Characterization of Prioritized Backordering for Slow Moving Spare Parts Inventory Control

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Abstract— The behaviour of prioritized backorders has been under-exposed in the literature as researchers rarely go beyond finding the proportions of backorders so as to enable the calculation of fill rate. Therefore, this paper used a high and low priority rationing spare parts inventory simulation model for slow moving parts using (S,S-1) policy to characterize the backorders. From the model, the results of the average number, mean response time and maximum queue length of backorders for four sensitive parameters (base stock level, critical stock level, high priority arrival rate and low priority arrival rate), were analysed. The results and analysis from this study will help in taking informed decision with regards to possible adjustment of inventory system so that huge backorder and consequently huge amount of money will not be tied down in inventory.

Index Terms— Backordering, Spare Parts Inventory, Slow Moving Parts, Mean Response Time, Average Number of Backorder

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1 INTRODUCTION

The major motivation that triggered off this study is the concern among some interested Mechanical and Industrial Engineers on the behaviour of prioritized backorders at varying conditions, following presentations of initial works [1][2] on criticality modeling of spare parts inventory with backorders. Generally, there are two major methods of taking care of inventory demands of different priorities that was not filled due to stockout. The first method is to model such demands in a lost sales environment. In this case, the inventory is easier to model because it avoids the complications arising from outstanding backorders for low priority customers and positive inventory levels reserved for high-priority customers [3]. The second method is to backorder the demand and fills it when enough replenishment order arrives. The type of model to adopt essentially depends on the condition of the system being modeled. Andersson et al [4] opined that it may be more representative to model stockouts as lost sales when the retailers are in a competitive market and customers can easily turn to another firm when purchasing goods. However, Grange[5] suggested that caution should be taken when lost sales environment is considered because the failure to capture information about lost sales of slow-moving items creates additional estimation challenge.

A stream of interesting studies in a prioritized inventory demands exist that do not consider backordering in their models but lost sales, like Axsater [6], Cohen et al. [7] and Melchiors et al [8]. Another stream of interesting studies exist that considered a mixture of backorders and lost sales for their inventory demands like Duran et al. [9] and Frank et al.[10]. Yet, there exist a third stream that considered completely prioritized backorder like Kocaga et al. [11], Okonkwo et al.[1], Mu-Chen Chen et al. [12] and Wan et al.[13]. This paper focuses on this third stream of research.

2 PRIORITIZED BACKORDERING AND CLEARING MECHANISM

Various criteria peculiar to systems being modeled must be used in differentiating/prioritizing the demand classes. Duran, S. et al.[9] considered a manufacturing environment serving two customer classes where one wants the item immediately and the second receives a discount to accept a delay. They showed that an ($S;R;B$) base stock policy is optimal under service differentiation, where S, R and B are the order-up-to, reserve-up-to, and backlog-up-to quantities. Deshpande et al. [14] formulated a similar one in which the two demand classes differ in delay and shortage penalty costs. Kleijn & Dekker [15] differentiated the demands by considering a situation that has two-echelon inventory system where the highest echelon (like warehouse) faces demand both from customers and from lower echelon stocking points (like retailers). Henaux & Semal [16] considered the same two-echelon inventory system where retailers are prioritized based on the countries where they are located, because of the varying needs and expectations that they have. Dekker et al [17] studied a large petrochemical plant in which the spare parts demands were prioritized based on the critical nature of the part demanded in sustaining the plant production in a safe and efficient way. Kocaga et al [11] used the same critical nature but based its criticality on whether it is a down order or for maintenance order.

Having differentiated the various inventory classes, one or a combination of inventory policies can then be put in place for allocating demands and for prioritizing the possible resulting backorder as a result of stockout. The most common is the use

of critical level policy. Another popular policy involves the variation of the replenishment lead time by using more than one mode like in Duran S. [9] and Wang et al [18]. Another can involve a combination of more than one policy like in Okonkwo et al [1]. Besides adopting a rationing policy in a service differentiated environment, formulation of models for clearing unfulfilled demands for those that incorporate backorders in their models is another challenge. In this regard, researchers have considered managing multiple demand classes through various clearing mechanisms. The simplest of the clearing mechanism is first backordered first cleared (FBFC), without any consideration on the priority of the backorder. This is unpopular in a service differentiated environment because it annuls the effect of service differentiation in the clearing mechanism process.

