

Performance Measures for a System Managed Using Backflushing: Medical Device Manufacturing's Case

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Abstract

Lean Manufacturing philosophy is centered in the idea of eliminating waste, such as unnecessary transactions. It is common for manufacturers to track every material movement, creating with each movement a transaction. Backflushing techniques are employed in order to reduce the number of transactions triggering them only in two specific stages: at the entrance of material to the system and at the exit of products from the system. This technique is better suited for products with small lead times. Motivated by a medical device manufacturing facility with long lead times, our work provides the project site an inventory tracking system that estimates the current usage of material keeping backflushing's spirit. A simulation model was developed gathering the characteristics of the current system relevant to the study. The inventory tracking system estimates work in progress inventory through weighted average of scrap. The system is accurate with less than 10% of error.

Resumen

“Lean Manufacturing” basa su filosofía en la eliminación de desperdicios como por ejemplo, transacciones innecesarias. Las compañías manufactureras llevan registro de cada movimiento de material, creando de esta manera una transacción al sistema por cada uno de ellos. “Backflushing” es una técnica empleada con el objetivo de reducir el número de transacciones. Estas transacciones se llevan a cabo únicamente en dos puntos específicos: a la hora de entrar material al sistema y cuando el producto terminado sale del mismo. Una de las características principales que deben tener los sistemas que adquieren este método es el corto tiempo que transcurre entre estas dos transacciones. Motivado en manufacturera de componentes médicos, nuestro trabajo provee a la empresa un sistema de rastreo de inventario que estima el uso de material actual manteniendo el mismo número de transacciones. Se desarrolló un modelo de simulación el cual reúne las características del sistema que son relevantes para este estudio. El sistema de rastreo de inventario estima el inventario en proceso a través de un promedio ponderado del desperdicio. El valor estimado es certero con menos de 10% de error.

To God for being my light all the time
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Table of Contents

Abstract	iii
Resumen	iv
Acknowledgments	vi
Table of Contents	viii
Table List	x
Figure List	xi
1. Introduction	1
2. Background	3
2.1 Company's Background	3
2.2 Traditional vs. Backflushing System	5
2.3 Backflushing's Implementation Appropriateness	7
2.4 Suggestions and Examples	9
3. Problem Statement	12
3.1 Machine Center's Material Flow Description	13
3.2 Material Usage Calculation	14
4. Methodology	18
4.1 Data Analysis	18
4.1.1 Manufacturing Process Description	18
4.1.2 Transaction Data	20
4.1.3 Material Usage Calculation and its Challenges	21
4.2 Theoretical Model	25
4.2.1 Inputs Variables	27
4.2.2 Model Description	29
4.2.3 Model Verification	30
4.2.4 Model Validation	32
4.2.5 Performance Measure Methodology	34
a. Attempt: Constant Loss Rate	35
b. Attempt: Lot Case	36
c. Attempt: Lower and Upper Scrap	41
4.3 Sensitivity Analysis	42

5.	Results	43
5.1	Constant Loss Rate	43
5.2	Lot Case	44
5.3	Lower and Upper Bound on Scrap	44
a.	Fixed Yield	44
b.	Yield Based on a Normal Distribution	46
c.	Yield Based on Uniform Distribution	48
d.	Yield Based on Triangular Distribution	51
5.4	Yield Monitoring	54
5.5	Planning Tool	56
6.	Conclusions and Future Work	58
7.	Bibliography	61
8.	Appendices	63
A.	Glossary	63
B.	Kanban Card	65
C.	Transaction Historical Summary Report	66
D.	MU Equation Proof	67
E.	Family Type A Flow Chart	69
F.	Family Type B Flow Chart	71
G.	Manufacturing Planning Sheet	73
H.	Normal probability plots	77
I.	ProModel Codes	79
J.	Attempt: Lower and Upper Scrap Sheet Results	104
K.	WIP Estimate Implementation Methodology	109

Table List

Table 1. Material Usage versus Scrap	15
Table 2. Material Usage versus Scrap and WIP for October 2012	16
Table 3. Percent of yield per process	27
Table 4. Entities used in the Simulation Model	28
Table 5. Lot Size per Entity	28
Table 6. Confidence Interval Results	34
Table 7. Variables to be vary	42
Table 8. Constant Loss Rate: Average Absolute Error Results.....	43
Table 9. Lot Case: Average Absolute Error Results	44
Table 10. Fixed Value of Yield: Average Absolute Percent of Error Results.....	45
Table 11. Average Absolute Percentage Error Using Normal Distribution	46
Table 12. Average Absolute Percent Error Using Uniform Distribution	48
Table 13. Average Absolute Percent Error Using Triangular Distribution.....	51
Table 14. Yield monitoring Example	55
Table 15. Planning Tool	56
Table 16. Pivot Table Number of Lots Transactions made to Stock.....	111

