Push Can Perform Better than Pull for Flexible Manufacturing Systems with Multiple Products

Ananth Krishnamurthy and Rajan Suri
Center for Quick Response Manufacturing, University of Wisconsin-Madison
1513 University Avenue, Madison, WI 53706-1572

Mary Vernon
Department of Computer Sciences, University of Wisconsin-Madison
1210 W Dayton Street, Madison, WI-53706

Abstract

We study the performance of a flexible manufacturing line producing multiple products under different material control strategies. Specifically, we compare the throughput versus average inventory characteristics when the line operates under *pure pull* and *pure push* strategies. Using simulation we show that the pure push strategy has a higher throughput for a given level of inventory than the pure pull strategy in systems with product mix changes affecting demands and processing times of the different products. The better performance of the pure push strategy suggests that specific hybrid (push/pull) strategies might be required to control production on such lines.

Keywords

Production control, performance evaluation, MRP, kanban, push systems, pull systems

1. Introduction

In the last decade there has been considerable interest in the study and analysis of production control strategies for manufacturing systems. These studies classify production control strategies as either *push* or *pull* driven. The most common quoted examples of push and pull systems are the forecast driven MRP systems and the kanban systems respectively. The successful implementation of kanban systems as well as analytical studies done on simplistic lines have led to the belief that pull systems are generally superior. Our experience with some companies struggling to implement kanban systems leads us to believe that the pull systems are fundamentally handicapped for certain manufacturing environments [1]. Through this research we compare the performance of push and pull strategies in these environments.

In the *pure pull* strategy, such as the typical kanban control system, production is triggered only in response to actual consumption of inventory. In addition, the pure pull strategy imposes a bound on the inventory of each product at each machine. On the other hand, in the *pure push* strategy, production is triggered based on due dates of customer orders or desired restocking to inventory levels. Unlike the pull strategy, the push strategy does not impose any bounds on the inventory at each machine.

Qualitatively, we argue that pure pull will require that at least a minimum inventory of each product be maintained at each machine for the system to function. This makes it impractical for lines manufacturing a large variety of engineered to order or custom products. Also, pure pull was initially designed for manufacturing environments producing repetitive products with stable demands. In such environments, using current inventory consumption as a proxy for future demand is not a very restrictive assumption. However, in environments with changing product mix, infrequent orders or custom jobs, this might not be a reasonable assumption. Hence, the pure pull system might not work well in such environments. On the other hand, the production triggers in the push strategy are based on due dates of customer orders or desired inventory levels. Therefore, the pure push system appears to be better equipped for environments with changing product mix, infrequent orders or custom jobs.

To investigate further these arguments, we compare the performance of pure push and pure pull systems for a flexible manufacturing system producing multiple products. As of this paper our comparisons are through simulation. In our ongoing work we are developing queuing theory models to support our simulation results. We consider a serial production line producing multiple products. We study the performance of the system for product mix changes affecting demands and processing times of the different products. Such variability is very common in lines manufacturing engineered-to-order or custom products. A description of the system and the main assumptions is given in the next section. The description of the experiments is given in section 3 and the results are summarized in section 4. Finally we present our conclusions in section 5.

2. System Description

We consider a serial production line with 3 machines (*j*=1,2,3) manufacturing 8 different products (*i*=1,…,8) as shown in Figure 1. We make the following assumptions.

- Customer demands for the 8 products are independent Poisson processes.
- The processing times at the machines are exponentially distributed.
- There is sufficient supply of raw material before the first machine.
- Setup times are negligible on all machines and for all products.
- Unsatisfied demands get backlogged.

