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Recoverable System Performance with Server Vacations

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Abstract

This paper considers the performance of the remanufacturing system with finite buffers and random length server vacations. The term *server vacation* may be used to cases where the server leaves the primary queuing system to work on an external workload for a random duration every time the server becomes idle (i.e. server is unavailable due to the processing of additional tasks or preventive maintenance of equipments). Remanufacturing operations involved with highly uncertain recovery rate of used products and parts that complicate the planning and control of the process. Also, recovery operations tend to be labor intensive that lead to significant variability in the processing times at various shop floor operations. Thus, to reduce the effect of these uncertainties we need to employ server operating policy. We model the remanufacturing system as an open queuing network and use the decomposition principle and expansion methodology to analyze it.

Keywords: Remanufacturing, inventory control, server vacations, open queueing network, expansion method.

1. Introduction

Extended manufacturer concept puts the responsibility of product recovery management on the manufacturing company. The objective of product recovery management as stated by Thierry *et al*. (1995) is “to recover as much of the economic (and ecological) value as reasonably possible, thereby reducing the ultimate quantities of waste”. The product recovery options include repairing, refurbishing, remanufacturing, cannibalizing and recycling. Remanufacturing is an industrial process in which worn-out products are restored to “like-new” conditions. Thus, remanufacturing provides quality standards of new products with used parts. Remanufacturing is not only a direct and preferable way to reduce the amount of waste generated, it also reduces the consumption of virgin resources. Recycling on the other hand is a process performed to retrieve the material content of used and non-functioning products without retaining their identity.

Remanufacturing operations are labor intensive that lead to significant variability in the processing times at various shop floor operations. The uncertainties surrounding the returned products further complicate the modeling and analysis of product recovery problems. As such, forecasting the quantity and the quality level of used products is difficult. Unknown conditions of the returned products lead to different routings and highly varied processing times within the remanufacturing system. The serviceable inventory level coordination between remanufactured products and the new products which are procured from outside further complicates the optimization of the system performance.

In this paper, we incorporate various stochastic factors, such as used product return rate, service rate, vacation time for the servers and re-usable rate of returned products in remanufacturing systems. An open queuing network model is constructed to represent the remanufacturing operations with finite buffers and service time is subject to interruption as a result of the server vacation (Fig. 1.). In other words, the server will stop service for a random amount of time during which arrivals can occur. uring the vacation period the server appointed to secondary operations in the remanufacturing system or goes to preventive maintenance before starting to process of new jobs. Thus, the motivation for a server vacation

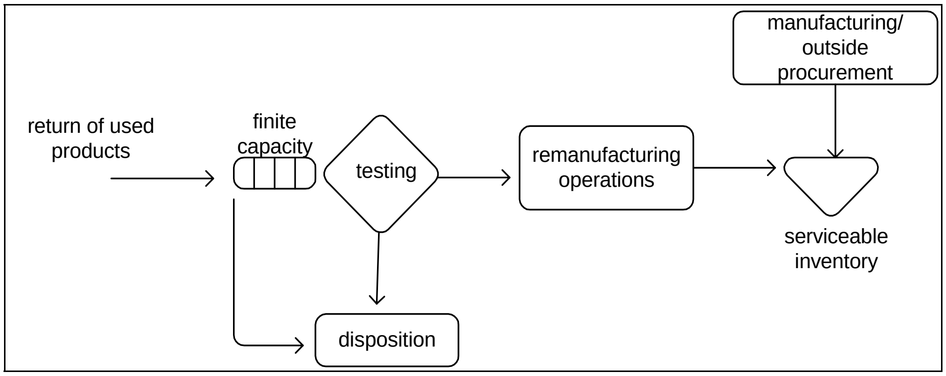

Figure 1. Remanufacturing/ manufacturing system.

model comes forward from the need to use the idle time of the server more efficiently. In order to analyze the queueing network, we use the decomposition principle and expansion methodology.