Even when it was implied by Grange [2] that models that consider backordering capture information on the backordered demands so as to show the behaviour of such demand at varying condition, but it was found that the capturing is tilted in one direction only. In this regard, the previous studies typically focused on single information, that is, finding the ratio of backordered and filled demands so as to calculate the stockout probabilities. Hence, very little and shallow research exists on the character of the backorder, beyond helping in the determination of the stockout probabilities. Even though this paper recognizes the very important nature of stockout probabilities, which is used in determining the service level or fill rate, however, there are some behaviours of backorders at varying conditions that require characterization, so as to give more insight into the entire system and consequently help spare parts inventory control managers in taking informed decisions.

3 MODEL FRAMEWORK

This paper is set out to simulate the characteristics of prioritized (high and low priority) backorders of spare parts inventory control of slow moving parts. Its analysis will focus on the results obtained for the average number of backorders, mean response time and maximum queue length. At each instance of simulation, one inventory parameter is varied while others are kept constant and the behaviour of backorders is determined throughout the incremental simulation. This was done for the four parameters used.

Table 1: Table of Codes and Meaning

S/N	Code	Meaning
1	CNHD	Cumulative No of High priority Demand
2	CNLD	Cumulative No of Low priority Demand
3	CNB1	Cumulative No of High Priority Backorder
4	CNB2	Cumulative No of Low Priority Backorder
5	DTLD	Due time of the Low Priority Demand
6	Lr	Replenishment Lead Time
7	Ld	Demand Lead Time
8	MQLB$_1$	Max Queue Length of High Priority Backorder
9	MQLB$_2$	Max Queue Length of Low Priority Backorder
10	MRTB$_1$	Mean Response Time of High Priority Backorder
11	MRTB$_2$	Mean Response Time of Low Priority Backorder
12	NB1	Current Number of High Priority Backorder
13	NB2	Current Number of Low Priority Backorder
14	NTHD	Next Time of High Priority Demand
15	NTLD	Next Time of Low Priority Demand
16	NTRO	Next Time of Replenishment Order
17	PI	Physical Inventory
18	S	Base Stock Level
19	S^*	Critical Stock Level

The explanation of the model of the simulation which was written in C.Net and the summary flowchart for the sub-routines of the model are presented in Figures 1, 2 and 3 are carried out in this section.
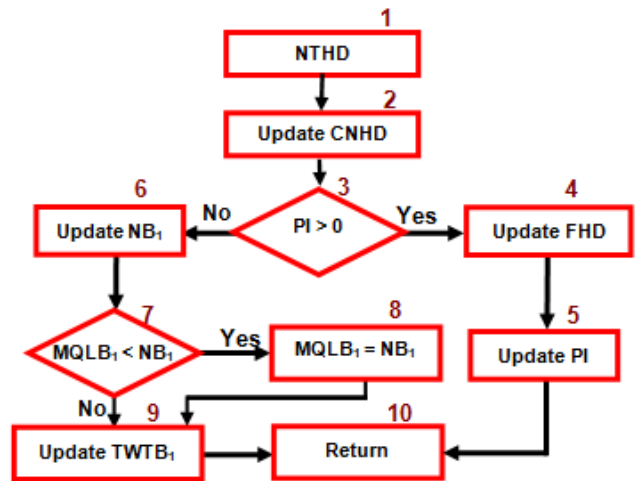

