A Simulation-Based Changeover Frequency Optimization Methodology to Minimize Unit Cost

Shortt D. A.
Webasto Roof Systems, Inc.,
1757 Northfield Drive, Rochester Hills, MI 48309 USA
duane.shortt@gmail.com

Abstract

Optimization of product changeover becomes difficult when manufacturing systems capable of producing multiple part types vary in uptime efficiency and changeover time, supply and delivery of parts are not constant. This is a continuation of the structured process improvement methodology proposed by Shortt, et al. [1], where simulation-based methods are used to reduce the Cost of Ownership (CoO) through the reduction of WIP. This research will utilize discrete event simulation to determine the optimal number of changeovers of a multi-part manufacturing system, with a continued focus to reduce the CoO. The developed methodology was applied to a multi-part engine block machining system used previously, to prove its validity.

Keywords:
Discrete-event simulation, Batch sizing, Unit cost optimization

1. Introduction

The modern trend in manufacturing is to design agile and flexible systems that are capable of producing multiple part types. This is gaining rapid interest, since companies that can produce various products are able to satisfy a wider range of customer demand, generating additional revenue. However, this ability does have a downfall; loss of productivity due to changeovers.

To minimize the changeover impact, two methods are commonly employed. First, common fixturing designed specifically for Flexible Manufacturing Systems (FMS). This method uses a common pallet that can accommodate each part type to be processed by the system. A part is mounted to the pallet and the pallet/part assembly is programmed by a Radio Frequency Identification (RFID) tag. This tag identifies the type of part currently moving through the process, so that the machines can quickly modify their programming to handle the new part. The benefit of common fixturing is its capability to handle multiple part types with little or no changeover time required, making it a very attractive option for many companies. However, as Elkins et al. [2] explained, the widespread use of FMS has not yet taken off due to the fact that many companies have yet to see the promised cost reductions materialize.

The second and more common method to handle multiple part configurations are the batched production of similar model types. Similar part styles are run in “lots” to minimize the loss of productivity due to changing over. However for batch sizing to be effective, the size of the lots must be “balanced” to reduce the productivity losses without creating excess work-in-process inventory [3].

When a manufacturing system has very little variation in availability, the changeover times are stable and consistent, and the delivery patterns of the raw material and finished goods are constant, the optimum value of changeover frequency can easily be determined through analytical means. However, most manufacturing and supply systems are much more complex, and all of the factors affecting batch size calculations can vary greatly with unique distributions.

To handle this stochastic complexity, the simulation-based methodology is developed. This methodology begins with a model that is run through a large number of iterations to provide the most likely value of the systems true throughput. Using the resulting throughput, a simplified analytical calculation use used to determine the initial change over frequency. This frequency is then re-entered back into the simulation model to determine the resulting throughput impact and WIP. A CoO is then calculated using these final values to determine effectiveness of the schedule.

2. Literature Review

Since the scope of this research is directed towards multi-part manufacturing systems, a literature survey was conducted on the methodologies used to determine optimal batch size. A number of studies have been conducted that focus on the determination of batch sizing (or often called “lot sizing”), for those systems that produce more than one part type.

Spearman [4] studied a lot sizing technique to minimize cycle time. In his research, he discussed the traditional EOQ method and a method that seeks minimal cycle times. His investigation used an analytical formula to determine the amount of time spent on setup and processing. He concluded that while the EOQ method is a better approach for minimization of the total cost, the minimal cycle time method is a good alternative to reduce the costs understated in most accounting systems. Bertrand [5] investigated a method to determine an optimal batch size for multi-part work centers. In his work, he outlined a method that used a queuing model to evaluate different batch size inputs; the best combination goes through an “economic evaluation” step in which the costs are evaluated. He concluded his research that the queuing/economic evaluation model can reduce the batch size cost error, although further work is required to validate his findings using computer simulation.

Roundy et al. [6] explored the use of heuristic models and Integer Programming to determine optimal batch sizes. Through a number of case studies, the authors showed that the integer programming formulation had “remarkable” results in calculating the most favorable batch size. In the case of heuristics, they concluded that modeling time as a discrete variable is not appropriate for industrial applications, and a continuous-time version of the method is more feasible. However the heuristic method does show promise in calculating batch size.