Figure List

Figure 1. Illustration of MRP and Backflushing transactions points	6
Figure 2. Drouillard Matrix based on Drouillard (2011).....	8
Figure 3. Material flow and transactions.....	19
Figure 4. Mismatch between material usage and scrap cause and effect diagram	21
Figure 5. Material Usage Variability.....	24
Figure 6. Material Usage vs. Scrap	25
Figure 7. Input – Output Variables.....	26
Figure 8. Model Conceptualization	29
Figure 9. Truncation Point	30
Figure 10. Performance measure graphic representation	36
Figure 11. Case 1 Graphical Example.....	37
Figure 12. Case 2 Graphical Example.....	38
Figure 13. Case 3 Graphical Example.....	39
Figure 14. Case 4 Graphical Example.....	40
Figure 15. Fixed Value of Yield: Average Absolute Percent of Error	45
Figure 16. Average Percent of Error Results: Yield Based on a Normal Distribution, 5 Days MU Period	47
Figure 17. Average Percent of Error Results: Yield Based on a Normal Distribution, 10 Days MU Period	47
Figure 18. Average Percent of Error Results: Yield Based on a Normal Distribution, 20 Days MU Period	48
Figure 19. Average Percent of Error Results: Yield Based on a Uniform Distribution, 5 Days MU Period	49
Figure 20. Average Percent of Error Results: Yield Based on a Uniform Distribution, 10 Days MU Period	50

Figure 21. Average Percent of Error Results: Yield Based on a Uniform Distribution, 20 Days MU Period	50
Figure 22. Average Percent of Error Results: Yield Based on a Triangular Distribution, 5 Days MU Period	52
Figure 23. Average Percent of Error Results: Yield Based on a Triangular Distribution, 10 Days MU Period.....	52
Figure 24. Average Percent of Error Results: Yield Based on a Triangular Distribution, 10 Days MU Period.....	53
Figure 25. Probability plot for AC_398 (Real Data).....	77
Figure 26. Probability plot for AC_398 (Simulated Data).....	77
Figure 27. Probability plot for AH_402 (Real Data).....	78
Figure 28. Probability plot for AH_402 (Simulated Data).....	78
Figure 29. Transaction Historical Summary Oracle Window	109
Figure 30. Exported Report in Microsoft Excel Sheet	110

1. Introduction

This project proposes a material tracking system that estimate actual work-in-progress (WIP) inventory achieving less than 10% of error based on an average percent of scrap. The system was developed for a **job shop**¹ keeping a **minimum number of transactions**. The suitability of the system is tested in an actual manufacturing facility.

Why minimum number of transactions? Traditional planning systems and control, such as Material Requirements Planning (MRP) systems, keep track of every material movement. The benefit of this system is that each transaction is tracked and recorded (including scrap and work-in-progress inventory). Therefore, real time monitoring of manufacturing activities become easier. On the other hand, traditional systems require massive number of transactions. Massive number of transactions results in a higher likelihood of data entry errors; as well intensive labor effort is required.

The actual system has been implemented at the company since 2003. This system reduces the number of transactions contrary to MRP system. Some of the benefits this system encourages are reduction in man-hours due the minimum transactions and decreases data entry errors. The challenge of this system is that it is designed to be appropriate in manufacturing areas with specific characteristics such as short lead time which is not the case we are studying.

The WIP estimate presented in this project was developed for a **job shop** system with long lead times. In order to find a system that could be implemented easily at the company keeping the minimum number of transaction's concept, a methodology process frame was developed. First, we analyzed the actual system and studied it challenges. As a second step, a theoretical environment

¹ Note: Bold words are used to identify terms explained in the appendix (A).

was created using simulation software called ProModel©. The model gathered the characteristics of the current system relevant to the study. This model was validated using lead time as the main metric. Once our model was validated, it was used as reference of the real system. Several attempts were worked out to obtain an average percent of error less than 10% estimating WIP inventory. Then, additional models were created to analyze system behavior while varying specific parameters. An accurate performance measure was developed and suggested to the company.