Fig. 1: Flowchart for Arrival of High Priority Demand

Fig 1 describes a typical sub-routine of the system which is the channel for next time of high priority demand. The arrival of a high priority demand will register in the simulation clock (module 1) while in module 2, it updates the cumulative number of high priority arrivals by adding the arrival that has just come to the previous arrivals. Thereafter, it will check whether the inventory is positive to fill the demand (module 3). If the inventory is positive, it will satisfy the demand (Module 4) and update the physical inventory in the system by reducing it as appropriate (module 5). On the other hand, if module 3 has no inventory to fill the demand, then the number of backorders is updated (module 6) by increasing the number of backorder appropriately. A decision module which will enable the updating of the high priority maximum queue length (module 7) and its subsequent update (module 8) is encountered and executed. Finally, the total waiting time of the backorder is

calculated (module 9) before the event is returned back to the centre schedule (module 10), in readiness to jump to the next time of event scheduled for execution, due to its stochastic nature.
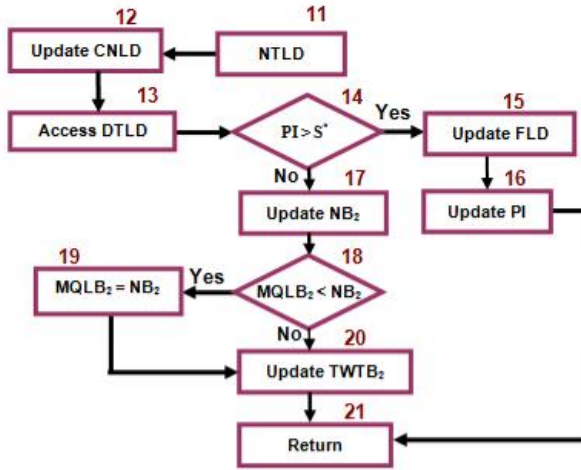

Fig. 2: Flowchart for Arrival of Low Priority Demand

In Fig 2, the low priority arrival is handled. On the arrival of a low priority demand, it will first register on the simulation clock (module 11) while the counter for cumulative number of low priority demands is increased (module 12). Due to the fact that a low priority arrival is not replenished immediately, (i.e. it requires a lead time) before it is filled, it will then access the lead time and update the simulation clock. Thereafter, it moves to module 14 where decision is taken on whether to fill the demand. In this case, not only the fact that there will be inventory, but the inventory must be greater than the critical stock, hence, the checking is done and if it is satisfied then the inventory is filled and the filled low priority demand (module 15) and the physical inventory (module 16) are updated by increasing and reducing them, respectively, accordingly. In contrast, if the demand cannot be filled, then the number of low priority backorders is updated (module 17) by increasing the backorder appropriately. By the same token, a decision module which will enable the updating of the maximum queue length (module 18) and its subsequent update (module 19) is executed. Finally, the total waiting time of the low priority backorder is calculated (module 20) before the event is returned back (module 21).
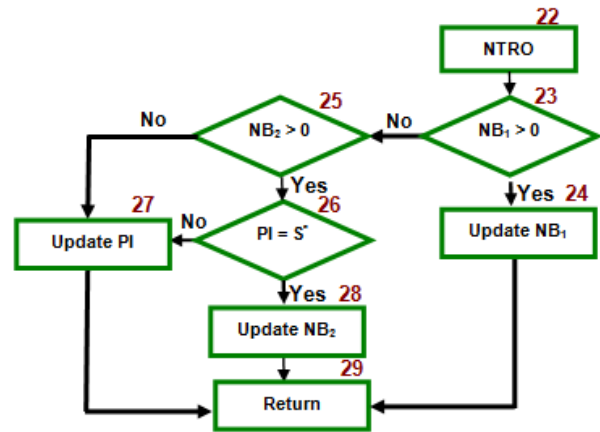

Fig. 3: Flowchart for the Replenishment of a Demand

The flowchart for the replenishment of demand, which is a sub-routine of the model is shown in Fig 3. On the arrival of a replenishment order (module 22), it checks whether there is a high priority backorder (module 23), if there is one, it takes a higher priority and therefore is immediately filled and the number of high priority backorder is consequently updated (module 24). However, if there is no high priority backorder, it checks again for a low priority backorder (module 25), it is cleared only if the physical stock is above S*, which is another decision module (module 26). If it is satisfied, then the number of low priority backorder is incremented (module 28) and the inventory is returned back (module 29). Otherwise, the physical inventory is incremented (module 27), before the event is returned back.