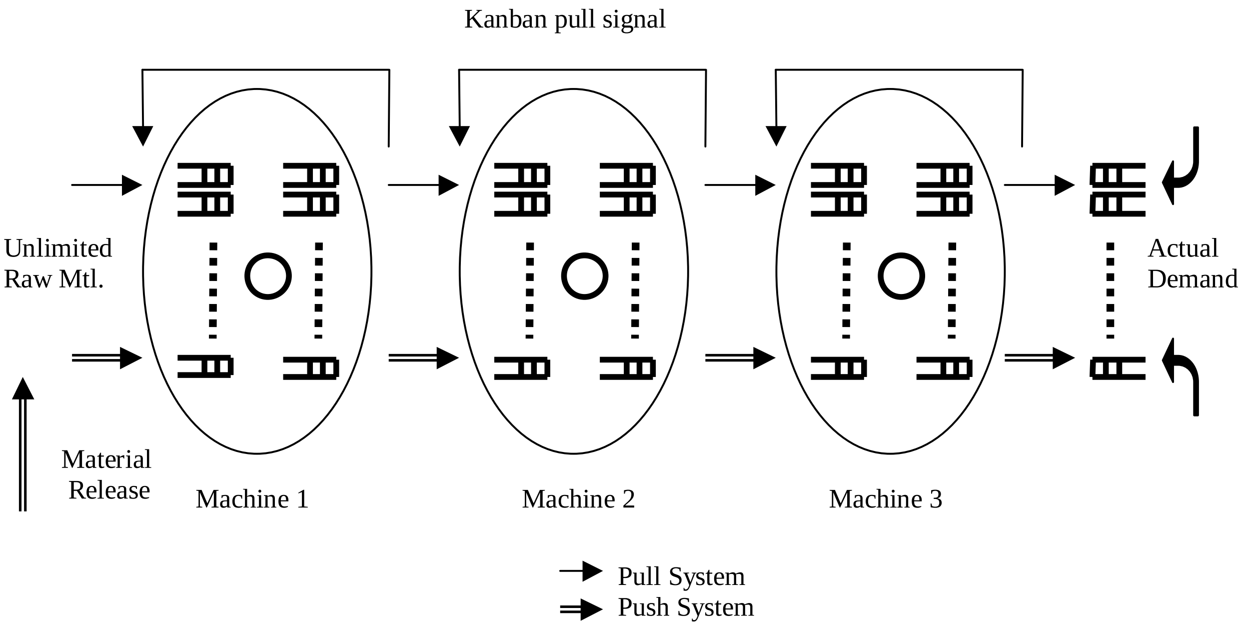

Figure 1. Schematic of the system

We next describe the operation of the pure pull and pure push strategies in our simulation experiments.

Pull strategy: Initially all the kanban cards are attached to finished parts at the output buffer of each machine. The production trigger originates at the end of the manufacturing line in response to an actual customer demand. Customer demand is satisfied from the output buffer of machine 3 and this releases a kanban card triggering production at machine 3. This triggers a sequence of releases of kanban cards triggering production at machines 1 and 2. In the pull strategy, therefore, kanban cards play the dual role of controling inventory as well as triggering production and thereby determining the throughput for the different products. For our simulation experiments, we model the customer demands as a Poisson stream. We increase the number of kanbans in the system and observe the average inventory corresponding to the different values of throughput.

Push strategy: The production trigger originates at the beginning of the line in the form of raw material release at machine 1 for the different products. The release rate of raw material is based on due dates of various orders or restocking to desired inventory levels for the different products. Once material is released into the system at machine

1, it is simply pushed through the subsequent machines. In the push strategy, therefore, it is the release rate of the material determines throughput of the line as well as the inventory of various products at each machine. For our simulation experiments, we model the material release as a Poisson stream. As we increase the material release rates, throughput as well as the average inventory for the different products increase. We observe the average inventory corresponding to the different values of throughput.

We define,

S_{ij} = the mean processing time for product i at machine j (i=1,…,8 and j = 1,2,3)

D_i = the mean demand rate for the product i, i=1,…,8

We assume that initially the line is well balanced and set

S_{ij} = 1 for all i and j

D_i = 1/8 for all i for the pull system

= D/8 for all i for the push system ,where D ranges from 0.5 upto 1.0.

Note that for this case, all the products have identical demand (or release rate) and service time parameters, there is no one bottleneck in the system, and the maximum total throughput of the system is 1 product/unit time.

For the push strategy, since release rate is a control parameter, we run simulation experiments for different values of D ranging from 0.5 to 1.0, and observe corresponding average inventory in the system. However, for the pull strategy, we are interested in the maximum throughput of the system for any given number of kanbans. We therefore need to assume that there are sufficient customer demands waiting for the finished goods and set D_i =1/8 for the pull system.