Bicheno [7] considered batch sizing in a lean environment. In his work, he studied the existing methods of EOQ, MRP and MPS and determined that none of the methods are capable to provide optimal solutions when the amount of time for changeovers is limited. In his research, he developed a new method to determine optimal batch sizes when the amount of time to conduct changeovers is limited. Calling it Fixed Period Requirements (FPR), he applied his work to a press shop and determined that the procedure does provide a significant savings of more than 10% without breaking the capacity constraints.

Based upon the research of Guild [8], capacity based lot sizing is the path to save more money by the simultaneous improvement of throughput and inventory. He indicated that unlike EOQ, capacity based methods is based on the total capacity of the resource, and how that capacity is consumed. He uses a replenishment interval formula, Equation 1, to calculate to determine the length of time allowed to build a complete batch.

$$\mathrm{RI} = \frac{\sum \mathrm{CO}}{(\mathrm{A} * \mathrm{U} - \sum(\mathrm{D} * \mathrm{CT}))} \tag{1}$$

Where,

RI = Replenishment interval
A = Daily resource time available
U = Uptime percent
D = Daily demand
CT = System cycle time
CO = Changeover time

Price and Simonin [9] explained that EOQ frequently calculates batch sizes that are much larger than needed. Using a form of the replenishment interval equation, the authors use an "inflexibility diagram" to visually represent the operational management of two part types. An example of an inflexibility diagram is shown in Figure 4.

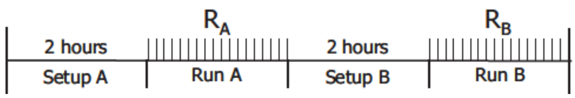

Figure 1: Example Inflexibility Diagram [9]

3. Simulation-Based Methodology

The developed simulation-based changeover frequency optimization methodology is broken out into to following five following steps:

3.1 Determination of the Customer Requirements

Before a changeover frequency optimization can be conducted, an understanding of the customer demand must be realized. Three major pieces of information are needed to obtain a clear picture of the delivery requirements, are as follows:

1. Number of variant part types.
2. Amount of each part type required.
3. Frequency of need or "pulls" of the various part types.

It is important to know if the customer demands parts on an hourly, daily or weekly frequency, as this will affect the time required to supply the needed parts. Obviously, a daily customer demand schedule will require a different changeover strategy than a weekly pull schedule.

3.2 Simulation Modelling of the Manufacturing System

To determine the true output of the manufacturing system under real-life stochastic conditions, a simulation model must be created. The simulation model must be created to include the best fit distributions of raw material delivery and manufacturing process utilization.

Once a validated model has been created to represent the real system, a large number of iterations must be ran to ensure that the resulting throughput is a stabilized value from a many combinations of variable inputs from their unique distributions. Figure 2 represents the basic output of a simulation model when the variations of input are applied without changeover.

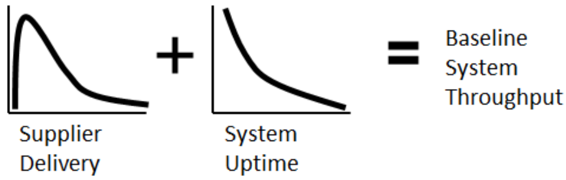

Figure 2: Simulation output with basic system variables

3.3 Changeover Frequency Calculation

When determining the optimal changeover frequency, it is critical to verify that the system can exceed the rate of customer demand. Throughput that exceeds the demand does not necessarily reduce unit cost, however, it does allow for additional changeovers. Excess capacity of the system can be converted into time to conduct more changeovers, and more changeovers allow for smaller batch sizes. By having smaller batch sizes, the inventory held due to part type variation can be minimized, reducing the unit cost.

Batch sizes are determined by the number of changeovers that can be effectively conducted. More changeovers result in smaller batches and fewer changeovers create bigger batches. As McClellan [10] indicates, batch size is determined on the time is takes to perform a changeover.

The first step in the batch size calculation determines the total amount of excess time the system has above the customer requirement to conduct changeovers. The total time is taken during one cycle of the customer demand window, whether it is an hourly, daily or weekly pull schedule. This relationship is shown in equation 2.

$$E = H - \left(\frac{H * CR}{TH}\right) \tag{2}$$

Where E = Excess time taken to build more parts than the customer demands (hour), H is the hours of production in a customer frequency (hour), CR is the customer demand rate (parts per hour) and TH is the throughput rate (parts per hour).