When the maximum time allocated for the simulation has exhausted for a given input parameter, then the values obtained which are stored are then used important results. Beyond the calculation of the fill rate which is the obvious objective of most inventory modelers in this regard, it will automatically calculate the average number of backorders for low and high priority backorders, the mean response time of the backorders for both using the total waiting time of the backorders as well as the maximum queue length of backorders.

4 RESULTS AND DISCUSSIONS

Each of figures 4a, 4b and 4c show the behaviour of the average number of backorders, mean response time of backorders and maximum queue length of backorders, respectively on the variation of the base stock level. The general trend of the three graphs is that as the base stock level increases, it decreases both the average number, mean response time and maximum queue length of backorders, which is logical and reasonable because every other parameter is kept constant. However, it will be observed that the low priority of each of the characteristics is more sensitive than that of high priority. This is because the low priority is always prone to being backordered as a result of the barrier facing it due to the critical stock level and priority clearing mechanism which it suffers. Consequently, increasing the base stock level is making additional stock provision which is used to fill a relatively larger portion of low priority which could have otherwise been backordered.

Fig 5a shows that the increase of the critical stock level favours the high priority demand as the average number of its backorder decreases correspondingly. But, it does so at the expense of the low priority demand as it can be seen that it deteriorates speedily (rapid increase in average number of backorders) as the critical level increases. The logic in analysing Fig 5a can be applied in the analysis of Fig 5b and Fig 5c, involving the mean response time and the maximum queue length of backorders, respectively. The maximum queue length of low priority backorders is observed to be highest at the highest critical stock level and lowest at the lowest critical stock level. The reverse is the case for the high priority backorders but the magnitude of its sensitivity at each perturbation is smaller in the later. As can be observed, at a critical stock level of 7, no backorder is witnessed; consequently, the values of the average number of backorders, mean response time of backorders and maximum queue length of backorders are zero.
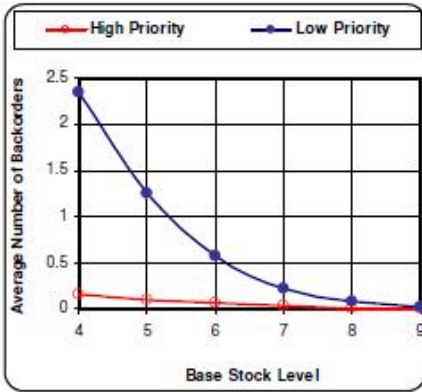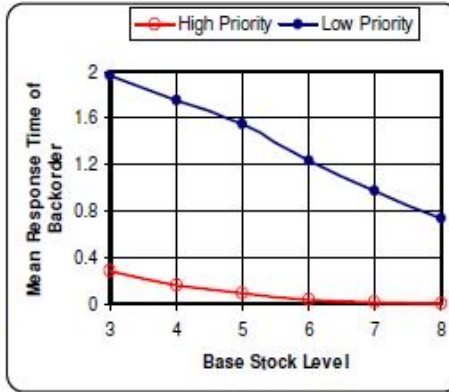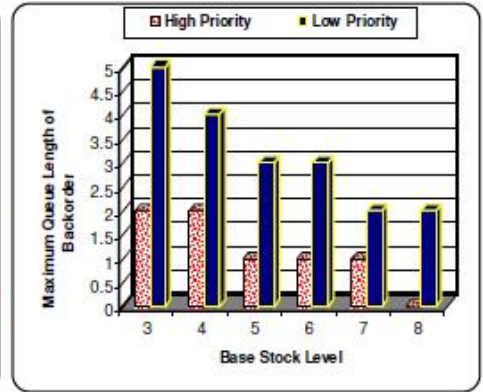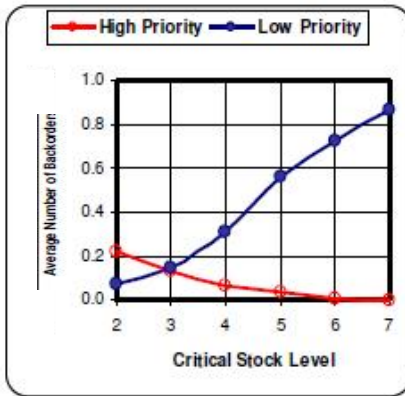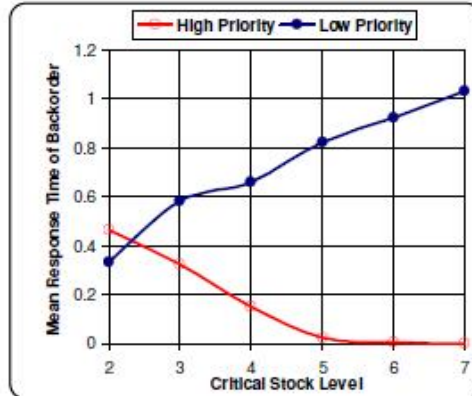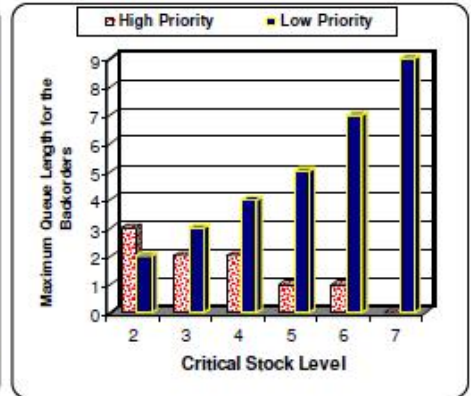
(4a)	**(4b)**	**(4c)**

