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Heuristic Solution For Separated Manufacturing Process

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To the Graduate Council:

I am submitting herewith a thesis written by James Dee Davis entitled "Heuristic Solution For Separated Manufacturing Process." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Industrial Engineering.

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Heuristic Solution For Separated Manufacturing Process

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ABSTRACT

Downtime is a major issue for manufactures. Downtime may occur from breakdowns, quality issues, lack of manpower, lack of materials, or in this case a lack of storage containers. A manufacturing system was studied that consists of an injection machine that supplies two assembly lines. The injection machine suffered from frequent downtime from lack of containers. The process was analyzed for root cause of downtime. After analysis of the system it was found that the injection process had high variability in production quantity and quality. The scheduling scheme called for production until all available containers were full regardless of actual demand. This created times when Injection would have to wait for Assembly to empty containers thus causing downtime. A production model was developed to compare different scheduling schemes for cost effectiveness. An economic order quantity based schedule was found to have least cost.

PREFACE

Socrates is credited as saying that the unexamined life is not worth living. Socrates was also fond of asking why, and why again, and why again; which should be credited as being the first 5 Why Analysis. Unfortunately today philosophy may be seen as irrelevant, perhaps caused by questions like, “How much of a sock can you replace and still have the same sock?” While this question may seem absurd on first inspection, just stop and think about it. How much of something can you replace and still consider it the same thing? That answer requires thinking, and how would a mathematical model explain it?

This project stems from a series of why, why is that, and how comes? Then seeking to understand how it is, how it is supposed to be, and then how it ought to be. This project helped me resolve, what seemed to be contrary concepts, into a more cohesive idea on production, production flow, and work-in-process.

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1 INTRODUCTION

Downtime is a major concern for manufactures. Unplanned downtime disrupts inventory flow and scheduling for future work. Unplanned downtime also adds costs to production. Correctly identifying the cause of the downtime is very important. In this study, the reason given for downtime was only a symptom of a system failure.

1.1 BACKGROUND

A large manufacture presented a downtime issue that was given the reason “Out of Racks/Totes.” After an initial investigation into the downtime issue, it was discovered that there was an overall system failure that caused the downtime issue.

The system starts with an injection machine that molds automotive doors two at a time, right hand and left hand. The doors are available in three colors. These doors are placed into racks and transported a short distance to a work-in-process area. The work-in-process area is adjacent to two assembly lines that add components to the doors and place them in a finished good rack.

There may be confusion between the “injection department” and the “injection process” when the general term injection is used. The same applies for the “assembly department” and the verb assembly. To distinguish the departments from the verbs, when the departments are referenced the word will be capitalized. So “Injection” refers to the department as a whole, and injection refers to the process. “Assembly” refers to the department, and “assembly” refers to the action.

Often the injection machine is down because there are no racks available for the doors. The downtime occurrence is listed as “No Racks/Totes” and the injection machine waits for racks to become available from assembly.

This paper presents the findings from the research into the root cause of the “No Racks/Totes issues.” First, there is a policy for injection to run until all racks are filled in an attempt to increase an Operation Equipment Effectiveness (OEE) percentage that is used as a performance metric; the higher the OEE the better. Then when the next shift begins there are no racks available for the injection machine to operate. Holding empty racks may be one solution to the issue, but the investigation yielded a deeper issue.

There is a gap between the ability of the injection machine compared to the production rate of assembly. Currently the injection machine produces around 70 parts per hour where injection consumes 116 parts per hour. Injection can only run one color at a time where Assembly runs all three.

The injection machine becomes the bottleneck of the system. Inventory problems escalate from forced color changes, overproduction of the wrong color, and quality issues.

1.2 RESEARCH QUESTION

What is the root cause of the downtime issue, what changes can be made to correct the issue, and what is an appropriate production scheme.

1.3 RESULTS

A production model was built around the WIP inventory level and the setup costs of the injection machine and the holding costs of inventory. Assembly has no setup costs because the line is dedicated to the single product. Holding cost is nominal in Assembly because the actual WIP on the line is what is immediately consumed for finished goods.

The holding costs for the inventory and the setup costs for the injection machines were developed.

The Economic Order Quantity (EOQ) was used as a basis to determine scheduling for the injection machines. EOQ is subject to multiple constraints that were adjusted to meet the situation. Multiple EOQ models were run to determine the lowest cost alternative. The EOQ results were then compared to a just-in-time model. The results were that a modified schedule EOQ model's cost was 62% of the JIT model.

Finally multiple recommendations are made to support the easing of the inventory issues.

Much has been written about the remarkable improvement that occurs when inventory is reduced to minimal levels in lean literature. Often the result of zero inventories is given as a goal. But on the way to zero inventory, what is an appropriate amount of inventory to hold? In depth case studies on production lines are difficult to find. This work presents a case study where the presented problem is only the symptom of a larger system issue. The process used to examine the system is detailed along with details of the issues in each department.

Economic order quantity analysis often has low yearly demand, high set up cost and low carrying costs [1].This model has a very high yearly demand, lower set up costs, and high carrying cost.

1.4 MAJOR DATA SOURCE

Daily production information for the injection process is entered daily into an Access Database. The data includes the date, part numbers, type and quantity of defect, and duration and cause of downtime. The database had recently been updated for better usability and data search. Data for the project was taken over a 90 day period immediately previous to the study.

1.5 DEFINING OPERATIONAL EQUIPMENT EFFECTIVENESS

This measure is important because Injection relies heavily on the OEE number as metrics for its performance. Considering this, the Access database used for data research was designed for ease of OEE calculation. Therefore all historical data used is from the Access database.

OEE has three components, Availability, Performance, and Quality and two major types of loss for each component known as the big six losses.

- Availability is the ratio of uptime to total scheduled time, which is the total scheduled time – downtime.

[1] For an example (Khan and Sarker 2002)

- Equipment failure losses such as breakdown and maintenance failures. For example, burst hydraulic hose.
- Change over, Set Ups, Adjustments losses. For example, tool changes and color changes.
- Performance is related to speed of the equipment while it is operating compared to its theoretical maximum.
- Temporary periods of inactivity i.e. idling, and minor stoppages. For example, having to pause production to change out work-in-process racks.
- In ability to work at theoretical maximum. For example, cooling length in injection cycle is set too long.
- Quality is the measure of defective units whether at startup or during steady production.
- Defects and rework. For example, color contamination in part.
- Startup losses waiting on stabilization of the process. For example, defective parts produced while waiting for tool to heat to correct temperature after die change. (Muchiri and Pintelon 2008)

$$OEE = A * P * Q \qquad (1)$$

$$A = \frac{U}{T} \qquad (2)$$

$$P = \frac{IC}{\frac{U}{TP}} \qquad (3)$$

$$Q = \frac{GP}{TP} \qquad (4)$$

Where:

OEE	Operational Equipment Efficiency
A	Availability efficiency
P	Performance efficiency
Q	Quality efficiency
U	Uptime
T	Scheduled Run Time
IC	Ideal Cycle Time
TP	Total number of pieces
GP	Number of good pieces

1.6 DOWNTIME

Downtime is defined time when the machine is not in operation during scheduled operation. If no work is scheduled, such as a holiday, then that time is not considered downtime. If there is no work scheduled, then there is no downtime. Downtime requires that the machine actually be scheduled to be in operation. Downtime is one of the six big losses (Muchiri and Pintelon 2008). These losses include breakdowns, setup and adjustments, small stops, reduced speed, startup rejects, and production rejects. These six different losses affect operational equipment effectiveness negatively. Confusion may occur with “scheduled downtime” or “scheduled maintenance”.

If the intention of the machine is not to produce during these periods then it is not downtime. Breaks, lunches, meetings and other activities that may be scheduled do not count as downtime as long as they were pre-planned and scheduling was changed for the machine. Of course, if the expectation of the machine is to operate 24 hours every day, then any downtime whether it is scheduled or unexpected would be counted as downtime.

1.7 ECONOMIC ORDER QUANTITY

What is the most economical lot size? The economic order quantity will be used for an inventory analysis. The economic order quantity (EOQ) is based on Harris's well known economic order quantity. (Harris 1913). The economic order quantity (Q) has several major assumptions. A strength of the EOQ is that the EOQ curve is very flat at the minimum so as long as the order quantity is near the EOQ there is not much change. A weakness of the EOQ is that the constraints are often not fully applicable to real situations.

1.8 EOQ WITH INSTANTANEOUS DELIVERY

The EOQ assumptions are,

- Only one item is considered
- Order arrives in its entirety
- Only order cost (a) and holding cost (h) is concerned
- Constant and continuous demand over one year (k)
- No stock outs or backorders
- Constant lead time

The EOQ function is given in Equation 17.

$$EOQ = \sqrt{\frac{2ka}{h}} \tag{5}$$

2 LITERATURE REVIEW

Lean is a major theme in today's manufacturing system. A good background in lean is required to fully understand the contrasts between economic order quantity and just in time philosophies.

For an interesting comparison of lean methodologies read Womack and Jones, *The Machine That Changed the World* (Womak and Jones 1990) Holweg credits Womack and Jones's book as part of the catalyst for the lean movement. Holweg explains that the book was in a story format that made it easier to read and understand by management and government officials. Previous papers had been more tool centric where *Machine* had a systems aspect with a more holistic overview of the management process that needs to accompany lean production (Holweg 2007)

From the different pieces of literature, a history of how lean production came to being outside of Japan can be formed. However, Holweg gives a thorough overview along with a very convenient lean timeline. The first paper that explained these concepts had the lengthy title "Toyota Production System and Kanban System Materialization of Just-in-Time and Respect-for-Human System" (Sugimori, Kusunoki and Uchikawa 1977). Interesting in the literature the Toyota Production System (TPS), kanban, and just-in-time have heavy focus but "Respect-for-Human System" does not. Where *Machine* is over 300 pages Sugimori et. al, is only 12 pages and gives an easy to read solid foundation to the topic. Also included in the paper is the background information of why lean principles came to be created in Japan and why they were successful

Holweg explains why lean was so successful in Japan; limited resources, limited space, homogenous population, extraordinary work ethic, group consciousness, and lifetime employment. These reasons were same reasons many American companies believed that it was not possible. *Machine* refuted these claims that lean was not possible in the United States by showing its success in US based Japanese plants.

Womack and Jones showed the wide difference between lean facilities and non-lean facilities that made the benefits of lean clear and that lean was practical in the US. Even though *Machine* may be credited as the most influential book for the promotion of lean it did not coin the phrase. That credit goes to John Krafcik with “Triumph of the Lean Production System” Krafcik briefly explains how Toyota adapted Ford’s assembly line into its production system. Krafcik solidly refuted the concept that Japanese systems could not work outside of Japan by showing the success of the cooperation between General motors and Japan (Krafcik 1988).

