January 01, 2001

Effect of reusable rate variation on the optimal buffer allocation for remanufacturing systems

Surendra M. Gupta
Northeastern University

Hasan K. Aksoy
Northeastern University

Bibliographic Information

Aksoy, H. K. and Gupta, S. M., "Effect of Reusable Rate Variation on the Optimal Buffer Allocation for Remanufacturing Systems", ***Proceedings of the 2001 Annual Meeting of the Northeast Decision Sciences Institute***, Pittsburgh, Pennsylvania, March 21-23, pp. 116-118, 2001.

Copyright Information

Contact Information

Dr. Surendra M. Gupta, P.E.
Professor of Mechanical and Industrial Engineering and
Director of Laboratory for Responsible Manufacturing
334 SN, Department of MIE
Northeastern University
360 Huntington Avenue
Boston, MA 02115, U.S.A.

(617)-373-4846 ***Phone***
(617)-373-2921 ***Fax***
gupta@neu.edu ***e-mail address***

http://www.coe.neu.edu/~smgupta/ ***Home Page***

EFFECT OF REUSABLE RATE VARIATION ON THE OPTIMAL BUFFER ALLOCATION FOR REMANUFACTURING SYSTEMS

Hasan Kivanc Aksoy, Northeastern University, Boston, MA 02115, (617)-373-7635, hkaksoy@coe.neu.edu
Surendra M. Gupta*, Northeastern University, Boston, MA 02115, (617)-373-4846, gupta@neu.edu
(*Corresponding author)

ABSTRACT

We investigate the effect of reusable rate variation of cores (used products) on the performance of buffer allocation plan for remanufacturing systems. We model the remanufacturing system as an open queueing network and use the decomposition principle and expansion methodology to analyze it.

INTRODUCTION

This paper addresses the important problem of buffer allocation in a remanufacturing system and the effect of reusable rate variation of returned products on the optimal allocation of a given number of buffer slots with the objective of minimizing the expected cost. Allocating the buffers among the different stations in a strategic manner can improve the performance of the system. To this end, we present a near optimal buffer allocation plan (NOBAP) developed for remanufacturing systems that requires modeling the remanufacturing system as an open queueing network with finite buffers and unreliable servers [1] and making use of decomposition principle and expansion methodology [5], [6], [9], [10].

LITERATURE REVIEW

We present a brief review of the literature in the areas of product recovery, remanufacturing and buffer allocation of unreliable production lines.

Gungor and Gupta [4] review the literature in the area of environmentally conscious manufacturing and product recovery. The first step of product recovery is disassembly. Disassembly is a methodical extraction of valuable parts/subassemblies and materials from post-used products through a series of operations. The problems associated with disassembly and scheduling have been investigated by [2], [7], [12], [13]. 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. The problems associated with remanufacturing have been addressed by [3].

Only a handful of algorithms have been developed for the buffer allocation problem with unreliable production lines and none has been reported for the remanufacturing systems. Hillier and So [8] use an exact analytical model to conduct a detailed study of machine breakdowns and interstage storage that affect the throughput of a manufacturing line. Seong et al. [11] modeled the problem as a multi-objective function which maximizes the throughput rate and minimizes the WIP inventory. Vouros and Papadopoulos [14] proposed a knowledge-based system which determines near optimal buffer allocation plan, with the objective of maximizing production line throughput.

MODEL DESCRIPTION AND THE ALGORITHM

The remanufacturing system considered here consists of three modules, viz., the disassembly and testing module for returned products, the disposition module for non-usable returns and the remanufacturing module. After the remanufacturing operation, items are directed to the serviceable inventory from where the demand is satisfied. A queueing network representation of a typical remanufacturing system is shown in Figure 1 [1].

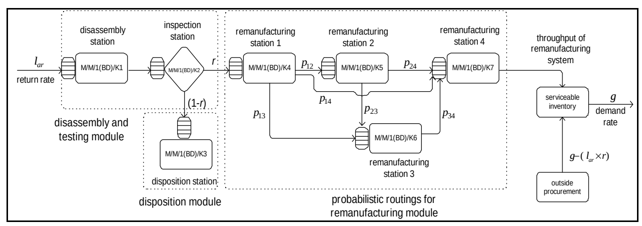

Figure 1. Remanufacturing network with unrelaible and finite buffer servers.