Fig 4(a,b,c)   Prioritized Average Number, Mean Response Time and Maximum Queue Length of Backorders, each versus Base Stock Level
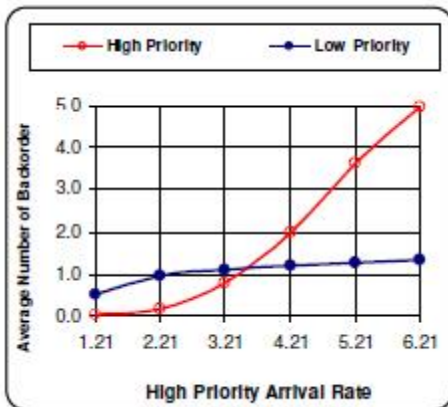

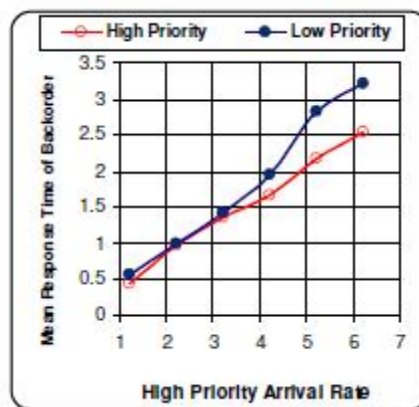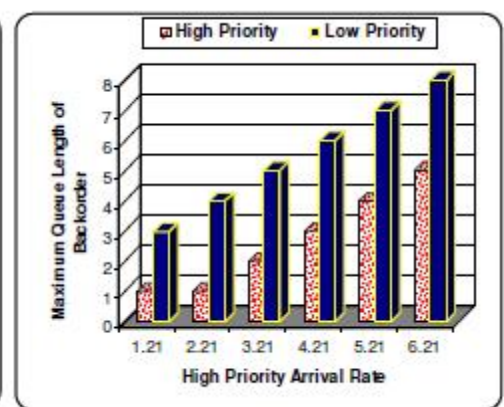|		
(5a)	**(5b)**	**(5c)**

Fig 5(a,b,c)   Prioritized Average Number, Mean Response Time and Maximum Queue Length of Backorders, each versus Critical Stock Level