2. Literature Review

Classical models of production planning and inventory control are not appropriate for remanufacturing and need to be modified for it. Several authors have made such attempts. Heyman (1977) analyzed the continuous-review inventory control problem where incoming returnables are disposed of whenever the inventory reaches a predefined level. The author assumed zero repair times and did not consider procurement lead times. Muckstadt and Isaac (1981) developed an approximate control strategy with respect to order points and order quantities for a single product case where returned products are remanufactured. They considered fixed lead times but without disposal of returned products. Van der Laan *et al.* (1996) present a general approach to production planning and inventory control for a combination of traditional manufacturing and remanufacturing. In a typical queuing system modeling of manufacturing system, it is usually assumed that when a server (or machine) becomes idle, it remains idle till the next job arrives. Obviously, in certain situations this is a waste of valuable system resources. A remedy is sometimes adopted where the machine/server is scheduled for an alternative (secondary) task (for instance process other jobs or perform preventive maintenance work) as soon as the queue in front of the server becomes empty. Single server queue with vacation has been investigated by several researchers; Doshi (1986) compiled the literature for the single server queues with vacation period. Lee (1984) studied the finite capacity M/G/1 queue with server vacations and obtained the performance measures of the queue in terms of Laplace-Stieltjes transforms. Keilson and Servi (1989, 1993) reveal important structural properties of the M/G/1/K queue by relating the length distribution of the corresponding infinite buffer queue to the finite buffer queue. Fuhrman and Cooper (1985) studied the aspects of M/G/1 type queue with multiple vacations.

3. The Remanufacturing Model

In this paper we analyze a single item, single location serviceable inventory system where returned products are remanufactured. A returned item gets into the system from outside through the first station (disassembly station) and is processed by all stations sequentially, and finally departs from the system after joining the serviceable inventory.

We assume that both return of products and demand arrive to the system according to a renewal process, viz., the inter-arrival times of products and demand are independently and identically distributed exponential random variables with rates λ_{ar} and γ respectively. There is one server and a finite buffer capacity represented by B_i at each station i. The service rate μ_i at each station is exponentially distributed and the service discipline is First Come First Serve (FCFS). γ_i vacation rate of node (station) i also exponentially distributed.

The blocking mechanism in the remanufacturing system is ‘block after service’ (BAS). When an item is ready to leave the *i*th station (after processing), the item goes directly to the downstream (*i*+1th) station, where it enters into service immediately if the server is free; otherwise, it joins the queue if there is a place in the buffer. If a buffer slot is not available in the downstream station the part stays at station *i* and blocks that station. For the period of blocking, station *i* remains idle and cannot process any parts that might be waiting in its queue. A blocked job is released to the downstream station as a space becomes available there. The only exception is when the used products first arrive at the disassembly station from outside. In that case, if a returned product finds the buffer of the station full, it cannot enter the remanufacturing system and is considered lost to the system. (However in this situation, because of potential recoverability of the returned product a penalty cost is applied). A remanufactured unit is instantly directed to the serviceable inventory from where the demand is satisfied. Any deficiency is fulfilled with outside procurement of new products. The transfer times of items between buffers and stations are assumed to be negligible. When a failure of a station occurs during the processing of a part, the part stays there while the station is being repaired. After the repair of the station, the part is reprocessed from the beginning.

The total cost function (*TC*) for a remanufacturing network of the type illustrated in Figure 2. consists of the following types of recovery and remanufacturing costs:

$E(RP)$: Expected rate of the returned products is represented by the arrival rate of returned products to the remanufacturing system (λ_{ti}).

$E(T)$: Expected rate of tested products is estimated by the throughput rate of the inspection station (th_2). After inspection, disassembled parts are directed to either the remanufacturing shops with the probability of r or disposed off with the probability (1-r).

$E(Dis)$: Expected rate of disassembled products is estimated by the throughput rate of the first station (th_1).

$E(OP)$: Expected rate of manufacturing/outside procurement is estimated by the difference in the demand and the return rate $(d - \lambda_{ti} \times r)$.

$E(I)$: Expected serviceable inventory level of the remanufacturing system is estimated by the average queue length of the serviceable inventory where the demand, d is satisfied. Serviceable inventory designed as a dummy station with the service rate equal to demand (d) rate with two arrival streams. One from the remanufacturing module (throughput of the remanufacturing system (th_6)) and the other from outside procurement.

$E(Ls)$: Expected rate of the lost sales is estimated by the starving probability of the serviceable inventory.

$E(Rej)$: Expected rate of the rejected items is estimated by the probability of buffer fullness of the first station (P_{K1}).

$E(Ri)$: Expected rate of the remanufactured parts in each station is estimated by the throughput rate of the associated stations (th_i, i=3, 4, 5, 6).