While Krafcik’s paper may have congealed the entire TPS concept into one word, its purpose was not to explain it. Instead Krafcik’s paper showed just how well lean practitioners did better than non-lean practitioners. After 1979, as Japanese auto manufactures increased their presence in the US and as Japanese methodology information became big sellers, steady material on Japanese methods were published. Holweg cites three major authors as for JIT and TPS during this period, Schonberger, Hall and Moden. (Schonberger 1982) (Hall 1983) (Monden 1983) For reading from the credited creator of the Toyota Production System see *Toyota Production System: Beyond Large-Scale Production* (Ohno 1988).

The typical American and European manufacturing systems carried large inventories and long set ups were often used to rationalize long production runs. Several books have been written about producing with little inventory (S. Shingo 1988) (Hall 1983)Shingo in 1985 explained how set ups (machine change overs from one part to another) could be greatly reduced so that a wide mix of products could be made. These extremely fast set ups are now referred to as SMED (Single Minute Exchange of Dies) (S. Shingo 1985)

Womack and Jones followed up their success with *Machine with Lean Thinking* in 1986. Here they provided case studies of small to large manufactures success with the implementation of lean principles. In this book they show that lean is very applicable outside of automobile manufacturing and again outside of Japan. (Womack and Jones 1996)Later various Toyota based books appeared on the scene for example *The Toyota Way* (Liker 2004)and *Toyota Kata,* which reports to be the first book that focuses on Toyota's management system of its people (Rother 2009). Practitioners of lean must properly reflect cost savings because time saved does not necessarily result in cost (Goldratt and Cox 2014) (Jones 2013)

Today freight is ubiquitous seen on every tractor trailer and what seems stacked impossibly high on cargo ships. Trent explains how deregulation from 1977 to 1998 unleashed the transportation system to compete and innovate (Trent 2008). As deregulation allowed more and more of those seemingly impossible cargo ships to be stacked with freight, the cargo ship became the container ship. The pivotal moment for container ships occurred in 1956 with the sailing of the Ideal X and its first load of wheel free containers. International shipping would soon become inexpensive just in time for

Japan to start shipping cars to the US (Cudahy 2006). And with that, the term container is now almost synonymous with those 40’ steel boxes. For insight into how the container and the container ship changed our thinking see *The Container Principle* (Klose 2015)

Since container has become to mean the large steel shipping container, packaging or transport items is the new terminology for item containers. Now items are packaged in either disposable or returnable packaging. That returnable packaging becomes part of a closed loop supply chain. For an overview reusable articles and closed loop supply chains see Gallego (Carrasco-Gallego, Ponce-Cueto and Dekker 2012). Closed loop supply chains typically refer to products that are sold and then returned. With the advent of packaging-for-every part so that packaging is included in the bill of materials, it may be adventitious to view returnable packaging as part of the closed loop supply chain. Read Van Wassenhove, Guide, and Harrison for an introduction (Van Wassenhove, Guide Jr. and Harrison 2003)

Mismatches in production and ordering along with overproduction and space to store inventory can bolster the bullwhip effect. Bullwhip can be seen when orders magnify as they travel from the customer through the supply chain (Klug 2013). Theory of Constraints (TOC) was popularized by *The Goal* (Goldratt and Cox 2014) which explains the concepts in a manufacturing environment. Goldratt expands TOC in *It’s Not Luck* (E. Goldratt 1994) *Isn’t it Obvious* explores TOC from a retailer’s and logistics view but still has practical application for manufacturing (E. Goldratt 2009)

Understanding Operational Equipment Effectiveness (OEE) is important to give a measure to the benefit of the suggested improvement. (Huang, et al. 2003). First introduced by Nakjima (Nakajima 1988) and later expanded by Hansen (Hansen 2002)

Operational Equipment Effectiveness (OEE) is a measure of efficiency of an operation.

3 METHODS

The reporting structure for downtime enumerates the description of the downtime not the actual causes. For example, downtime for die change is one downtime code. It does not reflect whether the die change was scheduled or not or why the die change occurred. Downtime codes listed describe what occurred during the event not the cause of the event. Therefore, a systems approach was taken to examine the issue. The steps for the methodology are

- Research the Downtime Issue
- Isolate investigation to a single machine
- Analyze the overall Production System:
- Assess the rack system
- Review the operations at Injection
- Review the Work in Process area
- Review the Assembly Area
- Develop a Production Model
- Estimate Costs
- Determine if EOQ or JIT is a better methodology for Injection and assembly
- Perform a Bottleneck Analysis
- Recommend Solutions

3.1 RESEARCH DOWNTIME ISSUE

The manufacture uses a comprehensive Access Database to record operational information for 40 injection machines. This database tracks the information daily from production reports on types of units made, types of defects and types of downtime. This information can be exported into a generalized report or the raw data into an excel file. The access data base was used to search for the particular downtime issue, determines its scope across the plant, and to isolate the injection machine that had the most occurrences of the downtime issue.

3.2 ISOLATE INVESTIGATION TO A SINGLE MACHINE

The analysis was isolated to a single machine for simplicity. The machines make parts that are used internally and externally. By identifying one machine to be representative of other similar machines then the findings could be applied to across the other like work centers.

3.3 ANALYZE THE SYSTEM

Before observing a particular section for causes, an overview of the system was completed. The system was defined as starting at the initial order and terminating when the finished good was placed in the shipping rack. The system was constrained to the schedulers, the injection machine, WIP, and assembly lines. Any process before the injection machine is not considered such as raw goods ordering, raw goods transportation. Any process after the completed part is placed in the shipping rack is not considered either, such as transportation to the warehouse or customer.

3.4 ASSESS THE RACK AND INVENTORY SYSTEM

The downtime code presented as the initial problem is “No Rack/Totes.” The rack system was investigated.

- How many racks are listed on hand versus actual inventory?
- What are the characteristics of the rack?
- Dimensions
- Cost
- Standard Number of Parts (SNP) per rack
- What should the actual inventory of racks be?

3.5 REVIEW THE INJECTION OPERATION

The injection operation was examined to determine how it functions. The system includes:

- From the scheduler: How does information flow to determine the operational schedule?
- To and from Assembly: How does assembly and Injection communicate:
- Access Database: How is the database used to track information?
- Racks: How are racks tracked and moved?
- Production Rate: What are the production rates, requirements and other aspects of the injection machine?
- Quality: What is the quality rate (how many defects are made) of the machine?
- Availability: What is the availability of the machine (downtime issues)?
- Performance: When running how well does it run?
- OEE: What is the Operational Equipment Effectiveness of the machine, and what can be learned from it?

3.6 REVIEW THE WORK IN PROCESS (WIP) AREA

The WIP area was reviewed to determine its characteristics.

- Location: Does the location of the WIP area affect the system?
- How much WIP can be held in the area?
- What is the appropriate size for the area?

3.7 REVIEW THE ASSEMBLY LINE

The Assembly area was analyzed for its characteristics

- What is the production schedule of the Assembly line?
- What is the demand from the customer for the Assembly line?
- In what order are parts produced?
- What is the appropriate rate for the Assembly line?

3.8 ESTIMATE COSTS

3.8.1 Base Costs

To determine the effectiveness of the different scheduling themes the various costs associated with production were estimated.

- What is the cost of the raw part?
- What is the holding cost of inventory?
- What is the cost of change over on the injection machine?

3.8.2 Setup Costs

Setup costs are considered to be accrued when the machine start/stops for the day and color changes. On startup there is an amount of lost time and material and at the end of the day there is lost material and a cleaning agent that adds to the cost. Color changes are also similar to the start/stop procedure in that the machine is cleaned, lost material and cleaning agent, and then loaded with new material, lost material waiting for the machine to come into tolerance.

The cost of changing over the injection machine from one color to another was estimated from a rate supplied by the manufacturer. The manufacturer quotes that from this particular machine the cost is $2.35 per minute. The actual cost is higher since a cleaning agent is needed for start/stops and color changes. The cost of the agent is estimated at 30 per color change and 30 per start/stop.

The total for setup costs is estimated at $100.00

3.8.3 Holding Costs

Holding costs were calculated as an accumulation of several different costs.

3.8.3.1 Internal Rate of Return:

The internal rate of return that the manufacturer reports is 18%.

3.8.3.2 Material Holding Cost

The cost of the door lower from injection is valued at $7.00. Therefore the opportunity cost is $7.00 * 18% = 1.26 per door per year.

3.8.3.3 Floor Space Cost

The value of the floor space is estimated at $100 per square foot per year by averaging the asking price per square foot of several large facilities that were for sale in the area. The cost is capitalized at the IRR *e.g.* (cost *IRR)

3.8.3.4 Rack Cost

The amount of racks is linear given the amount of inventory. Each rack is valued at $500. The cost of the rack is capitalized at the IRR.

3.8.4 Total Costs

A total cost model was developed from the setup costs and the various inventory costs for the injection and work-in-process inventory.

$$Yearly\ Cost = Setup\ Cost + Inventory\ Cost + Floor\ Space\ Cost + Container\ Cost \tag{6}$$

$$Setup\ Cost = CO * WD * CM * SVC \tag{7}$$

$$Inventory\ Cost = I * PV * IRR \tag{8}$$

$$Floor\ Space\ Cost = IA * FV * IRR \tag{9}$$

$$Container\ Cost = C * CV * IRR \tag{10}$$

$$C = I/CI \tag{11}$$

$$IA = C * SF/CS \tag{12}$$

Where:

CO	Average Change overs per Work Day
WD	Work Days

CM	Change over minutes
SVC	Change over cost per minute
C	Number of Containers
I	Average Number of Parts in Inventory
CI	Number of Parts in each Container
IA	Inventory Area
SF	Container footprint
CS	Container Stacking Factor
PV	Part Value
IRR	Internal Rate of Return
FV	Value per square foot
CV	Container Value

3.9 DEVELOP THE PRODUCTION MODEL

Various production schemes were simulated. Different EOQ sizes and Assembly and Injection production rates were used. For each combination a schedule was created within the constraints of the model. Then a chart was prepared to show the individual inventory levels and the total inventory levels. A production model was created in Excel to simulate the different production rates of injection and Assembly to determine how inventory levels are affected by the different schemes.

Table 3-1. Yearly holding cost of WIP

Variables	Value	Floor Cost	Inventory Carrying Cost	Rack Cost	Yearly Inventory Carrying Cost	Yearly Inventory Carrying Cost per Piece
IRR	18%	$1,206	$176	$900	$2,283	$16
CV	$500.00					
CI	14					
CS	13.41					
FV	$100.00					
C	10					

- Week starts at Monday at 6:00 A.M.
- Injection adds to WIP
- Injection can operate 24 hours but is not required
- Injection color changes require 30 min, production is lost
- Assembly level withdraws from WIP
- Assembly works 2 shifts
- No stock outs
- Bias toward reducing WIP

From the production model the number of hours work, number of hours free, starts/stops, color changes, average inventory, max inventory, and the associated costs can be compared. From this information the most economical choice can be made.

