_l . In addition, we assume that the remanufacturing and manufacturing times are exponentially distributed with rates m_{rm} and m_m , respectively. With these assumptions, we can model

the problem as a production line given in Figure 1. Here, the servers represent the transportation; remanufacturing and manufacturing activities while the buffers represent the earlier mentioned inventories. In order to analyze this model we employ a two-stage kanban control mechanism given in Figure 2. Here, κ_1 , κ_2 and κ_3 are the kanban control parameters. The demand arrives at the buffer, D , of synchronization station, J_2 with a Poisson arrival rate l and is accepted when the buffer is not full. Otherwise, it is considered lost at a cost of c_l per unit of demand. The accepted demand is queued in D for a backorder fee of c_b per unit time, until it is matched with a new or a remanufactured product at the *serviceable item inventory*, P_2 . When a product is matched with a demand, the kanban card attached to the product is detached and, depending on its type, sent either to the kanban buffer, F_2 , of the synchronization station, J_1 , to pull a returned product for remanufacturing or to node S_2 to trigger a the manufacturing of a new product. Here, we assume that there is sufficient raw material available. A kanban received at J_1 waits at the queue until it is matched with a returned product in P_1 and placed in the buffer of S_2 for remanufacturing. When this match takes place the kanban on the returned product is detached and sent to the kanban buffer, F_1 , of synchronization station J_0 , to pull a returned item from P_0 . When a returned item arrives at J_0 , it joins the queue at P_0 to be pulled by a kanban in F_1 , if P_0 is not full. Otherwise, it is rejected for disposal at a cost of c_d per unit item.

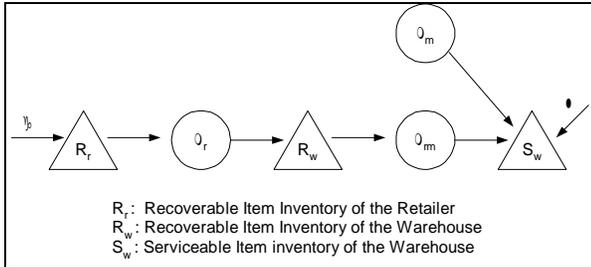


Figure 1: Two-echelon inventory problem as a production line

THE COST FUNCTION

The average total cost \mathcal{E} of this system consists of three parts, viz. the operational costs, the holding costs and the incurred penalties. A unit operational cost incurs when a unit product is sent to the warehouse for remanufacturing at a cost of c_r , or a unit remanufactured or manufactured product is sent to the serviceable inventory at a cost of c_{rm} or c_m , respectively. Thus, in order to find the total expected operational cost, we need the average throughput rates TH_r of the retailer, TH_{rm} of the remanufacturing system and TH_m of the manufacturing system. Similarly, a unit item accumulates holding costs of h_r , h_{rm} , or h_s , per unit time at the recoverable inventory, the remanufacturable inventory or the serviceable inventory, respectively. Therefore, for the calculation of the expected total inventory carrying cost, it is necessary to find the average queue lengths Q_r of the retailer inventory, Q_{rm} of the remanufacturing inventory and Q_s of the

serviceable inventory. Finally, in order to find the expected total penalties, we have to obtain the average backorders Q_b , the lost sales rate l_l and the disposal rate g_d . Then, we give the expected total cost function as,

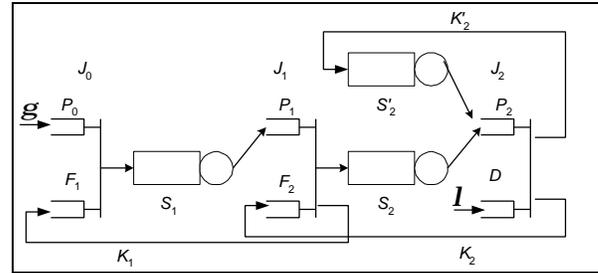


Figure 2: The kanban model of the two-echelon inventory problem

$$\mathcal{E} = \lim_{T \rightarrow \infty} \frac{1}{T} E \int_0^T [TH_r(t)c_r + TH_{rm}(t)c_{rm} + TH_m(t)c_m + h_r Q_r(t) + h_{rm} Q_{rm}(t) + h_s Q_s(t) + c_b Q_b(t) + c_l l_l + c_d g_d(t)] dt \quad (1)$$