The expected total cost expression can then be written as:

$$E(TC)=c_pE(RP)+ c_tE(T)+c_{dis}E(Dis)+\sum_{i=3}^{6} c_{ri}E(Ri) +c_mE(OP)+c_hE(I)+c_lE(Ls)+c_{rej}E(Rej)$$

Since each node is analyzed independently and in isolation, the throughput of each node is also calculated independently. The throughput of node i is calculated as follows (Gupta and Kavusturucu (2000)):

$$TH_i = (L_i - Lq_i)\mu_{i_i} + \lambda j_i (1 - P'_{K_i})^{\rho_i + \rho_{i-1}} (1 - P_{K_i})$$

where the expected number of jobs in node i,

$$L_i = \sum_{s_i=0}^{K_i} s_i P_{si}$$

the expected number of jobs in the queue at node i,

$$Lq_i = \sum_{s_i=1}^{K_i} (s_i - 1) P_{1s_i} + \sum_{s_i=1}^{K_i} s_i P_{0s_i} = L_i - \sum_{s_i=1}^{K_i} P_{1s_i}$$

P_{K_i}, P'_{K_i}, P_{qs_i} are depicts probability of having K_i jobs at the destination node i, feedback blocking probability in the expansion method and probability that there are s_i $(0 < s_i < K_i)$ jobs at node i and the server is either taking a vacation (q=0) or serving (q=1) respectively.

The throughput of the last node represents the throughput of the entire system.

4. Numerical Experimentation and Results

In this section we obtained system performance measures with various system parameters. The cost parameters and the routing probabilities in the remanufacturing module are given in Tables 1 and 2.

NOBAP rigorously on the remanufacturing network, shown in Figure 2., by comparing its performance against results obtained from exhaustive search. We present the numerical results that have been obtained for μ-balanced and γ-balanced cases in Tables 3and 4.

Table 1. Cost variables

$c_m = 25$	outside procurement/manufacturing cost.
$c_p = 4$	purchase cost of cores/item.
$c_{dis} = 5$	disassembly cost/item.
$c_{r3} = 3$	remanufacturing cost of station 3/item.
$c_{r4} = 2$	remanufacturing cost of station 4/item.
$c_{r5} = 3$	remanufacturing cost of station 5/item.
$c_{r6} = 1$	final inspection cost/item.
$c_h = 1$	on-hand serviceable inventory cost/item.
$c_l = 5$	lost sale cost/item.
$c_{rej} = 5$	penalty cost of rejected items from the system.
$c_t = 1$	testing cost/item.

Table 2. Routing probabilities p_{ij}

i / j	**3**	**4**	**5**	**6**
3	-	0.5	0.4	0.1
4	-	-	0.8	0.2
5	-	-	-	1
6	-	-	-	-

Table 3. μ-balanced and γ-balanced case with short vacations performance analysis: $\lambda_{ar} = 0.8,\ \ r = 0.6,\ \ \mu_i = 1,\ \ \gamma_i = 4,\ \ (i = 1,...,6)$

N	**Buffers**	**TC**	**Thr.**
7	(2-1-1-1-1-1)	27.645	0.198
8	(2-1-2-1-1-1)	28.102	0.215
9	(2-2-2-1-1-2)	29.119	0.247
10	(2-2-2-1-2-1)	29.795	0.262
11	(2-3-2-1-2-1)	30.534	0.278
12	(3-3-2-1-2-1)	31.093	0.289
14	(3-3-2-2-2-2)	31.787	0.334
16	(3-4-3-2-2-2)	32.745	0.360
20	(4-4-4-3-3-4)	33.926	0.406
24	(5-5-4-3-4-3)	34.622	0.418

Table 4. μ-balanced and γ-balanced case with long vacations performance analysis
$\lambda_{ar} = 0.8, \quad r = 0.6, \quad \mu_i = 1, \quad \gamma_i = 0.25, \quad (i = 1,...,6)$:

N	Buffers	TC	Thr.
7	(2-1-1-1-1-1)	25.038	0.071
8	(2-1-2-1-1-1)	25.292	0.079
9	(2-2-2-1-1-1)	26.520	0.101
10	(2-2-2-1-2-1)	26.720	0.109
11	(3-2-2-1-1-2)	27.513	0.125
12	(3-2-2-1-2-1)	28.534	0.129
14	(3-3-2-2-2-2)	29.119	0.167
16	(3-4-3-2-3-1)	30.046	0.153
20	(4-4-4-2-4-2)	31.956	0.226
24	(5-5-4-3-5-2)	33.526	0.250

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