This project is organized as follows: First, we explain the background about the company and their actual situation. Also, academic references about backflushing system. In Section 3, we provide a complete description of the problem. Methodology is explained in Section 4, including the analyses performed. In section 5 we include the results obtained by applying different attempts and scenarios. Finally, conclusions and future work are presented in Section 6. References are cited in Section 7. At the end of this document we add a glossary with the most important terms used in this study and appendices.

2. Background

This section reviews the most relevant works related to the Backflushing system. Backflushing's academic literature is scant, nonetheless, there are several examples of companies that have ventured in implementing this system in their manufacturing processes. Most of the information presented below was found in recent books and web pages. This section is organized as follows: a background of the company is provided first; second, we explain what backflushing is and how is different from MRP systems; followed by its implementation appropriateness; and, finally, a brief description on how companies have been succeeded in the implementation of backflushing.

2.1 COMPANY'S BACKGROUND

Worldwide organizations select several performance measures in order to manage their company to a competitive environment. Material usage is a common measure for systems managed using **backflushing**² method. Material usage (i.e. the arithmetic difference between input and output) specifically targets the performance of the system regarding material. However, backflushing is commonly used in systems with specific characteristics such as: employee high knowledge level, accurate traceability system, and short production lead time (Braggs, 2005).

In practice, a system meeting all of the above characteristics is very hard to find. This is the case for the company where this project takes place, a medical device manufacturer in Puerto Rico³. In such an example, the metric has been implemented with mild alterations to account for long **flow**

²Backflushing: is a method for issuing materials that do not make entry transactions to the floor unless a product has been completed (Bragg, 2005)

³ The company studied is a worldwide leader in the medical device industry. It is one of the largest players in the global orthopedic market.

times⁴. Even so, the results for material usage are incongruous (e.g. negative values in some instances) and most of the times are not close to the material usage values observed physically by the personnel familiar with the manufacturing area. Hence, this project targets to develop a performance metric inspired by the material usage metric's simplicity and leanness, providing an accurate performance metric.

The measure of *material usage* (hereafter referred as "MU") is a very well-known performance metric in the company. MU was introduced as part of a backflushing system (i.e. an alternative to material movement transactions which are considered waste within the lean manufacturing philosophy).

Lean Manufacturing techniques have been continuously implemented at the company since 2001. Lean Manufacturing implementation brought new inventory control systems such as **kanban** and **backflushing**. The application of kanban systems preceded the implementation of backflushing. Kanban was implemented as an inventory management technique to regulate material movement within the manufacturing facility. In this system, an electronic transaction was generated whenever a kanban card was moved. The electronic transaction had information about the part number moved, the quantity contained, and the route from-to information. See appendix (B).

As an effort to reduce the number of electronic transactions, a backflushing method was implemented in 2003. Backflushing, in theory, reduces the number of transactions by triggering them only at two specific stages: One transaction is made at the entrance of raw material to the manufacturing area and the other is made when finished goods are moved from the manufacturing area. However, the manufacturing area in question has intermediate transactions before the raw material is transformed into finished good. Nonetheless, the number of transactions is still less than in a regular kanban system.

⁴ For the purpose of this project long flow time (lead time) has been defined as per Braggs (2005). He stays "the production process must be a short one, preferably completing products in a single day".

In spite of backflushing reducing paperwork and the number of transactions made to the system, its implementation has brought disagreement between the Engineering Department and the Finance Department. Kaur (2011) explains that in terms of cost, backflushing is a “method that works backward from the output to assign manufacturing cost to **WIP** and inventories”.

Even though the current MU outcome is not easy to understand, the advantages of having a metric that calculates scrap or WIP accurately without incurring in system transactions and without relying in operators scrap reports is a good alternative. For this reason, the target for this project is to evaluate and develop a performance measure that could accurately keep track of the WIP inventory.

2.2 TRADITIONAL VS. BACKFLUSHING SYSTEM

As any company managed by “Lean Manufacturing Philosophy”, the medical device manufacturer has been implementing different techniques pursuing to eliminate any kind of waste. One of these powerful techniques is Backflushing. As per Brooks & Wilson (2007), backflushing is a method where the updating inventory records is made at a deduct point defined in the manufacturing process. “All of the parts assumed to have been used in the process to that point are then deducted from stock”. In other words, backflushing is a transactional method used by Just in Time (JIT) philosophy where not all physical movements’ records are necessary. Recall that unlike backflushing, in a traditional **MRP system** every inventory movement must be transacted.