It is assumed that both return and demand processes are independent and their interarrival times are exponentially distributed with rates l_{ar} and g respectively ($g > l_{ar}$). Re-usable rate of the returned products is represented by *r*. There is one machine at each station and the buffer capacity at station *i* is represented by B_i. The service rate, m_i, of each station is exponentially distributed and the service discipline is First Come First Serve (FCFS). The machines are prone to breakdowns. The breakdown rate of a machine, a_i, and the repair rate for a broken machine, b_i, are also exponentially distributed. At the time of an arrival of an item at node *i*, either its buffer is not full and the item joins the queue or the buffer is full and the item cannot join the queue and stays where it originated from and blocks that node. The only exception is when the product first arrives to the disassembly station from outside. In that case, if the product finds the buffer full, it cannot enter the system and is considered lost to the system. The blocking mechanism in the system is 'block after service' (BAS). Note that outside procurement is needed to supplement any demand that cannot be satisfied by the remanufacturing system. When the demand is not satisfied, a lost sales cost is incurred. Similarly, when the demand is less than the inventory level, an inventory holding cost is incurred.

Decomposition principle and expansion methodology are used to analyze the queuing network. [5], [6], [9].

The total cost function for the remanufacturing system of the type shown in Figure 1 is as follows:

$$E(TC) = c_p E(RP) + c_d E(D) + c_t E(T) + c_{dis} E(Dis) + \sum_{i=1}^{4} c_{ri} E(Ri) + c_m E(OP) + c_{hs} E(Inv) + c_l E(Ls) + c_{rej} E(Rej)$$

where

- c_d : disposition cost/item.
- c_{dis} : disassembly cost/item.
- c_{hs} : on-hand serviceable inventory cost/item.
- c_l : lost sales cost/item.
- c_m : outside procurement/manufacturing cost.
- c_p : purchase cost of cores/item.
- c_r : remanufacturing cost/item.
- c_t : testing cost/item.
- c_{ri} : remanufacturing cost/item (i=1, 2, 3).
- c_{r4} : final inspection cost/item.
- c_{rej} : cost of rejected prod./item.
- *E(D)* : expected number of disposed products.
- *E(Dis)* : expected number of disassembled products.
- *E(Inv)* : expected number of on hand inventory.
- *E(Ls)* : expected number of lost sales.
- *E(OP)* : expected number of products procured from
- $E(R_i)$: expected number of remanufactured products
- *E(RP)* : expected number of returned products.
- *E(T)* : expected number of tested products.
- *E(Rej)*: expected number of rejected items.
- *r:* reusable rate of returned products.

The optimal buffer allocation problem can be expressed mathematically as follows.

Find B_i so as to

Min. *TC*

Subject to $\sum_{i=1}^{7} K_i = N$

where K_i is the job holding capacity at station i and N is the total number of buffer slots available in the system.

The methodology to obtain the near optimal buffer allocation plan (NOBAP) for remanufacturing systems with finite buffers and unreliable servers has the following steps:

Step 0: Read in the values of the following system parameters and cost variables:

$l_{ar},\ N,\ r,\ c_d,\ c_{dis},\ c_{hs},\ c_l,\ c_m,\ c_p,\ c_{ri},\ c_t,\ c_{rej}$

and $a_i,\ b_i,\ m_i \quad \forall i \ \ (i = 1, \ . \ . \ ., \ I)$.

Set j = 0 and $BA = \{ \ \}$.

Step 1: Allocate buffers to stations. Initial allocation of buffers $(\bar{k}_0)$ to various stations can be generated by a number of different strategies. One of the strategies is considering the efficiency of each station and associated buffer's priority in the remanufacturing line. The efficiency of station i (p_i) can be expressed as (Jeong and Kim, 1997):

$$p_i = \frac{m_i b_i}{(a_i + b_i)} \ , \ \forall i \ \ (i = 1, \ . \ . \ ., \ I).$$

Then the priority of station *i's* buffer (PR_i) is defined as follows:

$$PR_i = \sum_{\substack{all \\ u(i)}} \frac{s_{u(i)} \times r_{u(i)}}{p_{u(i)}} + \sum_{\substack{all \\ d(i)}} \frac{s_{d(i)} \times r_{d(i)}}{p_{d(i)}}$$

where $s_{u(i)}$ and $s_{d(i)}$ are the number of buffers connected to upstream and downstream stations of buffer i respectively. $p_{u(i)}$ and $p_{d(i)}$ are the efficiency of upstream and downstream stations. $r_{u(i)}$ depicts the routing probability from the upstream station to buffer i and $r_{d(i)}$ depicts the routing probability from buffer i to the downstream station.