3. Impact of Changes in Product Mix

Our aim is to compare the performance of the system when subject to product mix changes while operating under pure push and pure pull control strategies. To study the effect of product mix changes, we study the change in system throughput for changes in the relative ratios of mean demand rates and mean processing times for various products. The mix changes we consider here would typically occur in the short term, say, over a week. For example, in a given week, cyclical demands, machine outages or other random disruptions could cause the line to produce parts that differ from each other in terms of processing times at various stations, demand rates or both. Over such short periods, we do not change our kanban allocations but expect the system to cushion against such variability.
For our simulation experiments, we assume,

D_i = λ_1 for i=1,…, 4

= λ_2 for i=5,…, 8

S_{ij} = τ_1 for i=1,…,4 and all j

= τ_2 for i=5,…,8 and all j

For the sake of comparison, we choose these parameters such that:

$$\text{Total demand for all products} = 4\lambda_1 + 4\lambda_2 = D \quad (1a)$$

$$\text{Total demand for all products} = 4\lambda_1 + 4\lambda_2 = 1 \quad (1b)$$

And,

$$\text{Expected service time at each machine} = \frac{\left(4\lambda_1\tau_1 + 4\lambda_2\tau_2\right)}{4\lambda_1 + 4\lambda_2} = 1. \quad (2)$$

Equation 1a is specific to the push strategy while equation 1b is specific to the pull strategy. They ensure that although we change the product mix, the total load on the system still remains the same as in the case of our initial balanced system. Equation 2 ensures that our product mix changes do not introduce any new unique bottlenecks in the system.

Additionally, by defining, $\lambda_1 = k1\,\lambda_2$, and $\tau_1 = k2\,\tau_2$ for some $k1, k2>0$, and using equations 1a (or 1b) and 2, we can express λ_1, λ_2, τ_1 and τ_2 in terms of $k1$ and $k2$. Note that $k1$and $k2$ reflect the relative ratios of the demand and processing times of the different products. By setting different values for $k1$and $k2$, we capture a wide spectrum of changes in product mix. Although we change the values of the processing times and demand rates, our constraints ensure that we are not introducing bottlenecks into the system. In addition, if $k1$and $k2$ are chosen such that $k1k2=1$, the utilization of each machine by each product is the same.

3.1 Simulation Details

The simulation study is carried out using PROMODEL. The results are taken from 6 independent simulation runs which represent the production of 30000 batches of products. The inventory in the input and output buffers of all the machines were considered for computing the average inventory in the system.

The graph of throughput against average inventory in Figure 2 compares the performance of push and pull strategies for different product mixes (corresponding to $k1$=1/5, 1, 5 and $k2$=1/5, 1, 5). Notice that by symmetry, we only need to consider the 5 of the possible 9 cases, namely when ($k1$, $k2$) equal (1, 1), (1,1/5), (5, 5), (5,1) and (5, 1/5). For example, the cases (1/5, 1/5) and (5, 5) yield identical results as in both the cases the demand and the processing times for one set of products is 5 times that of the other. Also, our initial system corresponds to the case when $k1$=1 and $k2$=1.

4. Results

Product mix changes affecting processing times and demand rates for products increase the variability in the system. The increased variability would necessitate additional inventory in the system to meet the required throughput, regardless of whether the line operates under pure push or pure pull strategies. However, our simulation studies show that product mix changes have a more significant impact on systems operating under the pure pull strategy.

For the single product system, we know that for any given throughput the pull system requires lesser average WIP than an equivalent push system [2]. However, Figure 2 indicates that this is not true for multi-product systems. Since the pure pull system requires kanbans for every product at every stage, there is a minimum average WIP for each product in the system irrespective of the throughput desired. We call this the *resident WIP*. This resident WIP is capable of yielding relatively high throughputs (about 70-85% of the maximum throughput in our experiments). In cases where seasonal trends require that the system operate at 50-75% of its capacity for certain periods of time the system has no option but to carry the resident WIP for each product. Comparatively, in the push strategy, the minimum WIP level is zero. The push strategy introduces WIP only according to the throughput desired of the system. Thus, for moderate throughput requirements, the pure push system is leaner, *i.e.* has less wasteful inventory than a kanban system.