Reduction in transactions is better explained with the following comparative example:

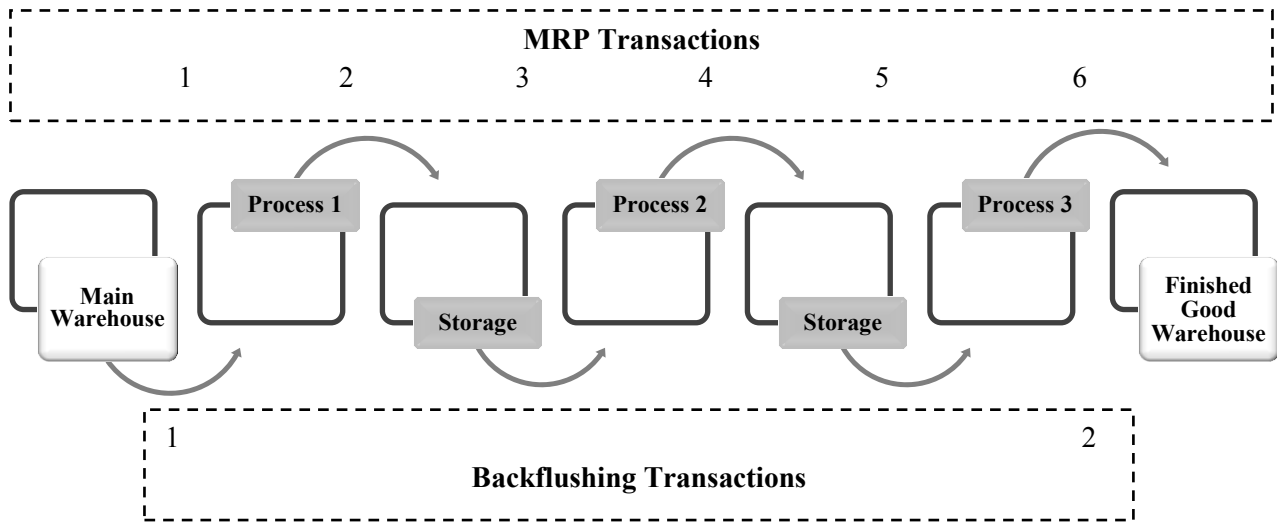


Figure 1. Illustration of MRP and Backflushing transactions points

Figure 1 depicts how backflushing implementation reduces the number of transactions in a manufacturing process. For this particular example, a traditional MRP system required six transactions for the entire process, one for each material movement from/to an inventory location. Backflushing technique only requires two transactions, one for incoming material and the other for outgoing material.

Transactions are considered as non-value-added activities in a JIT environment. Piasecki (2010), Braggs (2005), Drouillard (2011), and Gaw (2007) identify reduction in transactions, man-hours, and errors in data entry as the main contribution provided by a backflushing implementation. However, backflushing may not be suited for all processes, as it is known to work well for a subset of manufacturing processes meeting very specific characteristics.

2.3 BACKFLUSHING'S IMPLEMENTATION APPROPRIATENESS

Braggs (2005) explains that for a successful backflushing inventory tracking system the manufacturer must meet certain characteristics:

1. Process **lead times** should be short, if not a cycle-counting becomes necessary to report the WIP. It is preferable to complete the products in a single day to avoid inventory inaccuracy. In addition, "It may state that inventory is on hand that is actually currently in production".
2. The personnel in charge of making the transactions must be disciplined to minimize data entry errors.
3. Scrap generated in the process has to be traced. If this is not done, the reported inventory levels will be too high because it is not eliminated from the inventory database through backflushing.

Piasecki (2010) adds that backflushing is also advantageous when scrap is frequent in the finished item ("you continue to produce until you have a good quantity equal to the ordered quantity") and when point - of - use materials is applied. He also noticed that if production is very long (i.e. days or weeks), quantities produced need to be posted periodically (e.g. each shift or each day) instead of wait until the entire run is complete.

Drouillard (2011) created a matrix identifying conditions that make backflushing work. He explained that in the 4th quadrant (see Figure 2) backflushing requires fewer resources than the other three quadrants. Facilities located in this quadrant have the following characteristics: low variation in component usage (low scrap, infrequent non-standard component usage, no component substitution) and short manufacturing lead times (parts are manufactured fast, no waiting line queues, no traveling between operations). He also explains that if a company is located in one of the other quadrants, backflushing becomes expensive because:

- Unplanned inventory transactions and/or lack of inventory visibility due to long lead times.
- A dependence on **cycle-counts** becomes necessary due to inventory inaccuracy. He stays that “cycle counting is an expensive process that often introduces as many errors as it corrects”.