To obtain the initial buffer allocation vector $(\bar{k}_0)$, the priority of all stations are normalized and total number of available buffer slots (N) are distributed as follows:

$$K_{i,0} = \left\lfloor N \times \frac{PR_i}{\sum_{i=1}^{I} PR_i} \right\rfloor \qquad \forall i \ \ (i = 1, \ . \ . \ . \ , I),$$

$K_{i,0} \geq 1, \ \ \forall i.$

where $\lfloor x \rfloor$ denotes the largest integer less than or equal to x.

$\bar{k}^* := \bar{k}_0$ and $\bar{k}_0$ is appended to the *BA* list,

where $\bar{k}^*$ is the optimal solution.

The remaining buffer slots, if any, are assigned to the first station to reduce the rejection rate of the returned products from the system.

Step 2: Calculate the system performance parameters $(TC,\ TH_i,\ TH)$ at $\bar{k}_j$ by utilizing the decomposition principle and the expansion methodology.

Step 3: Determine the difference between the buffer capacity and the average queue length at each station to move from the current buffer allocation to a new one $(\bar{k}_j \rightarrow \bar{k}_{j+1})$ as follows:

$$d_{i,j} = K_{i,j} - L_{i,j} \quad \forall i \ \ (i = 1, \ . \ . \ . \ I).$$

Identify $Max(d_{i,j})$ and $Min(d_{i,j})$ $(i=1, \ . \ . \ . \ I)$.

***Step 4**:* Select a new buffer allocation $\bar{k}_{j+1}$ as follows

At the station with $Max(d_{i,j})$, set $K_{i,j+1} = K_{i,j} - 1$.

Similarly, at the station with Min $(d_{i,j})$, set $K_{i,j+1} = K_{i,j} + 1$.

Step 5: If $TC(\bar{k}_{j+1}) < TC(\bar{k}^*)$ and $\bar{k}_{j+1} \notin BA$ <u>or</u>

if $TC(\bar{k}_{j+1}) = TC(\bar{k}^*)$ and $TH(\bar{k}_{j+1}) > TH(\bar{k}^*)$ and $\bar{k}_{j+1} \notin BA$,

then set $\bar{k}^* := \bar{k}_{j+1}$ and $j := j+1$,

and include $\bar{k}_{j+1}$ in the *BA* list and go to *step 2*.

Otherwise, go to *step 4* and consider the next $Max.(d_{i,j})$ and transfer the buffers accordingly.

Stopping Rule:

If the existing optimal solution $(\bar{k}^*)$ cannot be improved after certain number of iterations (predetermined), STOP.

NUMERICAL RESULTS AND CONCLUSIONS

We present some numerical results that were obtained by using NOBAP for the remanufacturing system in Figure 1 and compare them with the results obtained from exhaustive search. The cost variables were assumed to be as follows:

$$c_m = 25, \ c_p = 4, \ c_{dis} = 6, \ c_d = 5, \ c_{ri} = 5, \ c_{hs} = 1,$$

$$c_l = 5, \ c_t = 1, \ c_{rej} = 5.$$

The routing probabilities are:

$$p_{12} = 0.5, \ p_{13} = 0.4, \ p_{14} = 0.1, \ p_{23} = 0.8, \ p_{24} = 0.2.$$

In Table 1, columns 1-3 present the system parameters, columns 4 and 7 give respectively the total cost and the buffer allocation obtained using NOBAP, columns 5 and 8 give respectively the total cost, *TC**, and the optimal buffer allocation obtained using exhaustive search, and column 6 gives D_{TC}%, the absolute percentage difference between TC^* and *TC*, i.e.

$$D_{TC}\% = (|TC^* - TC|)/TC^* \times 100.$$

From the representative results given in Table 1, we can see that the performance of the algorithm, when applied to the example network is consistent, robust and produces good results in a variety of experimental conditions. We observe that when the core return rates are low, the effect of reusability rate on the total cost is low. However, as the core return rate becomes higher, the effect of reusability rate on the total cost is also higher. However, we note that the absolute error percentage rate is within the 10% range, which is considered acceptable for the performance of such algorithms.

Table 1. Comparison of the NOBAP and the optimal buffer allocation.