3.10 PERFORM A BOTTLENECK ANALYSIS

Once the Injection, WIP, and Assembly lines are analyzed the bottleneck can be found for the system. The bottleneck is important since it limits the overall output of the system.

3.11 DETERMINE IF EOQ OR JIT IS A BETTER METHODOLOGY FOR INJECTION AND ASSEMBLY

EOQ and JIT are popular methodologies of production. Simulations using the production model and cost estimates were used to determine which methodology would be less costly.

3.11.1 Modifications to the EOQ model

The EOQ model is used to determine what the lot size for injection will be. The first modification is that production is not continuous in the effort to keep overall inventory reduced. Secondly batches are released incrementally not instantaneous. The EOQ model assumes that inventory will be drawn down to near zero and then instantaneously refilled. This scheme results in the holding costs to be ½ of the lot size. In this model the holding costs are calculated from using the scheduling model and estimating the average inventory.

3.11.2 Defining JIT

Just in time is a methodology that strives to have the right part at the right place at the right time. Part of this methodology is to carry low inventories so that only the part that is needed is produced when needed. For this study JIT is constrained at the injection machine as running at least all three colors every day. For the JIT scenario bias is placed on lower inventory to match the assembly process.

3.12 RECOMMEND SOLUTIONS

Manufacturing is a complex system. Improving the performance of the system could be accomplished in various ways. Several possible solutions were developed based on the circumstances and reviewed for applicability.

4 RESULTS

4.1 RESEARCH THE DOWNTIME ISSUE

The reported issue was that no racks were available for WIP to be placed. First the frequency and overall size of the problem was determined. The Access Database was used to search the previous 90 days for occurrences of the issue. Only the previous 90 days were used because the database was recently divided because of the size of the past information. The previous 90 days are also good representation of the current state and shows that the problem is still an issue and has not improved.

Overall downtime is an issue for the plant as shown in Figure 4-1. In the last 90 calendar days across all 40 machines the cumulative downtime was 18.4% (457,688 machine minutes of scheduled minutes/. 2,485,860 scheduled minutes.) Of the total downtime “No Racks/Totes” made up 12,079 minutes or 2.6% (12,079 minutes / 457,688 minutes).

4.2 ISOLATE INVESTIGATION TO A SINGLE MACHINE

Machine 28 and 18 both had significantly greater issues with “No Racks/Totes” The machine with the most occurrences of “No Racks/Totes” was machine number 28 as can be seen in Figure 4-2. However machine 18 had the greatest overall downtime as can be seen in Figure 4-3. Machine 28 was chosen for its less complicated production schedule, Figure 4- 4.

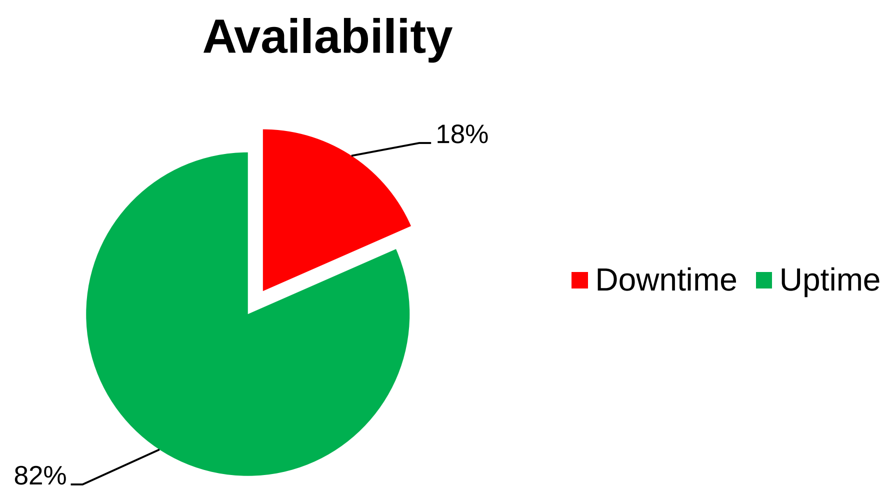

Figure 4-1. 18% Downtime across 40 Machines in 90 Days

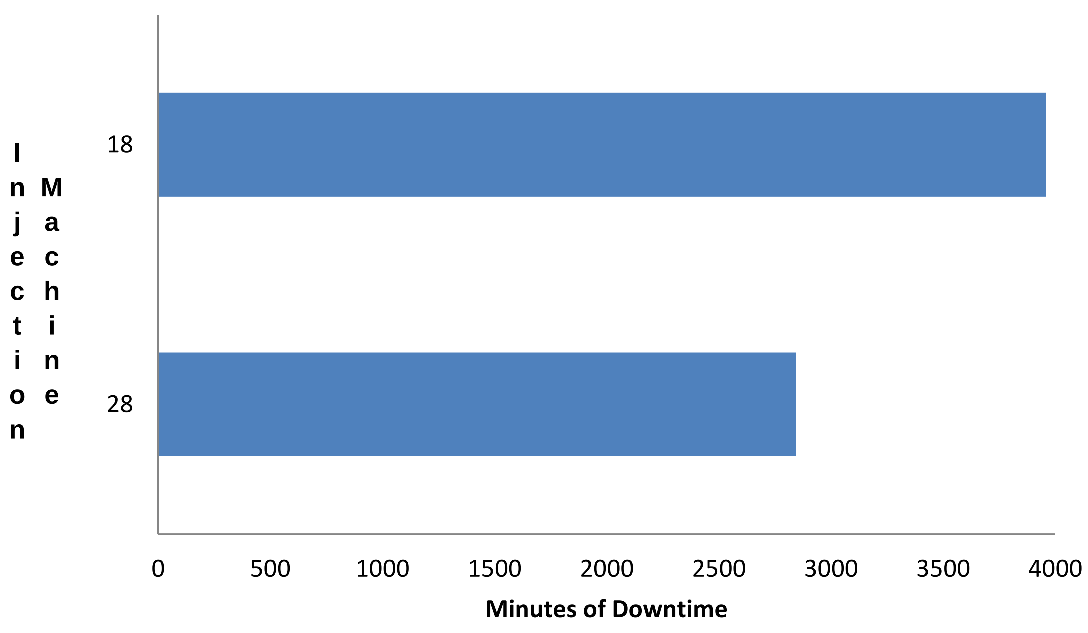

Figure 4-2. Machine 18 has 1116 more minutes of downtime than 28

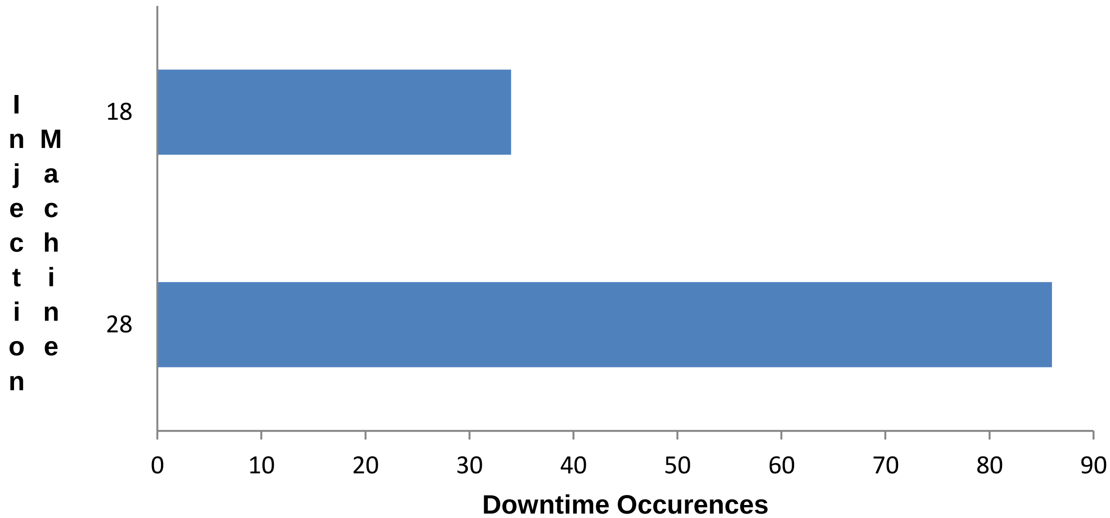

Figure 4-3. Machine 28 has 54 more "No Racks/Totes" occurrences than 18

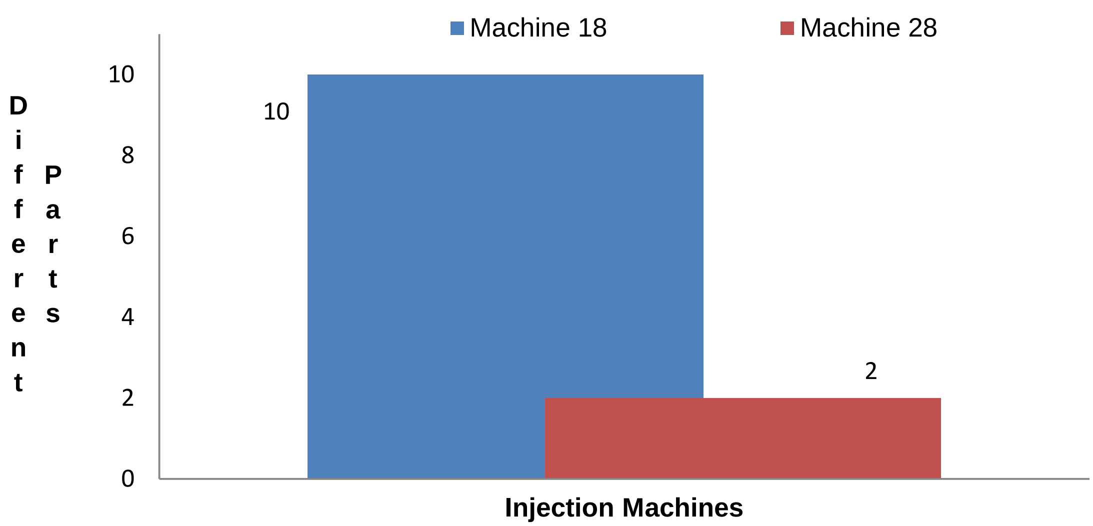

Figure 4-4 Machine 18 produces more part types than 28

Machine 28 primarily produces one type of part for Assembly and machine 18 produces 10 different parts for internal assembly and direct ship to the customer.

Therefore given 18's complexity in part types and internal and external shipping, Machine 28 was chosen for the study.

4.3 OVERALL PRODUCTION SYSTEM

4.3.1 Production Flow

Production starts with a firm order from the customer that is supplied by the customer through a dedicated computer system. The customer supplies a six month forecast that is revised up to the day of production. Raw material and components parts have already been ordered and are in stock ahead of the demand.