The company is located in the first quadrant. Medium or high input/output (I/O) ratio which means this ratio is not stable (positives and negatives values). Despite the existence of intermediate backflush points, the production lead time is considered medium or long (i.e. time between transactions).

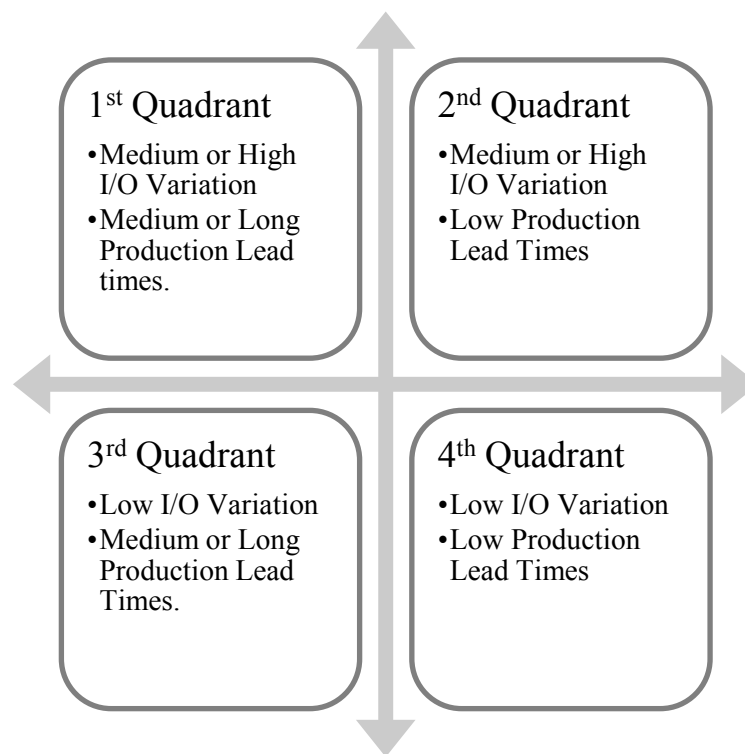


Figure 2. Drouillard Matrix based on Drouillard (2011)

Drouillard (2011) states that “without low part Input/Output variation through low scrap; non-standard usage; and substitution of parts, system inventory levels become unreliable”.

Transactions do not occur as quickly or accurately enough. This causes doubt of the system because of the discrepancies between physical and system inventory counts. Now, “without short manufacturing lead times, components get moved into production but don’t get relieved right away from the **Enterprise Resource Planning** inventory”. This leads to confusion. We observed these characteristics at the manufacturing area. Because input/output was not stable and the percent of scrap is around 5%; MU presents positives and negatives values. Also, as lead time is not short, physical inventory differs from database system inventory.

The works mentioned previously explain different scenarios where it is convenient to use backflushing (i.e. short lead time, report scrap in system, etc.). Since not all of these requirements are currently satisfied in the Machine Center (MC) area, backflushing implementation (MU as a performance measure) has been considered ineffective performance metric for the Engineering Department. Its value could be ambiguous for the Engineering and the Accounting Department. Therefore, our work will contribute to the previous by providing a performance measure for a job shop environment with the manufacturing characteristics presented in MC. The suggested performance measure accurately estimates scrap and WIP without having to physically count it continuously.

2.4 SUGGESTIONS AND EXAMPLES

Previously discussed literature (see subsection 2.2) coincide that one of the most remarkable disadvantages is associated with lead times. Costanza (2003) expresses that depending on the types and length of the processing times, intermediate backflush points for transactions are required. The creation of a material backflush deduct point management environment can be supported by the use of a management control of the reporting to maintain the accuracy of the inventory records. The manufacturing process lead time at the company is considered long (one

month approx.), plus, some parts receive an outside operation. Because of lead time and travels they use intermediate backflush to report material consumption. However, backflushing is still being a challenge for the managerial.

