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Understanding the Cause of Back-Orders in Logistic Systems

Christoph Roser
Masaru Nakano
Minoru Tanaka
Toyota Central Research and Development Laboratories
Nagakute, Aichi 480-1192, JAPAN

ABSTRACT

Logistic systems transport parts between different production locations and to the customers, with the goal to supply the customer with the parts he needs when he needs it. Ideally, there are always exactly as many parts available at any given time as requested by the customer. If the demand temporarily exceeds the supply, a stock-out occurs, resulting in back-orders. Back-orders can be reduced by increasing inventory. The resulting improvement in customer satisfaction and sales however is offset by the increase in inventory and the time to market. This paper provides a method to understand the causes of back-orders and to improve the allocation of inventory with respect to stock-outs and inventory cost using the example of a in-plant logistic system.

INTRODUCTION

Logistic systems organize the transport of parts from the source location to the destination. If the logistic system is unable to satisfy the demand for parts at the destination, a back-order occurs, also known as a stock-out. This is a very unfavorable situation, as it leads to idle equipment, waiting customers, or lost sales. In worst cases, it can even cause customers to switch to a different supplier, losing not only the current sale but also all future sales with this customer (Lambert 1998). Therefore, one aim of logistic systems is to avoid back-orders.

This paper describes a method to determine the causes of back-orders in logistic systems, based on a analysis of the blocking and starving events within the system (Roser 2003a). The example system is an in-factory logistic system consisting of 4 machines M1 to M4 connected by conveyor belts and two different parts, A and B, as shown in Figure 1. Orders arrive at machine M1, which then processes the corresponding parts. Parts of type A proceed to machine M2, and parts of type B proceed to machine M3. The transportation is done by conveyor belts with a fixed capacity and speed. All machines have an uniform distributed cycle time, and all conveyors have a constant speed as shown in Table 1.

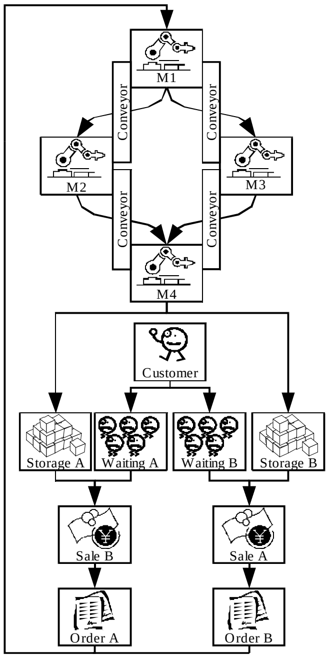

Figure 1: AGV System

Entity	Cycle Time (Minutes)	Distribution
M1	[5,8]	Uniform
M2	[7,11]	Uniform
M3	[17,27]	Uniform
M4	[5,8]	Uniform
ConvToM2	2	Constant
ConvrToM3	2	Constant
ConvFromM2	2	Constant
ConvFromM3	2	Constant

Table 1: Machine and Conveyor Parameters

After the processing is competed at machine M4, the parts are stored and wait for customers. Customers arrive with an exponentially distributed inter arrival time with a mean of 8.3 minutes. 70% of the customers seek a part of type A, and 30% of the customers seek a part of type B. If a part of the desired type is in stock, the customer purchases the part and leaves. If there is a stock-out, the customer waits until the next part becomes available, i.e. a back-order occurs.

The system is a pull-system, as the orders are generated based on the sales, with the aim to have a constant work in progress (WIP). By default, there is a WIP of 10 parts of type A and 5 parts of type B, including the completed stock. However, if back-orders occur, each back-order generates an additional orders to satisfy the demand more quickly. For example if there are 3 back-orders for part type A, the allowable WIP of part type A is not 10 but 13.