Machine 28 produces two door lowers simultaneously on each cycle. These are then stored on racks and moved to the WIP area near the Assembly process. The Assembly process draws its doors from the WIP area, assembles the final good and places the doors in the finished goods rack. The finished good rack moves to the warehouse until it is shipped to the customer, Figure 4-7

4.3.2 Information Flow

The customer supplies the demand information in quantity and sequence to the manufacturer. The Injection department attempts to schedule to the needs of the order Assembly works to the schedule supplied by the customer. However,

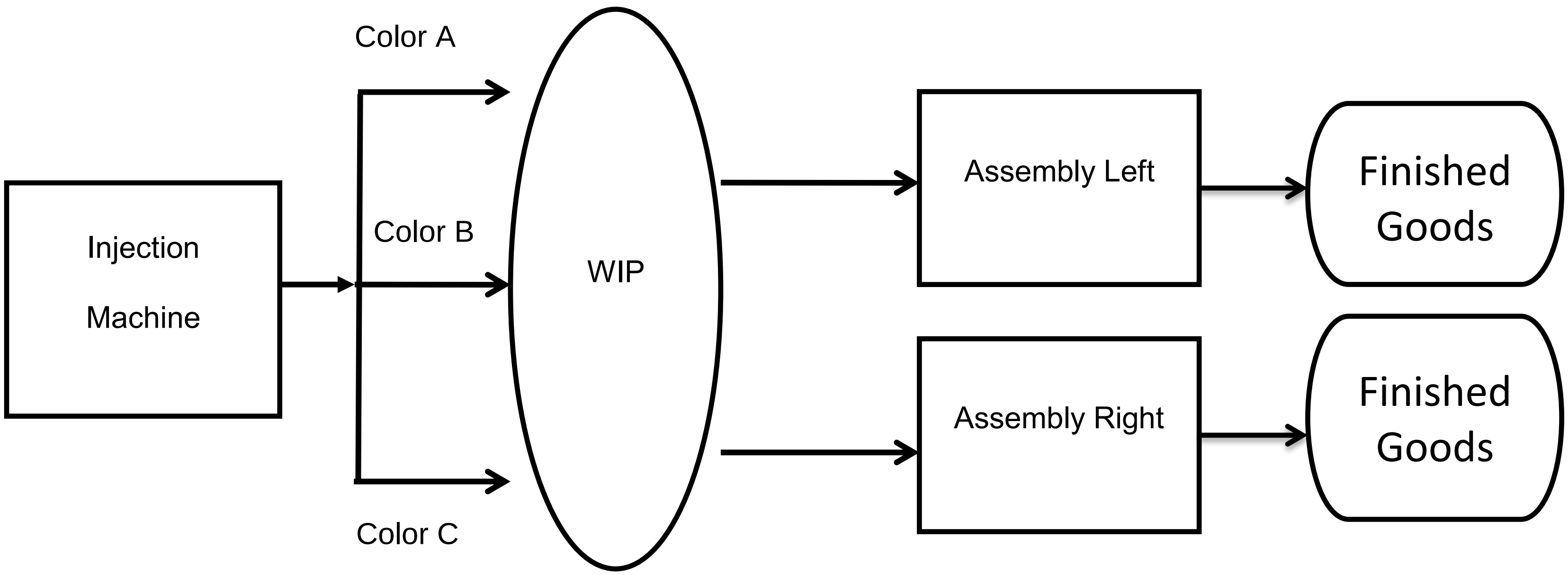

Figure 4-5. Overview of production system

proactive feedback between Assembly and Injection is poor as shown in Figure 4-8. The Injection schedule is out of sync with the requirements of Assembly. This was observed multiple times when Injection would have to stop its current color to produce the correct color that Assembly required to produce its current order.

The Injection and Assembly departments do not directly communicate on a normal basis to determine the proper scheduling of production. Assembly is required to work through the Injection scheduler to alter the production schedule to its needs. The feedback loop of information is broken and does not occur regularly unless there is a problem. At that point it has escalated so that it requires immediate action to prevent starvation at Assembly.

4.4 RACK AND INVENTORY SYSTEM

An inventory was performed to determine the actual quantity of racks on hand and the contents of the racks.

4.4.1 Characteristics

The racks are provided by the customer and are constructed from steel. The rack’s dimensions are 46”w x 42”d x 69”h. Each rack carries 14 parts and is stackable two high. The racks are primarily transported by forklift but are on castors for hand movement. The internal dividers are covered to protect the part.

4.4.2 Quantity of Racks

The assessment started with an inventory of the number of racks in the system. The number of racks listed in the system was 100 and the quantity found was 96, short 5 racks.

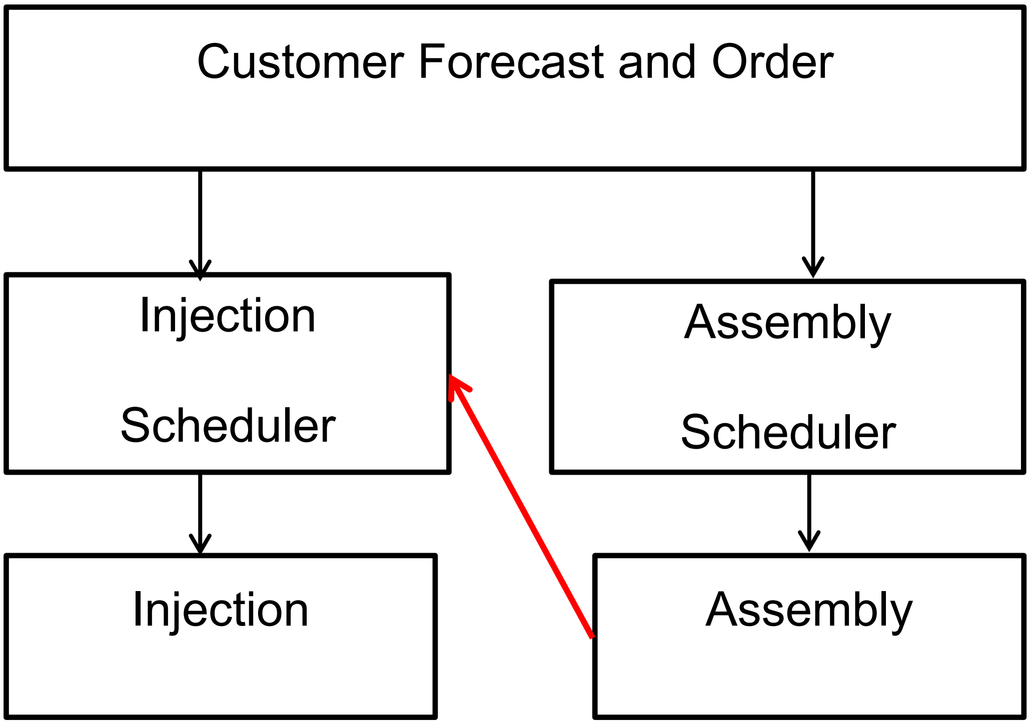

Figure 4-6. Communication between Injection and Assembly

4.4.3 Inventory vs. WIP

WIP is defined as material that has started production and is moving toward final production. Inventory is material or parts on hand that are not yet matched to a product moving toward a finished good. During the inventory 15 racks were found to have unmatched right hand door lowers. These right hand doors did not have a corresponding left hand door so they could not be moving toward a finished good. In this cast the 15 racks were being used to hold inventory in the case a run of extra left hand doors would occur.

From 8/2015 to 10/2015 there have been a total of 641 off hand doors produced. Figure 4-9 shows the extra doors for each color.

4.4.4 Rack Findings

A comparison was performed on the actual amount of racks on hand and the quantity listed in the records. This inventory was found to be 5 short. The major findings were that on the day of the count 15 racks were found to be holding inventory instead of WIP. This reduces the available racks from the book of 101 racks or 1414 piece of WIP to 1134 pieces of WIP. By not having all of the WIP racks available the probability of not having the correct color is increased.

4.5 OPERATIONS AT INJECTION

4.5.1 Production Type

The injection machine produces the door lowers 98% of its scheduled time. For each cycle two parts are made, a left and right door lower. It is not possible to block one.

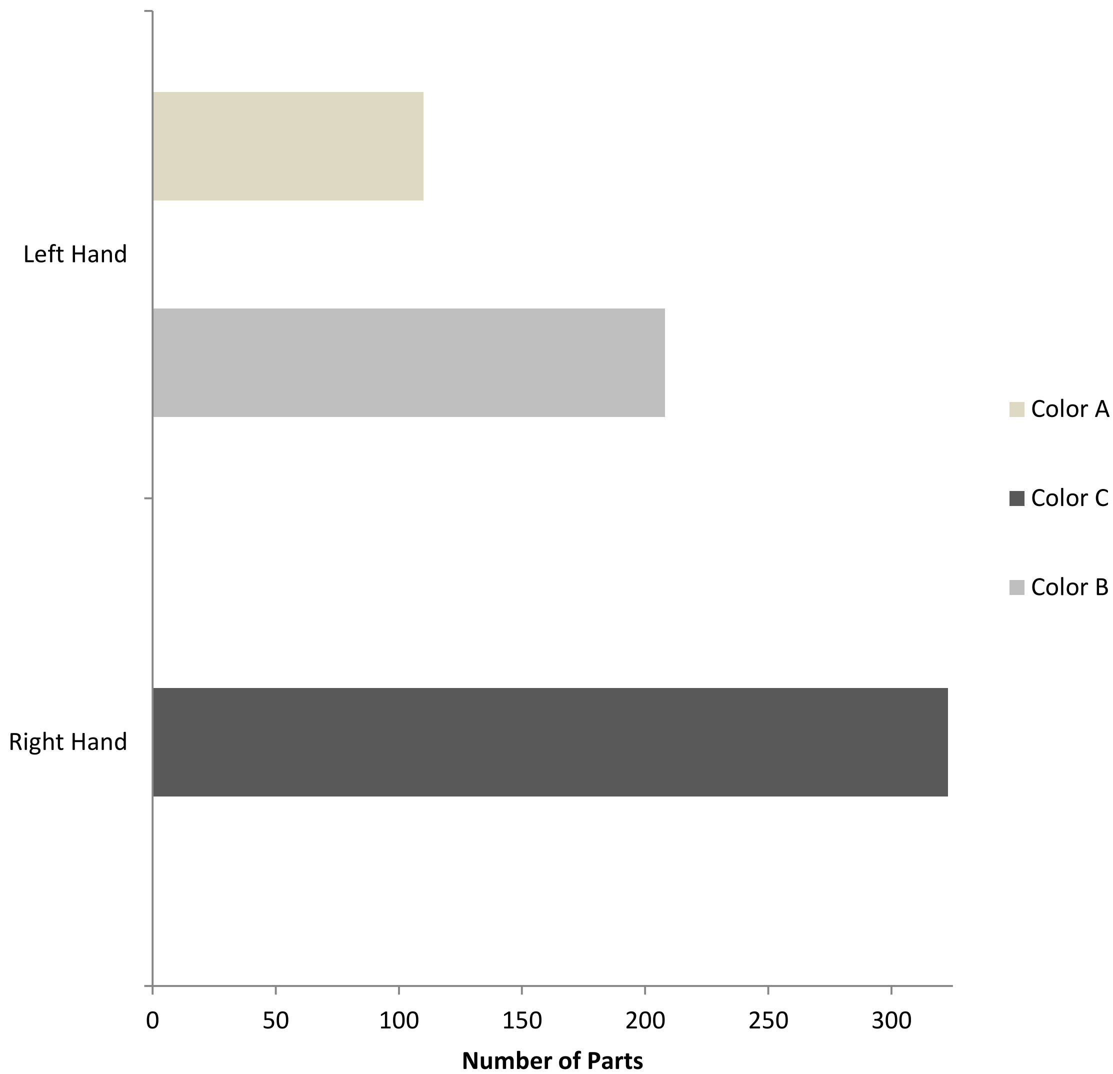

Figure 4-7. Quantity of unmatched left and right hand doors by color 8/2015- 10/2015 These doors are considered inventory and not WIP since they are not moving toward becoming a final product.