Gaw (2007), like Costanza (2003), states that if the manufacturing lead time is medium or long, it creates a problem because “the stock balance will never up to date”. As well, he states that “It makes cycle counting cut-offs difficult, and it can affect the ordering calculations”. Due to backflushing limitations, Gaw (2007) introduces the concept of **floor stock**. He explains that the use of floor stock in parallel to backflushing overcome some of the problems produced by this technique. Using floor stock, a low or high value items are transferred from the store to the floor stock balance. Thus, items are controlled and then it is applied to every **BOM** they were used on. Gaw (2007) also express that “When the assembly is completed and booked to stock, the floor stock items are backflushed to the floor stock balances, decreasing the balance held on the shop floor”.

Drouillard (2011) suggests two alternatives when conditions to implement backflushing do not exist:

1. “Dual issues and returns against discrete work orders”: this method required more transactions than backflushing. It consists in count components when issued to a work from stores immediately the work order is opened and counted when returned to stores and the work order is closed. This alternative also grants high inventory accuracy and no additional transactions to report scrap, material substitution, and non-standard usage.
2. “Simple issues and returns from stores”: in this alternative components are counted and issued to the floor without reference to a work order. Leftover components and produced parts are returned to stores.

Several companies have been implemented backflushing as material movement record method. A manufacturer of electric components in Puerto Rico⁵ implemented and has been using this technique for many years. Despite having a short lead time, in some instances challenges are presented due to the BOM inaccuracy or material substitution. Another company that has implemented backflushing is Hewlett – Packard (HP). Calvasina et. al (1989) published that this method complicates management's decision making. HP had to perform physical inventory counts to track their inventory balance. Recall that Lean Manufacturing philosophy is based on waste elimination and inventory counts is considered as one of the most crucial wastes. Since our objective is not to increase manufacturing transactions and cycle counting, these suggestions are not suited for our project.

⁵ The name of the company is not mentioned due to confidentiality rights.

3. Problem Statement

Motivation

This project arose by the necessity of the company in Puerto Rico, to find an accurate real-time inventory tracking system at a particular area within the company. The current situation is that the inventory tracking system implemented, i.e. Material Usage (MU), cannot be readily interpreted as measurement on the effective use of materials.

The MU measurement is defined per period, t , as the difference of all the material that entered to the production area in that period, In_t , and all the material that came out of the production area at that period, Out_t , i.e.

$$MU_t = In_t - Out_t. \quad (1)$$

MU was implemented on site in 2003 with the implementation of the backflushing inventory tracking system. The implementation was gradual; it began on the manufacturing areas following a **one-piece-flow** material movement. MU was a success on the one-piece-flow managed areas but it is a real burden at the Machine Center (MC). The MC is the only area on site where processes are organized as a job shop because of the high-mix low-volume nature of the products.

Notice from equation (1) that MU, when implemented correctly, is supposed to equal scrap plus any other material that remains in the system for that particular period, i.e. it is supposed to satisfy the following relationship: $MU_t = Scrap_t + WIP_t$. This relationship is not currently satisfied by the MU metric at the MC as illustrated later in this section.

Objective and Goals

Given the discrepancy between MU and the observed behavior of the system (i.e. observed WIP and scrap) **the main objective of this project is to provide the project site an inventory tracking system that will estimate the current usage of material.**

In order to achieve the main objective described before, the following specific targets have been accomplished.

Targets:

- Characterize the current scenario at the company and identify critical characteristics that make MU an unreliable performance measure.
- Simulate the actual situation at machine center and validate the model.
- Develop theoretical performance measures for manufacturing areas with long production flow time.
- Suggest an appropriate performance measure to the company.

3.1 MACHINE CENTER'S MATERIAL FLOW DESCRIPTION

Machine Center is currently managed as a job shop. The products manufactured at the MC are cylinders, their length are around 10", and diameter 0.2". There are several characteristics of the MC that makes the current calculation of MU a challenge. The most relevant are:

- high product mix
- low volume demand
- long production flow time

- nonexistent WIP reporting

Actually, there are two product family groups of raw material, A and B. These product families are comprised of 19 raw parts (9 type A and 10 type B). Given the heterogeneity of clients, these raw parts are combined and transformed into 107 final products. The production of these two product families is around 125,000 units per month.

As mentioned before, an efficient backflushing implementation requires short lead times (e.g. 1 day), Braggs (2005). Due to the nature of the process we are studying, the time between transactions (i.e. flow time) exceeds a week. Several factors contribute to aggravate the total flow time. The most relevant are the time spent at the washing and drying processes, batch processing, and delays caused by line queues. Because of the product's size, **an exhaustive counting of them could result in an intensive labor process**. In order to reduce waste, the corporation decided to remove WIP and scrap quantities reporting from the database system.