To reduce the number of back-orders, the capacity of the conveyors can be adjusted in order to improve the response time, i.e. the makespan from the order to the completion after machine M4. Initially, all conveyors have a capacity of 1, meaning that if there is one part on the conveyor, no further parts can be loaded until the current part is unloaded. The next section describes the performance of the initial system

BEHAVIOR OF THE INITIAL SYSTEM

The initial system has been simulated for 200,000 minutes excluding a warming up period of 1,000 minutes, producing 17,000 parts of type A with one part every 11.79 minutes and 7,700 parts of type B with one part every 26.93 minutes. While the system is able to satisfy the demand by the customers in the long term, there might be temporal stock-outs due to the high variability of the customer inter arrival time. Figure 2 shows the available stock and the stock-outs for part type A over a short period of time. While usually there are parts available, sometimes the demand exceeds the supply and back-orders occur. Table 2 shows the summary of the back-orders for the two part types.

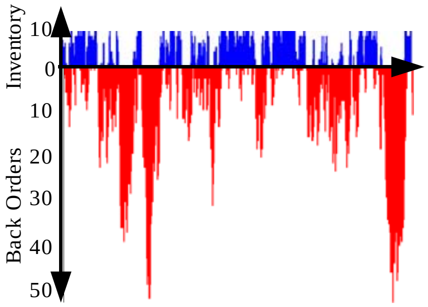

Figure 2: Stock and Back-orders of Part A

Part Type	Back-orders	
	Average	Maximum
A	6.01	54
B	2.67	24

Table 2: Back-orders of Initial System

UNDERSTANDING BACK-ORDERS

In the long term, the system is able to satisfy the demand of the customers. Only for short periods of time the demand exceeds the supply because the system cannot produce parts fast enough. Investigation showed that with unlimited demand the system is able to provide one part of type A every 11.35 minutes and one type of part B every 25.94 minutes. If the arrival rate of the customers temporarily exceeds this production rate, stock-outs may occur.

One way to avoid this is to increase the allowable WIP, i.e. to increase the buffer to handle rapidly arriving customers. However, an increase in WIP causes an increase in inventory cost, storage cost, and the makespan, and is therefore in general undesirable. This paper focuses instead on the increase in the conveyor capacity. Adding conveyor capacity can usually be done at a reasonable cost, and since this pull system has a limited WIP the increased conveyor capacity does not lead to an increase of the WIP.

To find the optimal conveyor configuration the system was analyzed using the bottleneck detection method (Roser 2002; Roser 2003b) and a slightly modified buffer analysis method (Roser 2003a), were the conveyors are considered to be buffers. Figure 3 shows the bottleneck probabilities of the four machines. Machine M3 is the main bottleneck, followed by machine M2. Therefore, the improvement of the logistic system should aim to provide more parts to the main bottleneck to reduce the idle time of the main bottleneck. Core point of this analysis is the blocking and starving analysis, determining the cause of every idle period of every machine. Figure 4 shows the causes of the blocking and starving for every machine in 4 different system layouts similar to Figure 1. For example, in the layout in the upper left corner, machine M1 is highlighted. Machine M1 is starved by the order process and blocked by machines M2 and M3. Sometimes machine M1 is blocked by machine M4 through M2. Similar, in the layout in the upper right corner, machine M2 is mainly starved by machine M1, which in turn is sometimes starved by machine M3 such that machine M3 starves M2.