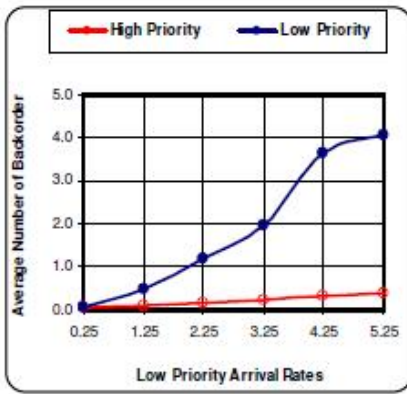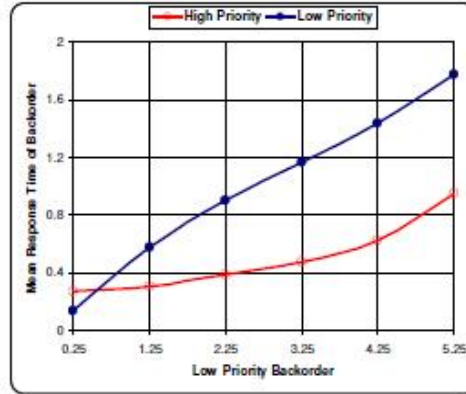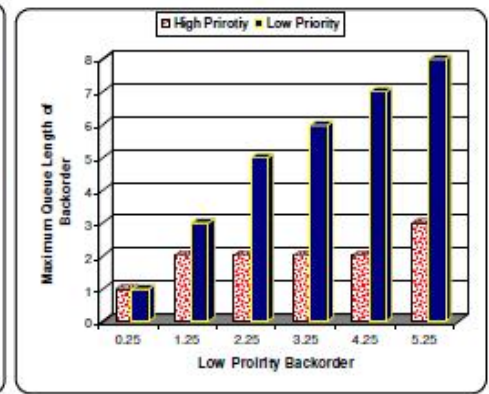|		
(6a)	**(6b)**	**(6c)**

Fig 6(a,b,c)   Prioritized Average Number, Mean Response Time and Maximum Queue Length of Backorders, each versus High Priority Arrival Rate
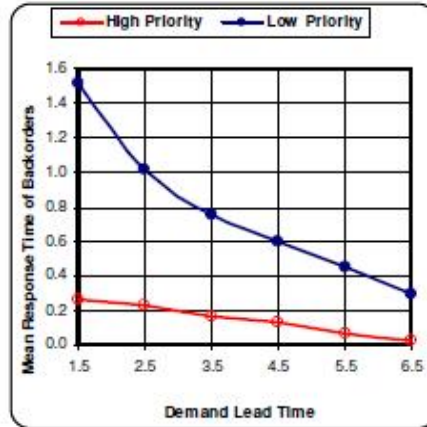
(7a)   **(7b)**   **(7c)**

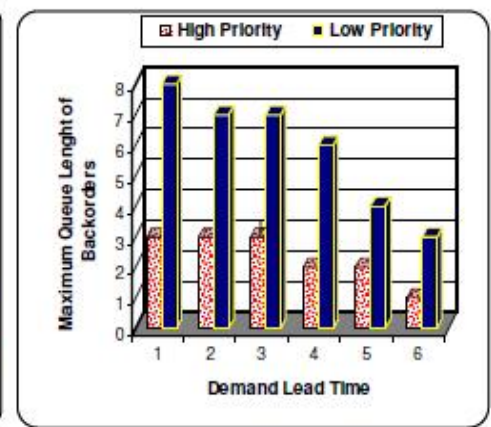**Fig 7(a,b,c)   Prioritized Average Number, Mean Response Time and Maximum Queue Length of Backorders, each versus Low Priority Arrival Rate**
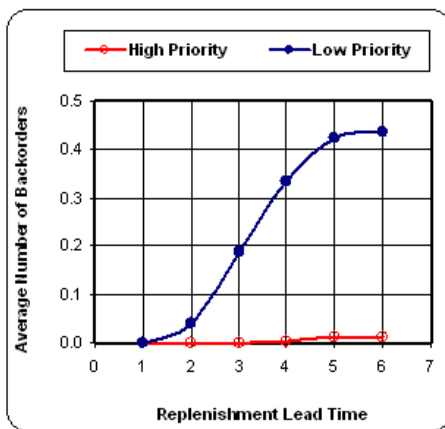