3.2 MATERIAL USAGE CALCULATION

At the medical device manufacturer, material usage calculation is managed by the Finance Department. Incoming and outgoing transactions are downloaded from database system (Oracle⁶) through *Transaction Historical Summary's* report (see appendix (C) for details). MU is reported period by period (i.e. monthly) to the Engineering Department in order to keep them abreast about the behavior of this metric. For the purpose of exposition, we first introduce the MU calculation currently in place at the company and this will be followed by the evidence of its unsuited use in its raw form as a performance measure.

⁶ Oracle provides a complete, open, and integrated business software and hardware systems for database technology and applications in enterprises throughout the world. The company is the world's leading supplier of information management software and the world's second largest independent software company.

MU report is currently performed once a month for each month, t . In the report, a calculation of the MU metric is done for each part number h in raw material family (or type) i . The company's calculation of MU, defined as $\mathbf{MU}_{i,h,t}$ for the MU of product number h in i , is based on the difference between the on-hand materials saved in the database system for that particular period t , i.e. $\mathbf{OH}_{i,h,t}$ and the previous period, i.e.:

$$MU_{i,h,t} = OH_{i,h,t} - OH_{i,h,t-1} \quad \forall i, h, t. \quad (2)$$

Although at first glance this equation does not look equivalent to equation (1), a proof of the equivalency is provided in appendix (D). Also note from equation (3) that neither work-in-process (WIP) nor scrap differentiation in the MU calculation. If we isolate “current quantity” (i.e. $OH_{i,h,t}$) from the equation (3), we obtain the following equation:

$$OH_{i,h,t} = OH_{i,h,t-1} + MU_{i,h,t} \quad \forall i, h, t \quad (3)$$

Because WIP and scrap are not reported to the Oracle[®] database, $OH_{i,h,t}$ could be inflated. Hence validation of “on hand” quantity becomes challenging.

The table below presents an example of the observed situation at the company:

Table 1. Material Usage versus Scrap

Part Number	Material Usage	Scrap
105-211-hhh	\$ - 12,757.22	\$ 3,465.09
105-199-iii	\$ - 9,050.57	\$ 3,300.27
105-199-jjj	\$ 9,705.22	\$ 1,268.83
105-211-kkk	\$ 8,071.89	\$ 1,268.83

In Table 1 part numbers identification numbers are masked for the purpose of confidentiality. However, the numbers at the MU and scrap columns are real. Observe that the columns for MU and scrap for the given month do not match. Material usage information was obtained using Oracle® database while scrap data was found at manual reports developed in the production floor.

As a surprising remark, observe from Table 1 that at the MU column there are some negative values. These negative values mean that in this month the outputs were greater than the inputs or ($OH_{i,h,t} < OH_{i,h,t-1}$). This could be attributed to several reasons. For example, it could be due to inventory carried from a previous period (as such is not recorded as “in” for the current period but could be reordered as “out” if transformed into finish good). Also, it could be that the material that was on hold is finally going out as a finished good.

Table 2. Material Usage versus Scrap and WIP for October 2012

Part Number	Material Usage	Scrap	Inventory
105-202-iii	13,628	4,700	9,100
105-202-hhh	5,347	1,005	8,450
105-202-jjj	3,664	936	7,150

The table shown above (Table 2) depicts material usage, scrap, and WIP at October 31th, 2012. Notice that MU is not equal to Scrap + WIP. For Finance Department MU outcome (positive or negative) has little or no impact because if the entire inventory is finished and sold at the end of the year, inventory numbers will balance. Otherwise, Engineering Department expected that MU would be “scrap + WIP” at the time they calculate it (weekly, monthly, etc.) which is not the case.

Considering the inefficiency in applying the MU metric in a company with the characteristics existed at MC area, this project developed a convenient performance measure. This

performance measure keeps backflushing's spirit (minimum number of transactions) in order to preserve "Lean Manufacturing" environment. Also, the implementation of this estimate of WIP has no cost associated.

The following section presents the methodology employed to accomplish our objective.

4. Methodology

This section depicts the methodological plan followed during the development of this project. It is organized in two main phases: first, we provide a detailed description of data analysis, and then the second phase contains all the steps conducted to develop the theoretical model.