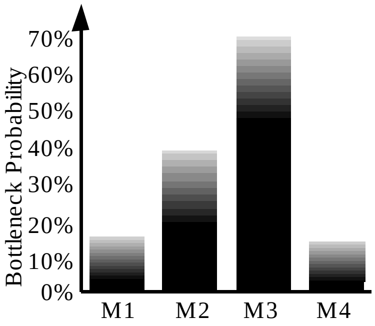

Figure 3: Bottleneck Probability

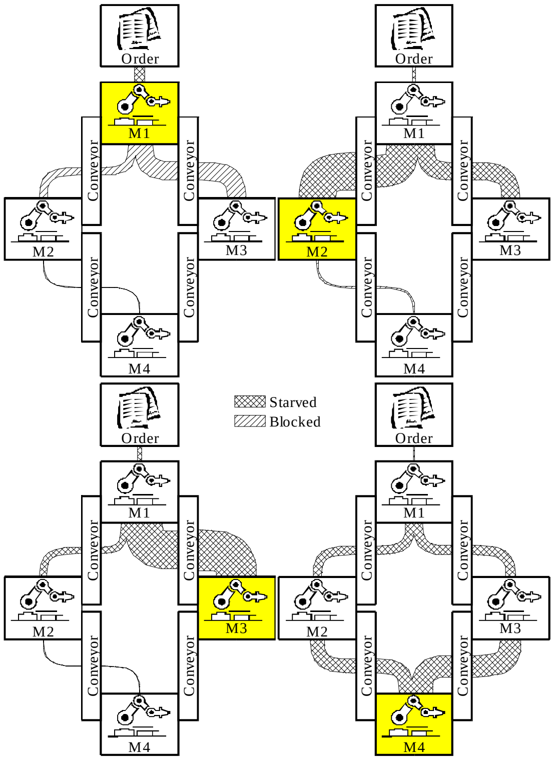

Figure 4: Blocking and Starving Analysis

Figure 4 also shows that machine M3 is mainly starved through the conveyor to machine M3. Therefore, it is estimated that an increase of the conveyor capacity before machine M3 would have the largest effect onto the entire system, improving the system performance and reducing the number of back-orders.

IMPROVING THE SYSTEM

The buffer analysis method is able to predict the improvement of the throughput due to a buffer increase for push manufacturing systems reliably. However, the presented system is a pull system with a limited WIP, and the performance measure are the back-orders. Furthermore, since the presented pull system has a fixed demand, the long term throughput will always be identical with the demand. The buffer analysis method therefore cannot predict the exact reduction in the back-orders, and the theoretical predicted improvement of the throughput for a push system is not realized due to the limited demand of the pull system.

However, the predicted throughput improvement can be used to estimate the significance of the different conveyors in the presented system. An increase in the throughput may not be realized in the long term, but is very useful for short term spikes in the demand, as this increased throughput is more able to satisfy a temporarily increased demand. Therefore, the stock is depleted slower, replenishes faster, stock outs are less common, and the number of back orders is reduced, both the average and the maximum number of back orders. Figure 5 shows the estimated predictions of the throughput for different conveyor capacities, even though the throughput improvement is not realized due to the limited demand. This prediction model can be used as a guideline for the allocation of the conveyor capacity.

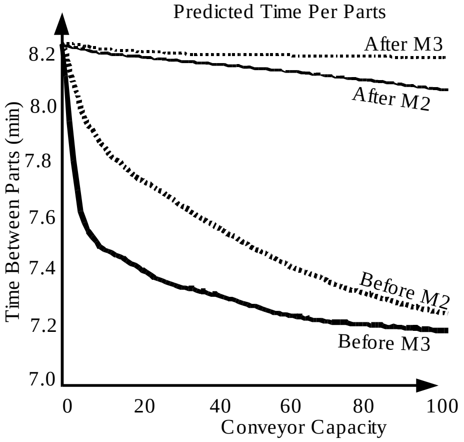

Figure 5: Theoretical Predicted Time Per Part

Figure 5 shows that the conveyor before machine M3 has the largest effect onto the system performance, followed by the conveyor before machine M2. The conveyors after the machines M2 and M3 have only a negligible effect on the throughput.