side of the die so that only one door can be made each cycle to balance the right hand left hand quantities. It has been attempted with poor outcomes

4.5.2 Scheduling

Scheduling is done by an office person that considers the on hand inventory, the customer demand, and the OEE of the machine. There is a focus towards attempting to ensure that the OEE is high, which leads to long color runs on the machine. The Injection supervisor relies on the scheduler to coordinate the appropriate color and amount instead of communicating with assembly.

4.5.3 Start up, Shut down, and Color Changes

At start up, material is fed into the machine and several parts are required before the machine is consistently making good parts. Shut down requires that the material in the machine be used and a cleaning agent used to completely clean the internals of the die. Color changes are estimated at 30 minutes. A color change is similar to the shutdown/startup procedure in that the die is emptied and cleaned (shutdown) before the new color is used (startup).

4.5.4 Operational Equipment Effectiveness

The OEE of the machine is important to production. OEE reflects how well the machine produced parts during production. The average OEE of the machine over the 8/2015 to 10/20115 is 69.1%.

Performance 94.7%: *The designed optimal rate is 50 cycles per hour, which yields 50 right hand lowers and 50 left hand lowers*. *The actual average performance is 94.7% as reported in the Access Database.*

4.5.4.1 *Quality 93.2%:* Of all the right and left had door lowers 6.8 percent are deemed defective for various reasons.

4.5.4.2 *Availability: 78.3%:* Over the 90 days reviewed that machine was down 21.7% of the scheduled hours.

4.5.4.3 *Result:* Even though the rate of the machine is 100 parts per hour the OEE was only 69.1% which means that it only created 69.1 parts in the time it should have created 100 parts. Figure 4-10 shows the hours to meet the daily demand as the OEE varies. As the OEE decreases the machine has to stay in production longer.

4.6 WORK IN PROCESS AREA

The WIP area is immediately adjacent to Assembly. The area can contain 1960 pieces of inventory and is only 2 minutes by fork lift from Injection. Therefore neither the location nor the size of the WIP area is a problem.

4.7 ASSEMBLY

Assembly consists of a right hand door line and a left hand door line. Each door line takes components and assembles the pieces and places the completed part in a finished goods container.

4.7.1 Scheduling

Scheduling is provided by the customer over computer system. The sequence of

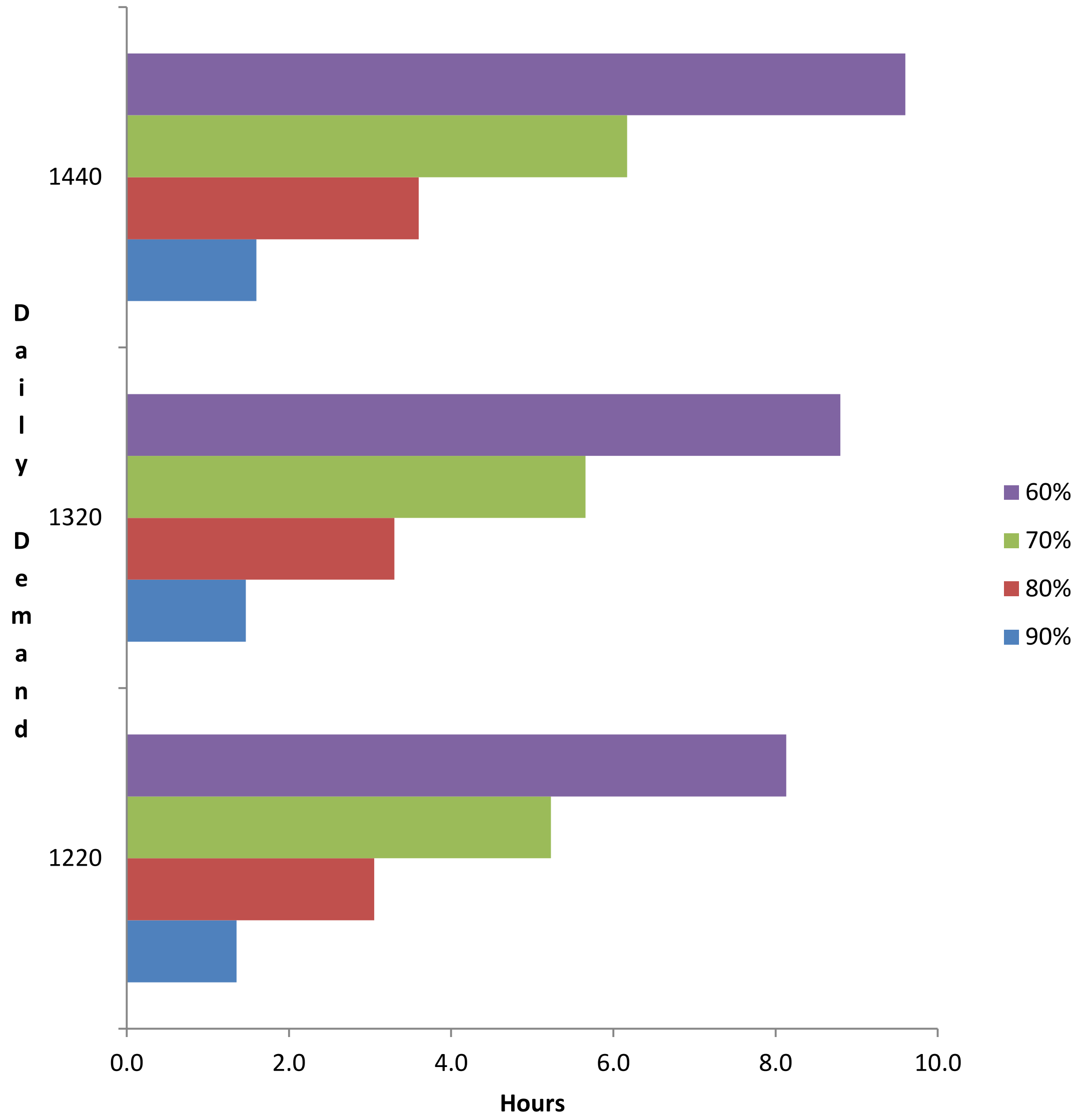

Figure 4-8. Extra hours required to meet demand by OEE

doors is displayed and verified by barcode scanner. Lots of 600 various doors are ordered at a time with a single due date. This gives Assembly some discretion about which order the sub lots of 30 doors can be produced.

4.7.2 Production Rate

Fully staffed each line can produce on average 58 doors an hour for a total of 116 doors per hour. A smaller second shift produces a total of 58 doors per hour to finish any demand not filled by first shift.

4.8 DETERMINE IF EOQ OR JIT IS A BETTER METHODOLOGY

To determine if EOQ or JIT is a better methodology first EOQ was used in various lot sizes and scheduling schemes to determine the best EOQ. Then a JIT methodology is used in the model and compared.

4.8.1 EOQ

To use the EOQ model first the yearly demand was estimated at 300,000 units by doubling the six month demand forecast. Then using the six month demand the color mix was estimated at 15% for color A, 40% for color B, and 45% for color C. These color mixes and yearly demand were substituted into the EOQ equation (Equation 5) and the results are in Table 4-1.

The overall EOQ lot size is 2739. These EOQ lot quantities were used in the production model to determine overall costs for the system. The individual colors were

Table 4-1. EOQ by color mix

	Color A	Color B	Color C	Total
Demand	45000.0	120000.0	135000.0	
EOQ	627.5	1024.7	1086.9	**2739.0**
Cycle Days	3.5	2.1	2.0	
Run Length	7.8	12.8	13.6	34.2

scheduled with their corresponding lot size in the model around the constraints. The inventory results are shown in Figure 4-9. The EOQ quantity of 2739 proved difficult to schedule given the constraints.

One of the benefits of the EOQ is that the curve is flat near the minimum lot size. A lot size near the 2739 quantity of 2400 was chosen since it is a multiple of the daily demand of 2400 pieces. Also the high lot size of color A proved difficult in scheduling and it was reduced to its color mix of 15% of 1200 or 180 pieces. Figure 4-10 shows the inventory levels for the 2400 lot size. This production quantity proved easier to schedule and the overall inventory was reduced. However during the periods when Injection was still continuously running and Assembly was not inventory built. Another method was used to split the continuous running and still have inventory sufficient for Assembly. This split-run scheme is shown in Figure 4-11.

Overall of the three EOQ simulations the split-run scheme was superior. The total costs for each scheme is given in Table 4-2.The split run benefited from its overall lower inventory holding costs. The split run model will be compared to the JIT scheme.