In the presence of product mix changes, the performance of the pull strategy deteriorates even for high throughput requirements. The graphs in Figure 2 show the gradual deterioration of pull strategies for different product mix changes. Consider especially the case when $k1$=5, $k2$=1/5, *i.e.* $k1k2$=1. In this case, although the product mix changes do not alter the relative utilization of machines for different products, the pure pull strategy requires more inventory for *all* values of throughput.

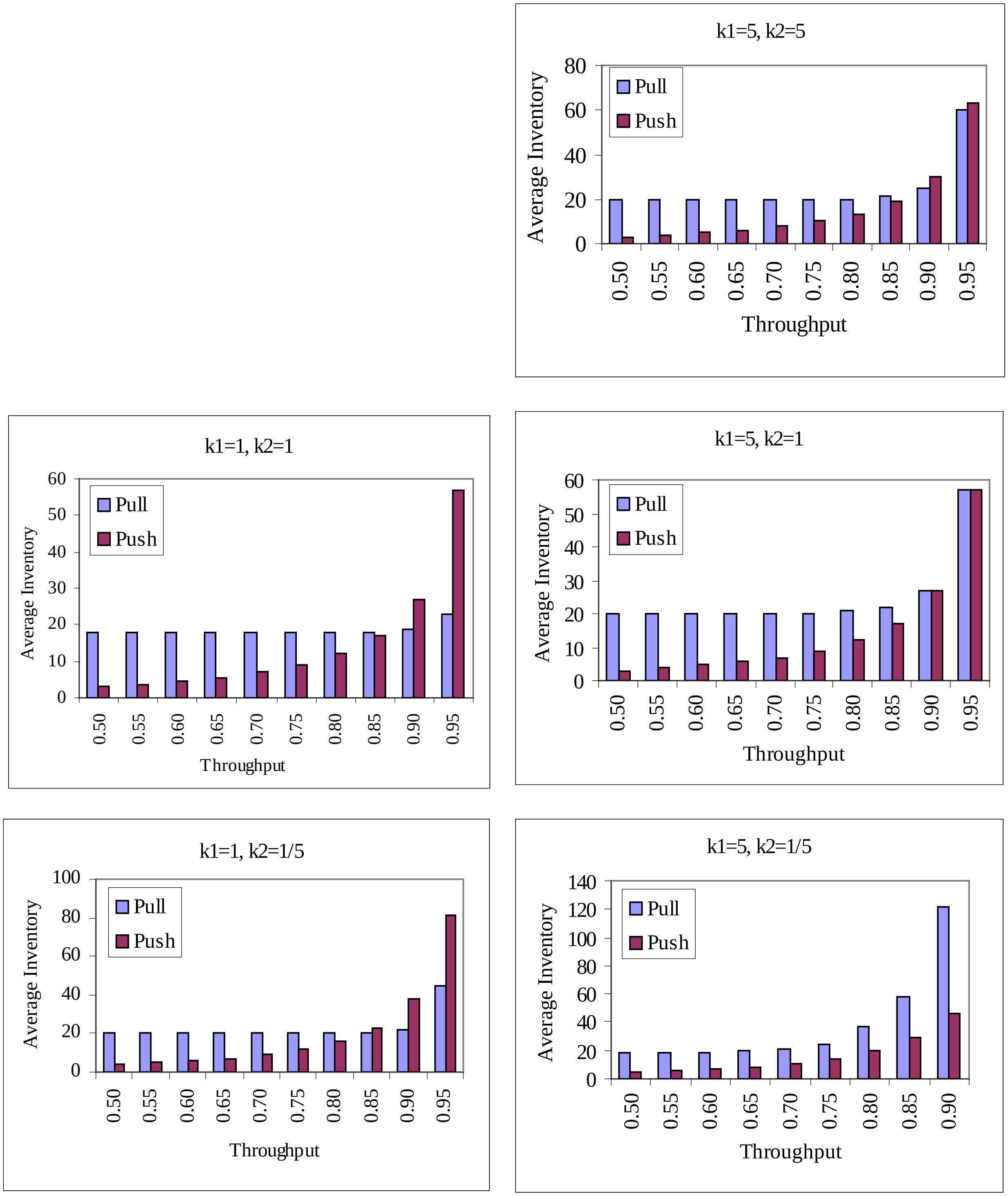

Figure 2. Performance of push and pull strategies under product mix changes

The deterioration in the performance of the pure pull strategy appears to be linked to the variability in the arrival and service processes at each machine. The product mix changes increases variability in the arrival and service process at each machine. In a pure pull strategy, this leads to increased blocking and starvation of the machines and hence a drop in system throughput. However, since the pure push strategy uses information about expected demands and accordingly releases material into the system, there is lesser blocking and starvation of machines.