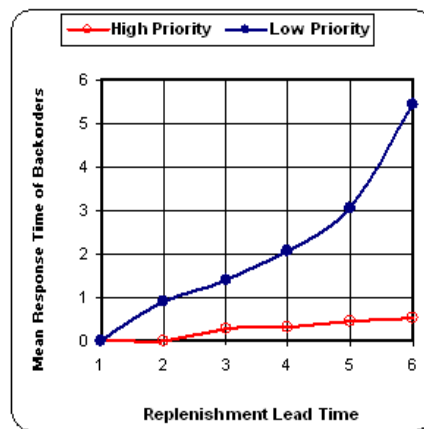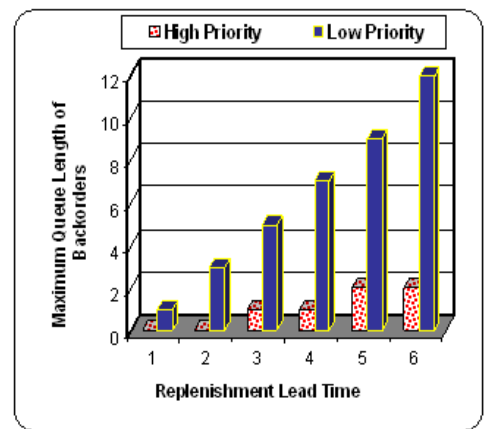**(8a)**   **(8b)**   **(8c)**

Fig 8(a,b,c)   Prioritized Average Number, Mean Response Time and Maximum Queue Length of Backorders, each versus Demand Lead Time

(9a)   **(9b)**   **(9c)**

Fig 9(a,b,c)   Prioritized Average Number, Mean Response Time and Maximum Queue Length of Backorders, each versus Replenishment Lead Time

In Fig 6a, the average number of high priority backorders which were initially less than that of low priorities, met and overtook it as high priority arrival rate increases. This is essentially because the cushioning effect that the critical stock level and priority clearing mechanism that could otherwise ensure that a small number of high priority backorder is witnessed, can no longer withstand the increase of the high priority rate. From Fig 6b, the mean response time of backorders increases for both priority demands, as the high priority arrival rates increases. By the same token, the maximum queue length of both priority demands increases as the high priority arrival rate increases as shown in Fig 6c. The reason is because increasing the rate of high priority demands brings additional demand, which has to be accommodated. The relatively uniform rise of the mean response time and maximum queue length of backorders is because what the low priority demands lost through rationing the high priority lost by having own additional demands.

Increasing the low priority arrival rate causes the average number of backorders in both low priority and high priority demands to increase as shown in Fig 7a. However, the sensitivity of high priority backorder as a result of the increment is very little compared with that of the low priority backorder because of additional burden that the increasing rate causes at the detriment of the low priority demand. The mean response time of backorders increases with increase in low priority demands and is shown in Fig 7b. However, it is more pronounced in low priority than in high priority demands. Fig 7c shows that the maximum queue length increases for both priorities as the arrival rate of low priority demands increases, but more pronounced in low priority demands.

On a general note the introduction of a demand lead time, reduces backorders. The average number of backorders, mean response rate of backorders and maximum queue length of backorder decreases as the demand lead time increases as shown in Figures 8a, 8b and 8c, respectively. It can be noted that notwithstanding that the demand lead time is observed only in the low priority demand, but the impact is felt also on the low priority demands. However, this impact is very small in the high priority demands than on the low priority demands. This is essentially because of the more impact (i.e. with regards to sensitivity) which the demand lead time has on the low priority demands than on that of the high priority.

Increasing the replenishment lead time increases the average number, mean response rate and maximum queue length of backorders for both high and low priority demands as can be seen from figures 9a, 9b and 9c. The sensitivity is far more pronounced in the low priority than in the high priority class. The reasons are: the high priority demand is naturally modeled to be filled more often than the low priority demand, through the process of rationing. Therefore, the backorder that occurs as a result of the increment of the replenishment lead time will naturally fall harder on the low priority demands.

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