EXPERIMENTAL RESULTS

To verify if the behavior of the conveyor increase was estimated correctly, a number of simulations have been performed for various conveyor capacities. Figure 6, Figure 7, Figure 8, and Figure 9 show the results of these simulations for the different conveyors. While these figures show the mean number of customers waiting for conveyor capacities between 1 and 10 parts, and Figure 5 shows the time between parts for conveyor capacities between 1 and 100 parts, the shapes are very similar because the improvement in the throughput is directly correlated to the reduction of the number of back orders. As expected, the increase in the conveyor capacity of conveyor BM3 had the largest effect as shown in Figure 7, followed closely by the conveyor BM2 shown in Figure 6. The capacity increase of conveyor AM2 in Figure 8 showed only a small improvement for an increase to 2 spaces, and no further improvement thereafter. An increase in conveyor AM3 showed no improvement at all as shown in Figure 9.

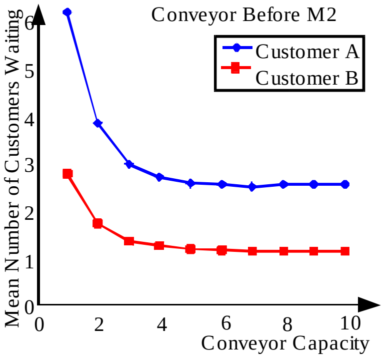

Figure 6: Increasing Conveyor before M2

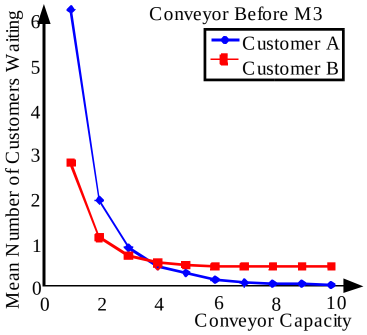

Figure 7: Increasing Conveyor before M3

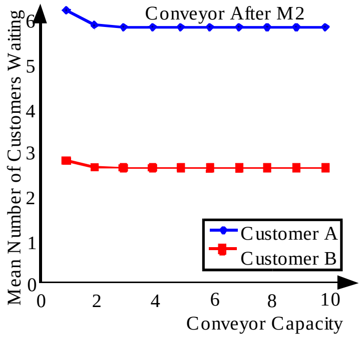

Figure 8: Increasing Conveyor After M2

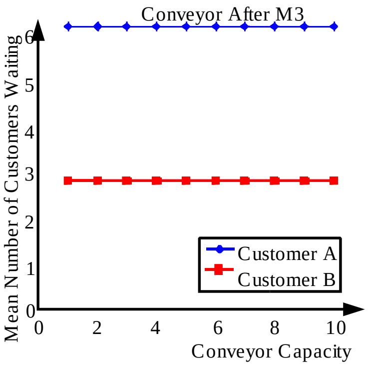

Figure 9: Increasing Conveyor After M3

This data correlates very well with the data shown in Figure 5. The best way to reduce the number of back-orders is to increase the capacity of the conveyor before M3. This will reduce the number of back orders to near-zero.

The conveyor before machine M2 is also significant, but less so than the conveyor before machine M3. Increasing this conveyor capacity can reduce the number of back orders to about ½ of the previous level. Increasing the conveyor after machine M2 by one space shows a minimal improvement in the back-orders, but further increases do not improve the system any further. Increasing the capacity of the conveyor after machine M3 has no effect whatsoever. Therefore, the suggestion would be to improve the conveyor before machine M3, and maybe also improve the conveyor before machine M2 to eliminate most back-orders.

SUMMARY

While the bottleneck detection method and the buffer analysis method was initially developed for manufacturing systems, it can also be applied to enhance the understanding of logistic systems. The presented paper shows how these methods can be used to develop a deeper knowledge of a logistic system with the aim to reduce the number of back-orders.

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The method has been implemented into an automated analysis tool *TopQ Analyzer* to analyze the simulation history files and automatically generate an excel spreadsheet containing the analysis results in numeric and graphical form.

Further development is in progress to improve the prediction for logistic systems to not only determine the significance of the individual stages of the logistic system but also provide a numeric prediction of the estimated performance measures.

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