(l_{ar}, m_i, b_i, a_i)	*r*	*N*	*TC*	TC^*	D_{TC}%	(NOBAP)	Optimal Alloc.
(0.5, 1.2, 0.1, 1)	0.4	8	32.813	32.353	1.422	(1-2-1-1-1-1-1)	(1-1-1-2-1-1-1)
(0.5, 1.2, 0.1, 1)	0.6	8	30.315	29.795	1.745	(1-2-1-1-1-1-1)	(1-1-1-1-2-1-1)
(0.5, 1.2, 0.1, 1)	0.8	8	27.617	27.053	2.085	(1-2-1-1-1-1-1)	(1-1-2-1-1-1-1)
(0.7, 1.8, 0.2, 2)	0.4	10	34.669	33.652	3.022	(2-2-2-1-1-1-1)	(4-1-1-1-1-1-1)
(0.7, 1.8, 0.2, 2)	0.6	10	31.662	30.179	4.914	(2-2-1-2-1-1-1)	(1-1-4-1-1-1-1)
(0.7, 1.8, 0.2, 2)	0.8	10	27.652	26.462	4.497	(2-2-2-1-1-1-1)	(1-1-4-1-1-1-1)
(0.9, 1.2, 0.4, 1)	0.4	10	33.115	31.436	5.341	(2-2-2-1-1-1-1)	(1-1-1-4-1-1-1)
(0.9, 1.2, 0.4, 1)	0.6	10	28.36	26.314	7.775	(2-2-1-2-1-1-1)	(1-1-1-4-1-1-1)
(0.9, 1.2, 0.4, 1)	0.8	10	22.58	21.240	6.309	(2-2-2-1-1-1-1)	(1-1-4-1-1-1-1)

REFERENCES

[1] Aksoy, H. K. and Gupta, S. M., 1999, An open queueing network model for remanufacturing systems. in *Proceedings of the 25th. Conference on Computers and Industrial Engineering*, New Orleans, LA, March 29-31, pp. 62-65.

[2] Brennan, L., Gupta, S. M. and Taleb, K. N., 1994, Operations planning issues in an assembly/disassembly environment. *International Journal of Operations and Production Planning*, 14(9), 57-67.

[3] Guide, Jr., V. D. R. and Srivastava, R., 1997, Buffering from material recovery uncertainty in a recoverable manufacturing environment. *Journal of the Operational Research Society*, 48, 519-529.

[4] Gungor, A. and Gupta, S. M., 1999, Issues in environmentally concious manufacturing and product recovery: a survey. *Computers and Industrial Engineering*, 36(4), 811-853.

[5] Gupta, S. M. and Kavusturucu, A., 1998, Modeling of finite buffer cellular manufacturing systems with unreliable machines. *International Journal of Industrial Engineering*, 5(4), 265-277.

[6] Gupta, S. M. and Kavusturucu, A, 2000, Production systems with interruptions, arbitrary topology and finite buffers. *Annals of Operations Research*, 93, 145-176.

[7] Gupta, S. M. and Taleb, K. N., 1994, Scheduling disassembly. *International Journal of Production Research*, 32, 1857-1866.

[8] Hillier, F. S. and So, K. C., 1991, The effect of the coefficient of variation of operation times on the allocation of storage space in production line system. *IIE Transactions*. 23, 198-206.

[9] Kavusturucu, A. and Gupta, S. M., 1999, Analysis of Manufacturing flow lines with unreliable machines. *International Journal of Computer Integrated Manufacturing*, 12(6), 510-524.

[10] Kerbache, L. and Smith, J. M., 1988, Asymptotic behavior of the expansion method for open finite queueing networks. *Computers and Operations Research*, 15(2), 157-169.

[11] Seong, D., Chang, S. Y., Hong, Y., 1995, Heuristic algorithms for buffer allocation in a production line with unreliable machines. *International Journal of Production Research*, 33(7), 1989-2005.

[12] Taleb, K. N. and Gupta, S. M., 1997, Disassembly of multiple product structures. *Computers and Industrial Engineering*, 32, 949-961.

[13] Taleb, K N., Gupta, S. M. and Brennan, L., 1997, Disassembly of complex product structures with parts and materials commonality. *Production Planning & Control*, 8, 255-269.

[14] Vouros, G. A. and Papadopoulos, H. T., 1998, Buffer allocation in unreliable production lines using a knowledge based system. *Computers and Operations Research*, 25(12), 1055-1067.