To test our hypothesis, we compared the performance of the pull and push strategies for increased variations of the product mix by running simulation for different values of k1 and k2. In this paper we only present the results for the case where *k1k2*=1, and *k1* taking values 1,2,3,4,5, and 7. Figure 3 illustrates the performance of pure pull strategies for these cases and Figure 4 illustrates the performance of pure push strategies. Figures 3 and 4 show that the performance of the pull strategy is more sensitive to increase in variability than the push strategy. Therefore, product mix changes have a more significant impact on systems operating under pure pull.

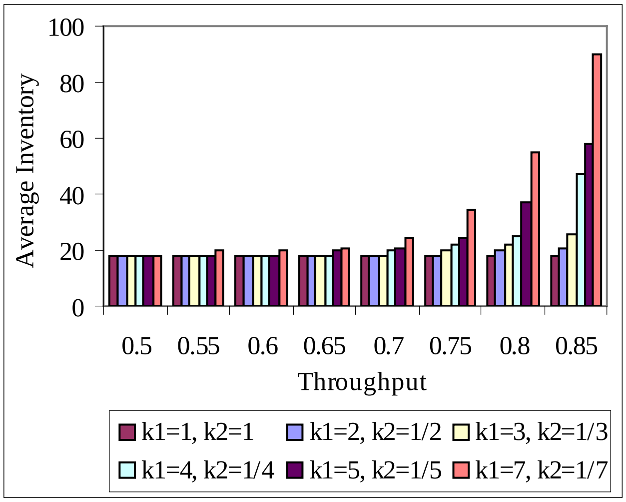

Figure 3. Performance of pull strategy

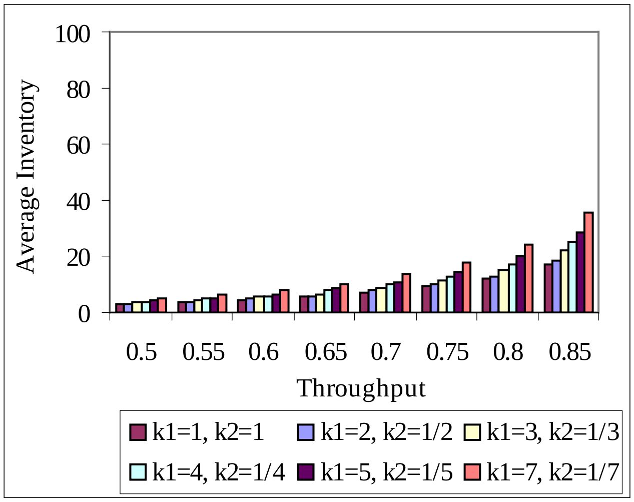

Figure 4. Performance of push strategy

5. Conclusions and Ongoing Research

Over the last decade, many researchers and practicing industrial engineers have tried to show that pull strategies are superior to the push strategies. We have illustrated the contrary through some simple simulation experiments. Pull strategy imposes rigid bounds on inventory of each product at each station. Also, the pull strategy authorizes replenishment of inventory based on the assumption that current consumption guarantees future demand. For high volume production lines, this tight control of inventory provides better system performance. However, for lines manufacturing engineered-to-order or custom products, the material control strategy must possess a degree of flexibility to adapt and adjust to changing environments easily. Our experiments show that the look-ahead feature of push could yield better performance than the rigid control of pull. Variants of pull systems such as the CONWIP have longer loops controlling inventory. Some interpretations of CONWIP also incorporate some look-ahead features [3]. Literature indicates that no one strategy completely dominates the other [4][5]. Our research findings help understand to an extent why some strategies might perform better than others in certain situations. Our ongoing research aims compare different material control strategies in an attempt to identify the extent of look-ahead and inventory bounds required for best system performance.

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