Once this total time is known, the total number of allowable changeovers can be determined by divided the total excess time by the average time is takes to conduct one changeover. This relationship is shown in equation 3.

$$M = \frac{E}{TC} \tag{3}$$

Where M is the maximum number of allowable changeovers, E is the excess time taken to build more parts than the customer demands (hour) and TC is the average time of changeover (hour).

Using the result of equation outlined by Shortt, et al. [1], the batch size of each type can be determined easily through the use of an inflexibility diagram. An example diagram is shown in Figure 3.

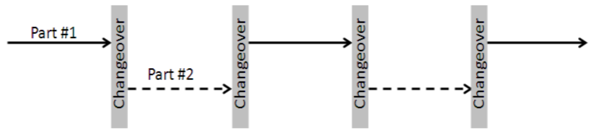

Figure 3: Inflexibility diagram

In the case of the diagram shown in Figure 3, when four changeovers are allowed, part #1 can be divided into three smaller batches, and part #2 can be divided into two smaller batches.

3.4 Simulation Modelling with the Calculated Changeover Frequency

When the baseline system through has been determined, and the number of allowable changeovers calculated, the simulation model is now updated to include the downtime due to changeovers both in duration and frequency and customer pull variation, as shown in figure 4.

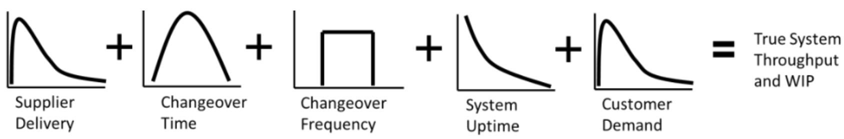

Figure 4: Simulation output with downtime due to changeovers included

3.5 Cost of Ownership Calculation

The objective function to minimize the unit cost which is a function of inventory and throughput is required. The objective function for unit cost reduction will be a slight variation of the Cost of Ownership (CoO) formula. The semiconductor industry developed the CoO model ($/piece), shown in Equation 4, to evaluate different manufacturing systems based on the total lifetime cost.

$$\text{Cost of Ownership} = \frac{\text{Fixed Costs} + \text{Recuring Costs} + \text{Yield Costs}}{\text{Life} * \text{Throughput} * \text{Composite Yield} * \text{Utilization}} \quad (4)$$

Nanez [11] utilized the CoO concept to reduce the cost of wafer manufacturing. The conceptualized CoO model is shown in Equation 5:

$$\text{Cost of Ownership} = \frac{\text{Cost to Produce Wafers}}{\text{Number of Good Wafers Produced}} \quad (5)$$

The CoO concept is utilized for developing the unit cost where evaluating different process improvement alternatives can be compared. The modified CoO is shown in Equation 6, and will be used as the objective function in this research:

$$\text{C} = \frac{\text{CF} + \text{CR} + \text{CI} + \text{CY}}{\text{L} * \text{TL}} \quad (6)$$

Where,

CF is the fixed cost, the cost of paying off the equipment
CR is the recurring or variable costs of the material, labor and repair
CI is the inventory cost, the Life Cycle Cost (LCC) of holding inventory
CY is the yield cost, the LCC cost due to yield loss from quality issues
L is the life, the remaining life of the system or current system in years
TL is the throughput, the total number of good parts to be produced per year

4. Application of Approach

The developed structured process improvement approach will be applied to the optimization of a multi-part engine block machining system. This system produces two distinct part types, labeled as “A” and “B” in this research. A detailed description of this process in outlined in Shortt, et al. [1].

4.1 Determine Customer Requirements

The customer (in this research, is an external engine assembly line) demands 3,500 total blocks per week in a 2:1 proportion of “A” type blocks to “B” type blocks. This equates to 2,325 type “A” and 1,175 type “B” blocks per week. From reviewing historical shipping records, it has been determined that the customer pulls weekly, at a normally distributed rate having an average of 61.1 blocks per hour and a standard deviation of 4.3.

4.2 Simulation Modelling of the Manufacturing System

To create the simulation model of the engine block system, the supply of raw material must be determined. From reviewing the historical receiving records The supply of raw materials is a constant weekly input of 3,550 pieces, with very little variation. Due to this finding, we can treat this variable as a constant value.

As for the modelling of the manufacturing system, a conceptual process flow plan was developed. This flow plan, shown in Figure 5, will form the structure of the model.