Here,

$$Q_r = Q(P_0) + Q(S_1),$$

$$Q_{rm} = Q(P_1) + Q(S_2),$$

$$Q_s = Q(P_2),$$

$$Q_b = Q(D).$$

Also, let B and BL give the capacities of P_0 and D , respectively. Then,

$$l_l = l R(D = BL), \text{ and}$$

$$g_d = g R(P_0 = B).$$

The performance measures of interest can be obtained by analyzing the kanban network as a queueing network with synchronization mechanisms as given in [2]. To this end, we first decompose the network into two sub-networks L^1 and L^2 , with station J^1 as the output synchronization station of L^1 and the input synchronization station of L^2 . Then using a recursive algorithm, we analyze L^1 as a closed queueing network in isolation by regarding the kanbans as customers [1]. When the algorithm converges, we obtain the state dependent arrival and service rates and the steady state probabilities of each station in L^1 . Then we pass the arrival rate of buffer P_1 calculated by this algorithm to a similar algorithm for L^2 . Once this algorithm converges, we pass the arrival rate of buffer F_2 to the first algorithm. We repeat these two iterations until the arrival rates for P_1 and F_2 converge. We then calculate the performance measures and the expected total cost function of the system using the probabilities obtained from the recursive iterations.

The uniqueness of our problem comes from the fact

that there are two sources, manufacturing and remanufacturing, that satisfy the demand. Thus, in order to re-

tain the

Table 1: Levels of the experimental variables

Levels	K	I	q_{rm}	m	c_r	c_{rm}	c_m	h_r	h_{rm}	h_s	c_b	c_l	c_d
Low	3	0.8	0.3	2	1	1	1	1	1	1	1	2	1
Med.	5	1.4	0.6	3	2	2	3	2	2	3	2	3	2
High	10	2	0.9	4	3	3	5	3	3	5	3	4	5

balance of the network, we introduce the routing probability $q_{rm} = \frac{r_2}{r_1 + r_2}$, for, $g \leq I$, for the output of J_2 when we analyze L_2 . Let, $\lambda(L_2)$ be the throughput of the closed queueing network L_2 . Then the arrival rate of kanbans at F_2 is given as $q_{rm} \lambda(L_2)$ while the arrival rate of kanbans at S_2 is estimated as $(1 - q_{rm}) \lambda(L_2)$.

EXPERIMENTATION

In the previous section, we defined the expected total cost, \square , of the system as a function of several performance parameters of the kanban system. Since, all of these measures can be written as functions of kanban sizes, we deduce that \square is a function of the kanban sizes K_1 , K_2 and K_2^+ . Here, let $K_2^+ = K_2 + K_2^+$, then, $K_2 = q_{rm} K_2^+$. Thus, $\square \rightarrow (\lambda_1, \lambda_2)$.

In this section, in order to explore the behavior of this function for different values of K_1 and K_2^+ under different cost and arrival stream scenarios, we designed an experiment, $L_{27}(S_2)$, using orthogonal arrays [11]. Orthogonal arrays enabled us to cover the entire experimental region with only 27 experiments for a three level design of 13 independent variables as opposed to a full factorial design of $3^{13} = 1594323$ experiments. The levels of the independent variables are given in Table 1. Here, K represents all buffer and kanban sizes while m represents all service rates.

CONCLUSIONS

The results of the experimental design and the kanban sizes are plotted in Figure 3. Here, the experimental data is sorted with respect to kanban sizes in order to demonstrate the impact of the kanban sizes on the total cost function. In addition, the trend of \square is fitted with a polynomial function of the fifth order. Thus, from these

results we can easily conclude that an increase in the kanban sizes causes an increase in the expected total cost. In order to compare this observation with other cases, the same analysis is applied to other parameters in the experiment. However, none of them had an impact as significant as the kanban sizes. Thus, kanban sizes are the primary control parameters in systems similar to the one we examined.

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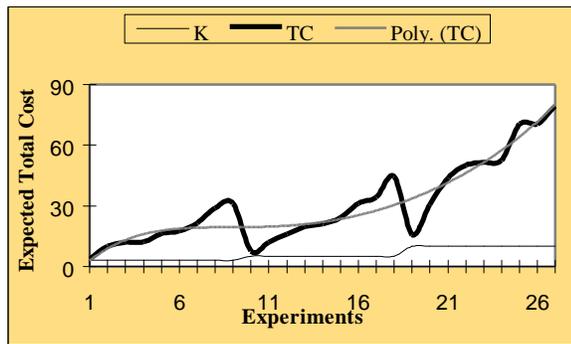


Figure 3: Trend of the total cost while K increases.