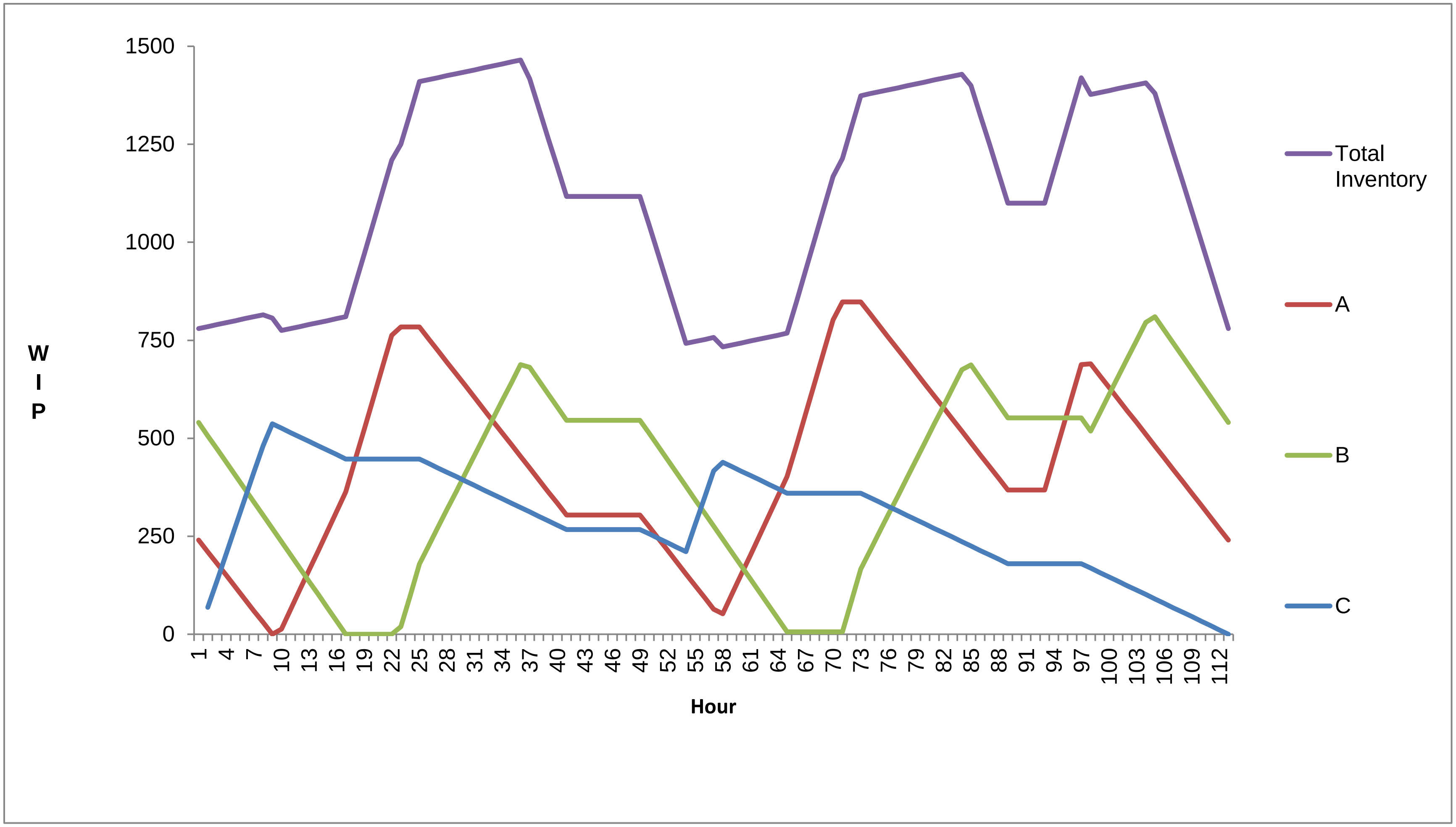

Figure 4-9. Inventory levels with EOQ of 2739

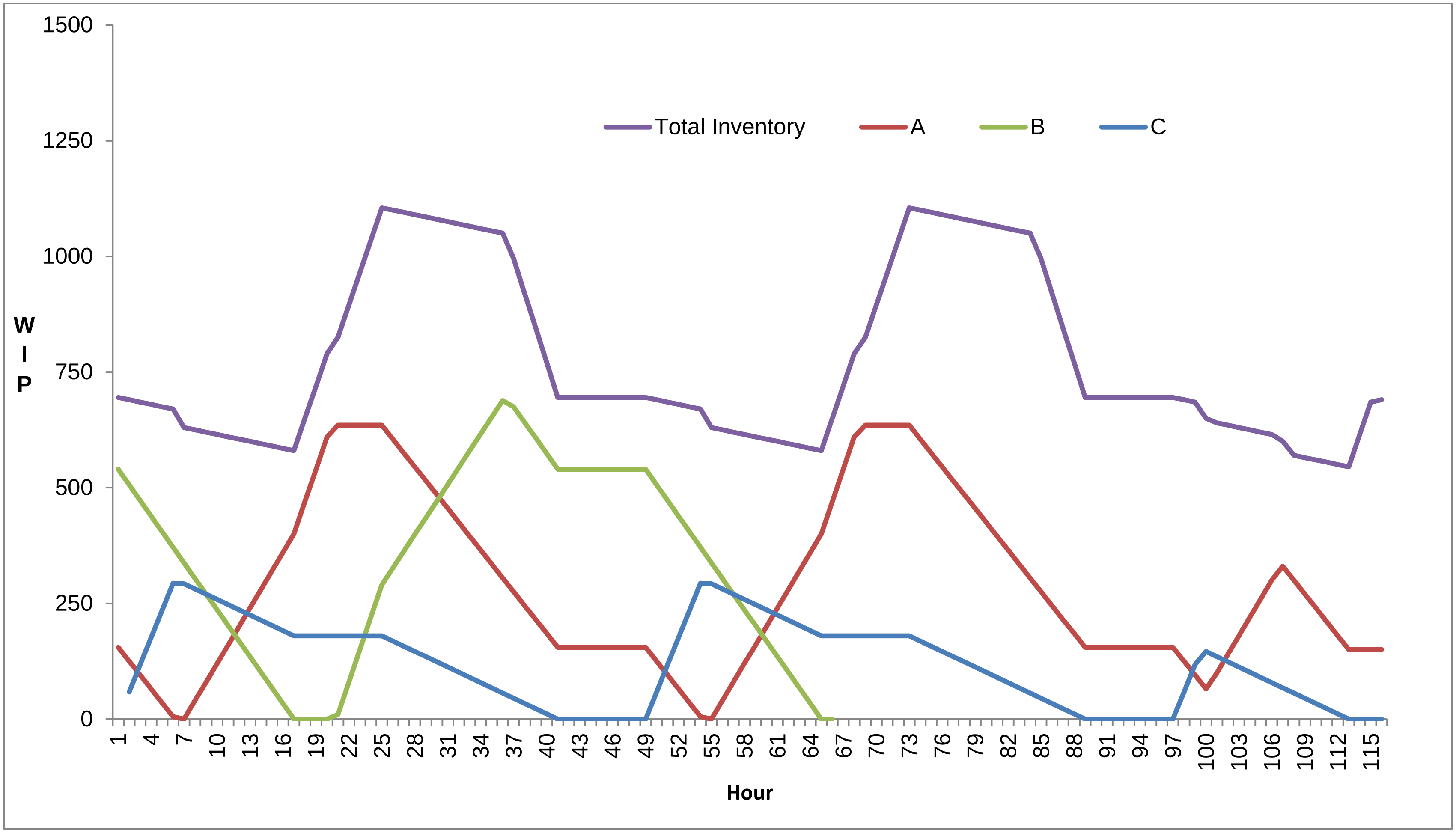

Figure 4-10. Inventory levels with EOQ of 2400

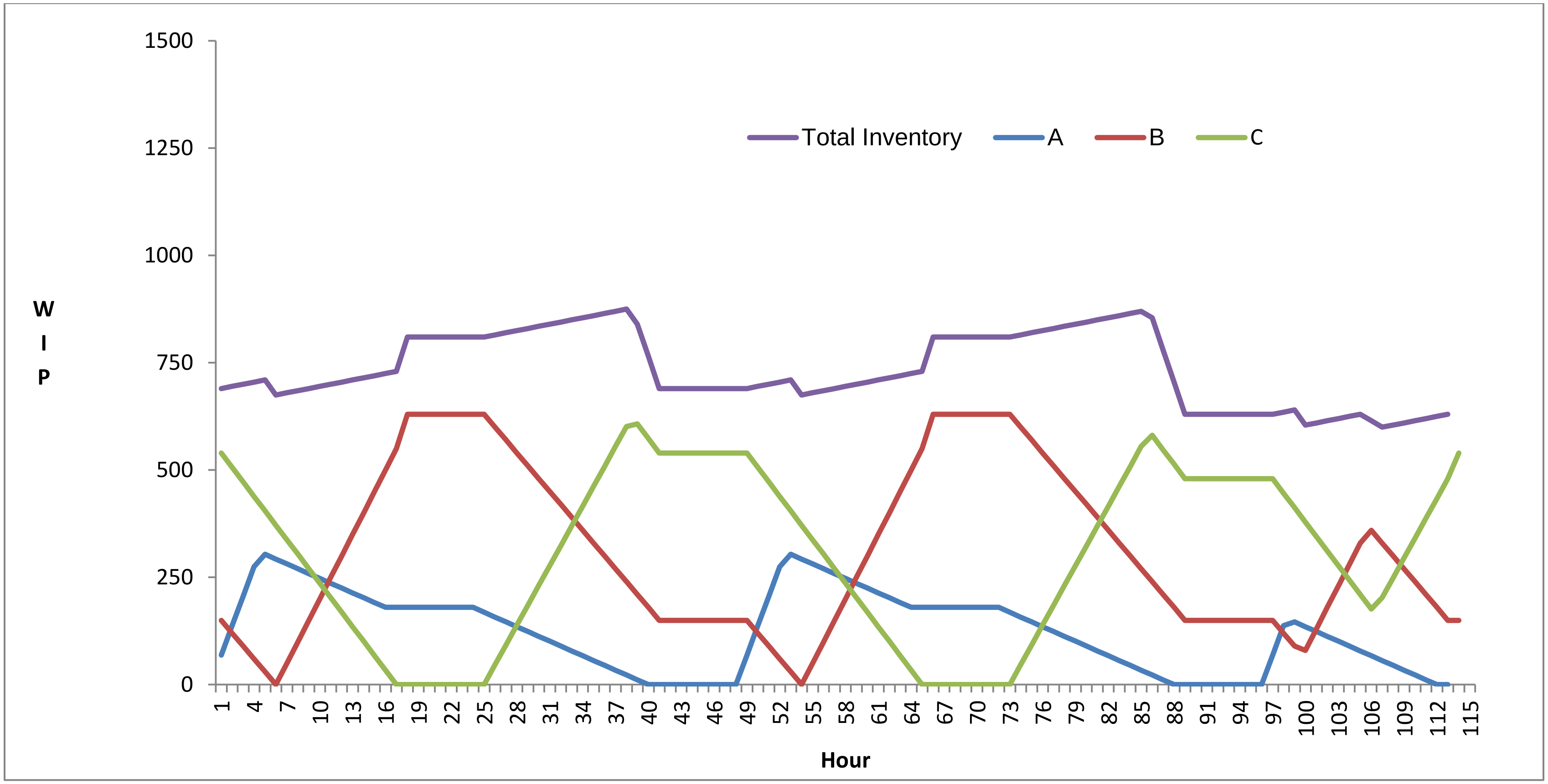

Figure 4-11. EOQ of 2400 and split run

Table 4-2. Comparison of the EOQ schemes

	Change over	Holding	Total
2739	$40,000	$19,185	$59,185
2400 Continuous	$45,000	$14,230	$59,230
2400 Split Run	$40,000	$11,296	$51,296

4.8.2 JIT Scheme

The JIT scheme consists of running all three colors every day. Each color lot will be its color mix of the overall daily demand. Figure 4-14 shows the inventory levels for the JIT scheme. Overall the JIT scheme produced significantly lower inventory levels compared to the EOQ models. However the JIT model produced much higher change over cost.