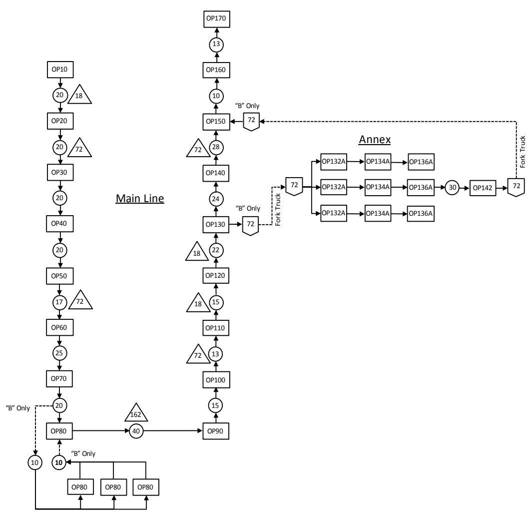

Figure 5: Process flow modelling concept

Process data was taken from an MES system is fitted into distributions and are entered into the model. Ten simulation runs at 5,000 minutes of warm-up and 100,000 minutes of runtime were conducted with different random number seeds (PRN) to generate a sampling of the results output from the model. The resulting output of the model indicates a system throughput of 64.5 JPH.

4.3 Changeover Frequency Calculation

The three main factors of the customer have previously been determined, and are shown below:

Customer pull rate:	61.1 blocks per hour
Demand frequency:	Supplied weekly
Weekly demand:	A type – 2,325 blocks
	B type – 1,175 blocks

Additionally, the basic information from the manufacturing system has also been determined:

Average changeover:	45 minutes
system throughput:	64.8 NJPH

Using the information collected in regard to the system and the customer, calculation of the optimal batch size can now be done.

$$E = 57.5 - \left(\frac{57.5 * 61.1}{64.8}\right) = 3.28\ hours$$

$$M = \frac{3.28}{0.75} = 4.37 \approx 4\ changeovers$$

Figure 6 shows the basic block scheduling diagram for both “A” and “B” part types. Since it was determined that four changeovers can be completed due to the excess time of more throughput than customer demand, the weekly total requirement for both part types can be determined. In one weekly schedule, the manufacturing system must provide 2,325 “A” parts types to the customer. If four changeovers are allowed, the 2,325 blocks can be run in three batched runs of 775. Similarly, the four changeovers allow for smaller batches of “B” parts types where the total of 1,175 can be made in two batches of 588 blocks.

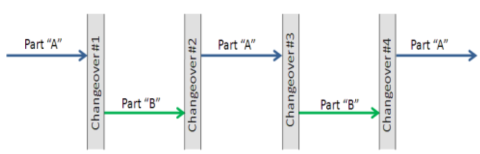

Figure 6: Block scheduling diagram

A similar batch result can be concluded in which two batches of part type "A" is produced and three batches of part type "B" is produced, allowing for batch sizes of 1,163 and 392 blocks, respectively. However, the objective of decreasing batch size is to minimize the inventory due to holding different parts for the customer. Therefore, the alternate calculation creating a larger size of the high runner is not an optimal option.

4.4 Simulation Modelling with the Calculated Changeover Frequency

The original weekly raw material inventory figures indicated a "saw-tooth" profile over the course of the week. This profile, shown in Figure 7, contributes to a significant inventory cost due to holding a week's worth of parts due to having two changeovers per week. One changeover to produce part B and another to return to part A. A histogram, shown in Figure 8, indicates an average supplied casting inventory of 1,379 parts. This makes sense, since the average of a full 3,550 delivery of raw stock on Monday morning to a zero stock condition on Friday afternoon is approximately 1,775 parts.

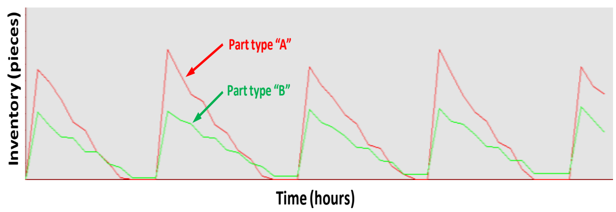

Figure 7: Supplier delivery profile chart

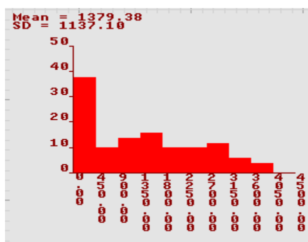

Figure 8: Single-run supplier delivery histogram

Using the calculated optimal changeover frequency, the manufacturing process will now allow the system to modify the existing supply frequency from a weekly delivery to a daily delivery. This will significantly reduce the in-house holding inventory, and having goods get to the point-of sale sooner. The average inventory due to having weekly delivery is 1,410 blocks. By changing this to a daily delivery, the average inventory drops to 175 pieces. Figure 9 shows the new supplier delivery variation profile output from the simulation model. Figure 10 shows the single-run histogram of the new profile with the statistical daily average of inventory.