4.8.3 EOQ JIT Results

A summary of the results is found in Table 4-3. The results from the multiple simulations are found in Tables 7-1, 7-2, and 7-3 in the Appendix. Even though JIT outperformed the EOQ model in some aspects it was not the most cost effective .

4.8.3.1 Changeovers

The split run EOQ model had 5 start/stops and 3 color changes per week. JIT had many more with 5 start/stops and 10 color changes per week. This greater quantity

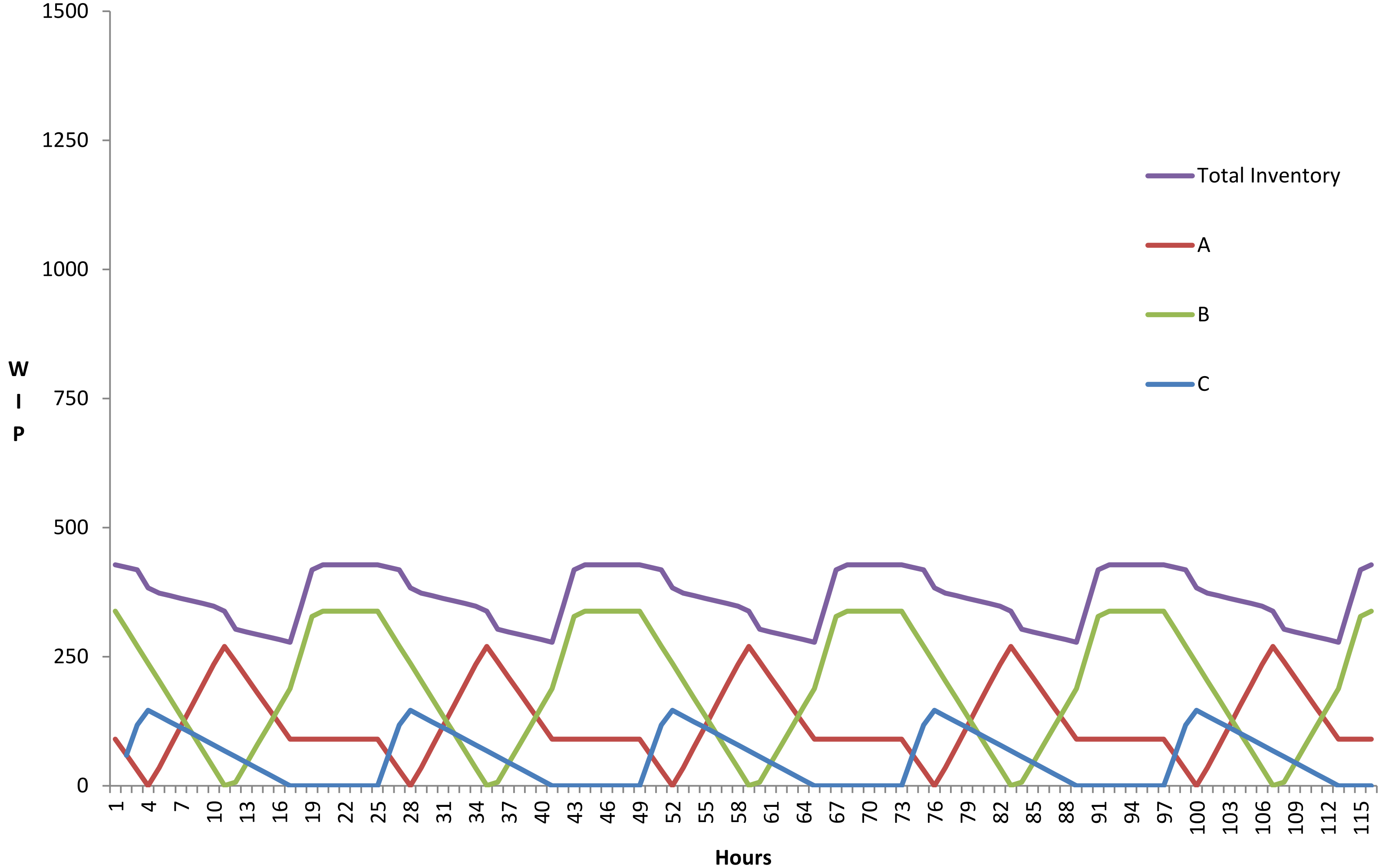

Figure 4-12. JIT Scheme at 1200 demand

Table 4-3. EOQ and JIT comparison results

	2739 EOQ	2400 Continuous	**Split Run**	JIT
EOQ	2,739	2,400	**2,400**	1,200
Daily Demand	1,200	1,200	**1,200**	1,200
Injection rate/hour	80	80	**80**	80
Assembly rate/hour	75	75	**75**	75
Holding Cost	$ 6.00	$ 16.00	**$ 16.00**	$ 16.00
Start/Stop/ Changeover Costs	$100	$100	**$100**	$100
Total Hours	112	112	**114**	113
Non Scheduled Hours	33	34	**36**	32
Startups/Shutdowns	3	3	**5**	5
Color Changes	5	6	**3**	10
Average Inventory	1,177	873	**693**	366
Max Inventory	1,525	1,365	**870**	384
Containers 14 parts each	109	98	**62**	27
Start/Stop/ Changeover Costs	$40,000	$45,000	**$40,000**	$75,000
Holding Cost	$18,832	$13,968	**$11,088**	$5,859
Total Cost	$58,832	$58,968	**$51,088**	$80,859

of color changes led the major cost difference with $40,000 for EOQ and $75,000 for JIT Inventory levels

JIT was significantly better in this category with an average inventory of 365 parts and a maximum of 428. Much better than the EOQ split model with an average inventory of 700 parts and a maximum of 815 parts. The cost savings from the inventory, $5327, was not enough to offset the extra $35,000 in color change costs.

4.8.3.2 Overall Costs

Overall the EOQ model's yearly cost was $51,296 compared to the JIT yearly cost of $80,969 for a difference of $29,673.

4.8.4 The EOQ model

For 2400 EOQ model with split a portion of the production models is found in Table 7-4 in the Appendix. Also in the Appendix in Figure 7-1 is a visual representation of the production schedule.

4.8.5 Could JIT cost less

Could the JIT model cost less if either the setup costs were lowered or the holding costs were increased. The setup and holding costs were varied until the JIT model became less costly than the EOQ split model. This occurred when the setup costs were $10 and the holding costs were $110 per year. The material used to change over the machine costs more than $10 dollars and it seems unlikely that the holding costs for a $7 part would be greater than $110 dollars.

4.9 BOTTLENECK ANALYSIS

Determining the bottleneck of an operation is key to improving flow from raw materials to finished goods. During the Assembly and Injection analysis the production rates of both areas were found. Optimally Assembly should be able to produce 116 parts per hour and Injection 100 parts per hour. In this case, Injection has low OEE so that its effective production is only 69 parts per hour. Since Assembly is able to keep its production rate as long as there are parts available, the Injection process is the bottleneck.

If Injection could keep pace with Assembly then 2784 doors could be produced in a day. Since Injection production rate averages 69 per hour then production is limited to 1656 per day. This means that Injection has to produce while Assembly is not to keep from starving assembly.

4.10 RECOMMENDATIONS

After analyzing the system, there are many opportunities for improvement. Recommendations for altering the system to increase throughput, reduce costs, are given.

4.10.1 Reserve empty racks for the next shift

The original problem that led to the investigation was the report of “No Racks/Totes.” Until some of the other recommendations could be implemented then several racks should be set aside during the day for the beginning of the next shift. This would alleviate some of the downtime associated with startup and increase the OEE of the machine.

4.10.2 Dispose of inventory held in WIP racks

The first suggestion is to dispose of the doors that do not have counterparts that are consuming the WIP racks. This inventory effectively prevents the bottleneck from being fully utilized since it cannot fill these racks with the appropriate part on time. By holding this inventory, scheduling the machine becomes more difficult and increases color changes.

Once scheduling and inventory levels have reduced and racks become free then racks can be held for offhand inventory. This inventory has to be restricted to prevent refilling with inventory.

The cost of disposing 15 racks of doors is $1470. Currently Injection averages 12 color changes per week. If the averages drop to 5 as in the EOQ model then the cost would be recouped in two weeks from reduced color changes.

4.10.3 Two shifts on Assembly

Assembly should be moved from the high output mixed shift model to a true dual shift operation. Moving to two shifts would reduce the production rate from 116 parts per hour to 75 parts per hour for the average demand of 1200 parts per day. This production level would more closely match the actual ability of the injection machine to produce and would lower inventory levels

4.10.4 Consider Injection and Assembly as part of one long process

Currently the injection machine is seen as a separate from the assembly process. The injection machine should be viewed as the first station in the assembly process. In the assembly process if one station required that 1400 parts be stored as

WIP to prevent the rest of the line from starving then the problem would be obvious. Since this machine serves the assembly line 98% of the time is should be considered the first station in assembly.

Currently the company hierarchy has Assembly and Injection in two separate management departments. The entire process, from raw injection material to final assembled part, should be managed by one team that had the overall goal of producing finished doors instead of their individual components.

4.10.5 Improve the effectiveness of the injection machine

The injection machine has a low OEE of 69%. This requires the machine to run much longer than it should. This also requires inventory to be built to prevent Assembly from starving. Assembly then can consume the inventory so fast that it often runs out of a color and forces a color change at Injection. The OEE of the machine should be improved so that inventory can be reduced. Overall throughput on this particular door model will not be increased because the demand is set by the customer. However, overall output of the machine may be increased by free time to run other products.

If other products are brought on board the machine the increased revenue from the new products would compensate for the increased die and color changes.

4.10.6 Let inventory run our for diagnostics

The current mode of operation for the manufacture is to fill all available racks and then close the machine for the weekend. Injection machines are difficult to troubleshoot when they are not producing. By allowing some free racks over the weekend the maintenance and improvement could be performed.

5 CONCLUSION

A large manufacturer presented with downtime issues attributed to racks not being available when an injection machine was scheduled to run. These racks carry work-in-process to an assembly area for completion into a finished good. A reactionary response would be to simply order more racks. Instead, a system analysis was performed to determine what the scope, cause, and an appropriate solution to reduce the downtime issue.

The downtime issue was found to affect every injection machine and the study was confined to the machine with the greatest occurrences of the issue. The machine was dedicated to produce one product 98% for an assembly process.

The most immediate cause for lack of racks was a procedure that all racks are filled before the injection machine was stopped for the night. Then injection and assembly would begin at the same time in the morning which caused injection to be down until assembly could empty racks. However this was not the true root cause.