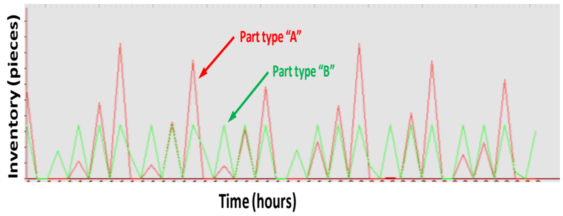

Figure 9: Improved supplier delivery profile chart

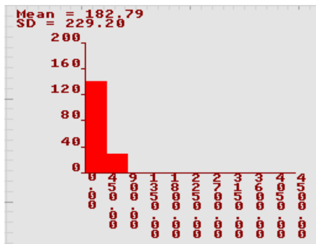

Figure 10: Single-run improved supplier delivery histogram

4.5 Cost of Ownership Calculation

Since this research focused on the reduction of unit cost to determine true financial impact, the unit cost of the original system must first be determined. An interview with the controlling department indicated the information, shown below:

Cost of Inventory (IC) = $18,000,000

Cost of Yield Loss (YC) = $1,075,000

Variable Cost (RC) = $55,000,000

Fixed Cost (FC) = $100,500,647

Remaining Life of the system (L) = 5 years

Baseline yearly throughput (TL) = 183,149

Using this objective function for unit cost determination, shown previously in equation 5, it has been found that the cost of each block for the original system was $190.64.

The output of the system using the new batch sizes was observed for three months, and the system's output was analyzed in order to calculate the final optimized unit cost. These results were sent back to the controlling department, to determine the estimated financial effect of the changes.

Cost of Inventory (IC) = $12,000,000*

Cost of Yield Loss (YC) = $1,000,000*

Variable Cost (RC) = $50,000,000*

Fixed Cost (FC) = $100,500,647

Remaining Life of the system (L) = 5 years

Baseline yearly throughput (TL) = 180,950

*Projected yearly estimates

The cost of inventory (IC) has been significantly reduced since the largest portion of inventory, supplier variation, has been nearly eliminated in addition to the excess inventory held in the offline buffers. The costs due to the constant handling of the excess blocks and providing a space to store them no longer apply.

The yield losses (YC) have somewhat improved since quality defects are no longer amplified to the large storage of block in the system. Since there are less blocks in the system, quality defects now have a minimal impact.

Variable costs (RC) have also significantly decreased due to this research. The customer pull rate and the throughput of the original system only allowed for a single mid-week changeover on second shift. This forced the variable costs to increase due to paying the additional premium.

There is also a slight reduction in the baseline yearly throughput (TL) due to the additional changeovers over the baseline.

From these improvements, the unit cost calculation yields a final unit cost of $180.71/block, or a savings of $9.93 per block. As a result, the total yearly savings is $1,796,833/yr.

5. Conclusions

This is a continuation of the system improvement methodology developed and applied by Shortt, et al. [1]. In using the proposed structured batch sizing methodology, the net inventory held in the system was reduced from an average of 2,550 to approximately 1,700 blocks, a 33.3% inventory reduction. The unit cost was reduced from $190.64/block to $180.71/block, a $9.93 savings per block. With 180,950 blocks being produced in a year, the resulting net yearly savings is $1,796,833/yr. The cost of supplying the manufacturing system on a daily schedule instead of a weekly one, the supplier will charge an additional $1,500,000/yr to cover overhead and transportation charges. Therefore the final savings yielded by this research is $296,833/yr. When multiplied by five years expected remaining life of the system, the total life net savings becomes $1,484,165.

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Biography

Duane Shortt is a manager for advanced manufacturing engineering at Webasto Roof Systems. Dr. Shortt holds a Bachelor of Science in Mechanical Engineering from Kettering University, Masters or Engineering in Manufacturing Systems and a Doctorate of Engineering in Manufacturing Systems from Lawrence Technological University. He is also a registered professional engineer in Michigan. His research interests include automated manufacturing and transport, simulation, smart manufacturing and artificial intelligence.