During the analysis the quantity of racks was found not to be the cause of the issue. However 15 racks were found to be carrying inventory instead of WIP which reduced the number or available racks.

Once the quantity of racks was ruled out, an analysis of the workings of the injection and assembly system was performed. Injection and assembly were found to have poor communication about the quantity and color of required product needed.

The injection machine was found to be the bottleneck operating nearly 24 hours per day while assembly operated about 12 hours. This mismatch in production required inventory to be built ahead of time to prevent starvation at assembly. Occasionally the inventory build was in the correct color which forced color changes at injection.

Rack quantity was not the root cause of the downtime issue. A combination of scheduling and production rates caused assembly to draw parts faster than injection could produce which causes color changes which caused the injection to produce even slower.

A production model was created to test several different production schemes to determine a better production method. Lowest cost was used as the judgment criteria for the model. Several versions of the Economic Order Quantity were compared to an JIT approach. One EOQ model was found to cost less than the other EOQ models and the JIT model.

Several recommendations were made on improving the process including changing the assembly's work schedule to be closer to the average injection production.

In complex systems, the symptom often highlights greater problems inside of the system. Treating the symptom may not cure the underlying issue. In this case a "No Racks/Totes" issue actually represented communication, scheduling, bottleneck, and production issues as part of the system.

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APPENDIX

Table 5-1.Part 1 of Simulations

Notes	Base	Continuous	Split	Continuous	Split
EOQ	2,739	2,400	2,400	2,400	2,400
Daily Demand	1,200	1,200	1,200	1,200	1,200
Injection rate/hour	80	80	80	70	70
Assembly rate/hour	75	75	75	75	75
Holding Cost	110	110	110	110	110
Start/Stop/ Changeover Costs	100	100	100	100	100
Total Hours	112	112	114	115	113
Non Scheduled Hours	33	34	36	25	24
Startups/Shutdowns	3	3	5	3	5
Color Changes	5	6	3	6	4
Average Inventory	1,177	873	693	773	698
Max Inventory	1,525	1,365	870	1,105	815
Containers 14 parts each	109	98	62	79	58
Changeover Costs	$40,000	$45,000	$40,000	$45,000	$45,000
Holding Cost	$129,470	$96,030	$76,230	$85,030	$76,727
Total Cost	$169,470	$141,030	$116,230	$130,030	$121,727

Table 5-2. Part 2 of Simulations

Notes	Continuous	Split	Continuous	Continuous	Split
EOQ	2,400	2,400	2,880	2,880	2,880
Daily Demand	1,200	1,200	1,440	1,440	1,440
Injection rate/hour	70	70	70	100	100
Assembly rate/hour	116	116	90	90	90
Holding Cost	110	110	110	110	110
Start/Stop/ Changeover Costs	100	100	100	100	100
Total Hours	113	114	118	112	112
Non Scheduled Hours	26	25	12	36	37
Startups/Shutdowns	3	5	3	3	5
Color Changes	6	4	6	6	4
Average Inventory	752	648	782	1,131	967
Max Inventory	1,227	898	1,047	1,787	1,147
Containers 14 parts each	88	64	75	128	82
Changeover Costs	$45,000	$45,000	$45,000	$45,000	$45,000
Holding Cost	$82,720	$71,280	$86,020	$124,410	$106,370
Total Cost	$127,720	$116,280	$131,020	$169,410	$151,370

Table 5-3. Part 3 of Simulations

Notes	Daily Setups - 60	Daily Setups - 70	Daily Setups -80	Daily Setups-90
EOQ	1,200	1,200	1,200	1,200
Daily Demand	1,200	1,200	1,200	1,200
Injection rate/hour	60	70	80	90
Assembly rate/hour	75	75	75	75
Holding Cost	110	110	110	110
Start/Stop/ Changeover Costs	100	100	100	100
Total Hours	116	115	113	110
Non Scheduled Hours	15	23	32	40
Startups/Shutdowns	5	5	5	5
Color Changes	10	10	10	10
Average Inventory	358	364	366	373
Max Inventory	462	428	384	465
Containers 14 parts each	33	31	27	33
Changeover Costs	$75,000	$75,000	$75,000	$75,000
Holding Cost	$39,380	$40,040	$40,282	$41,074
Total Cost	$114,380	$115,040	$115,282	$116,074

Table 5-4. Two Days of EOQ split schedule

		Injection Production			Assembly Production			Inventory			Total Inventory
Day	Hour	A	B	C	A	B	C	A	B	C	
1		360	960	1080					150	540	690
1	6:00	80			11	30	34	69	120	506	695
1	7:00	80			11	30	34	138	90	473	700
1	8:00	80			11	30	34	206	60	439	705
1	9:00	80			11	30	34	275	30	405	710
1	10:00	40			11	30	34	304	0	371	675
1	11:00		80		11	30	34	293	50	338	680
1	12:00		80		11	30	34	281	100	304	685
1	13:00		80		11	30	34	270	150	270	690
1	14:00		80		11	30	34	259	200	236	695
1	15:00		80		11	30	34	248	250	203	700
1	16:00		80		11	30	34	236	300	169	705
1	17:00		80		11	30	34	225	350	135	710
1	18:00		80		11	30	34	214	400	101	715
1	19:00		80		11	30	34	203	450	68	720
1	20:00		80		11	30	34	191	500	34	725
1	21:00		80		11	30	34	180	550	0	730
1	22:00		80					180	630	0	810
1	23:00							180	630	0	810
2	0:00							180	630	0	810
2	1:00							180	630	0	810
2	2:00							180	630	0	810
2	3:00							180	630	0	810
2	4:00							180	630	0	810
2	5:00							180	630	0	810
2	6:00			80	11	30	34	169	600	46	815
2	7:00			80	11	30	34	158	570	93	820
2	8:00			80	11	30	34	146	540	139	825
2	9:00			80	11	30	34	135	510	185	830
2	10:00			80	11	30	34	124	480	231	835
2	11:00			80	11	30	34	113	450	278	840
2	12:00			80	11	30	34	101	420	324	845
2	13:00			80	11	30	34	90	390	370	850
2	14:00			80	11	30	34	79	360	416	855
2	15:00			80	11	30	34	68	330	463	860

Table 5-4. Two Days of EOQ split schedule

(Continued)

		Injection Production			Assembly Production			Inventory			Total Inventory
Day	Hour	A	B	C	A	B	C	A	B	C	
2	16:00			80	11	30	34	56	300	509	865
2	17:00			80	11	30	34	45	270	555	870
2	18:00			80	11	30	34	34	240	601	875
2	19:00			40	11	30	34	23	210	608	840
2	20:00				11	30	34	11	180	574	765
2	21:00				11	30	34	0	150	540	690

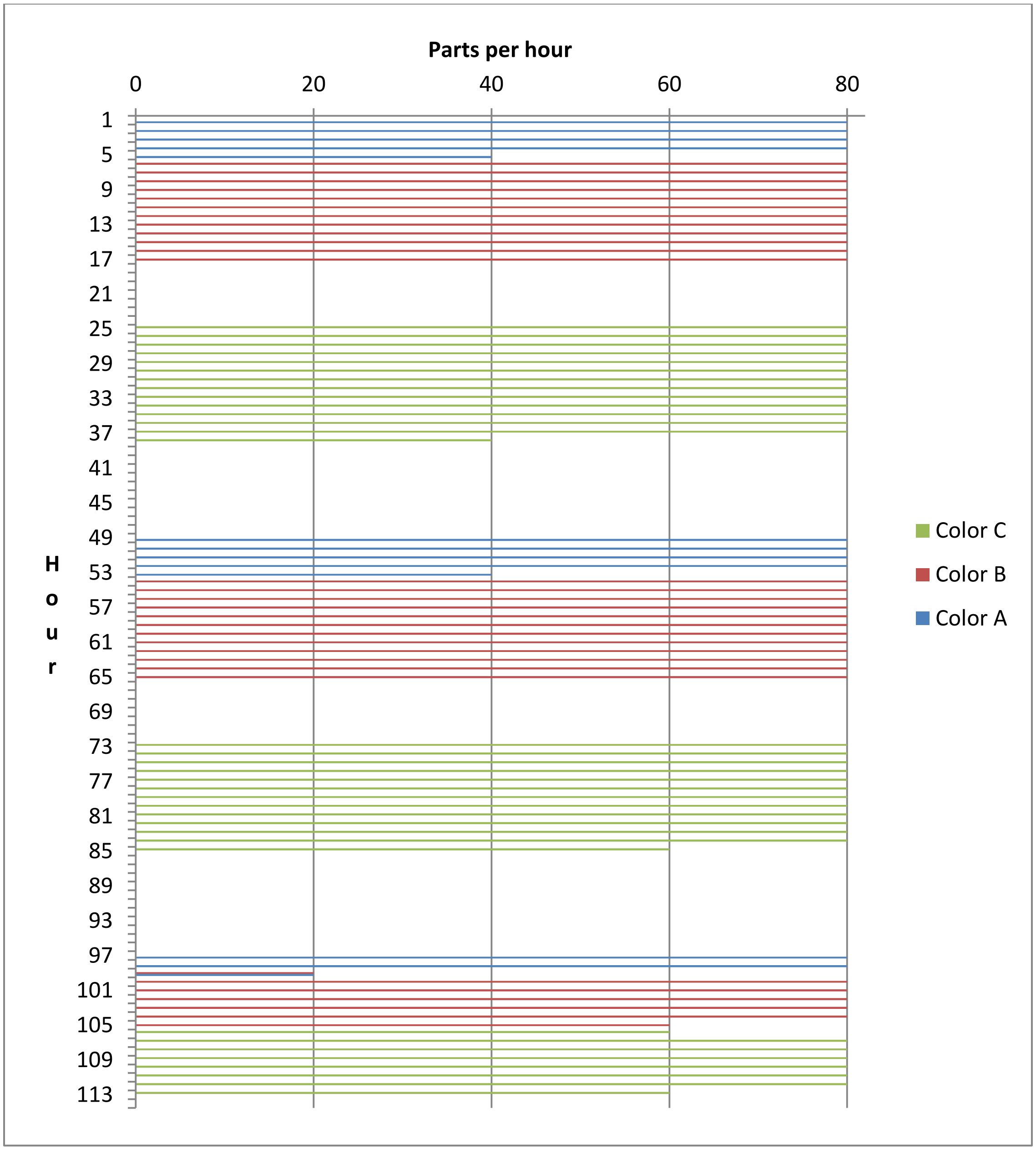

Figure 5-1 Visual representation of three color scheduling on EOQ 2400 split

VITA

James is a graduate of the University of Tennessee at Martin (UTM) with a Bachelors of Science in Engineering and the University of Tennessee with a Masters in Industrial Engineering. James was president of the local student chapter of Society of Manufacturing Engineers (SME) at UTM. He enjoys philosophy, movies, and finding subtly implied messages in commercials.