4.1 DATA ANALYSIS

4.1.1 Manufacturing Process Description

The first phase in every system evaluation consists in observation. The company was visited several times in order to observe the process in the machine center. In the first couple of visits operators, technicians, engineers, supervisors, and managers were interviewed in order to understand the problem and its causes. Figure 3 presents an overview of material flow and transactions. Please refer to Appendix (E) and (F) for a detailed process **flow diagram** which contains manufacturing processes and entry – output material transactions.

Material Flow

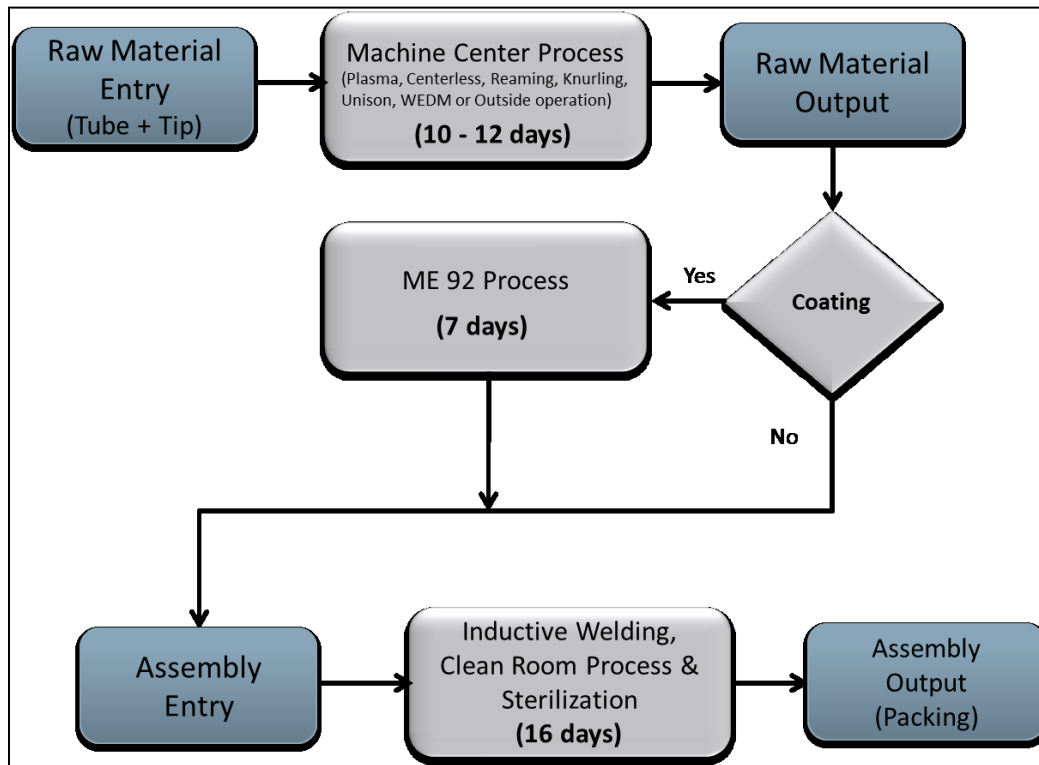


Figure 3. Material flow and transactions. Blue figures identify required transactions in the entire process. Gray shapes identify the group of processes required to convert the raw material (family A, family B) as a finished good (family A assembled with family B).

We are studying two types of family products that are subject to several processes. The processes start with the raw material entrance from the main warehouse to MC area, and include operations performed on site and outside the company. This project is focused on the subset of processes that are performed in the machine center, i.e. processes between “Raw Material Entry Transaction” and “Raw Material Output Transaction” (see Figure 3). The average flow time between transactions is around 10 and 12 labor days.

4.1.2 Transaction Data

For each material movement in check points a transaction is generated. Part numbers' transactions data were collected from January through November 2010 and from July through November 2012. At the moment, the information of transactions is downloaded from the computer system by a Cost Accountant who belongs to the Finance Department. The report contains all entries and outputs made in a specific period (e.g. monthly). To ease MU calculation, the report is exported to Microsoft Excel[®]. After report completion, the Finance Department facilitates it to the Engineering Department since they are responsible for the material usage performance. A high material usage means that most of the entries could not be converted as an assembly or finished good at the end of the period. In contrast, a negative material usage means that in that period the material that was converted into finished good was greater than the quantity entered of this material.

4.1.3 Material Usage Calculation and its Challenges

Bearing in mind the company's first consideration (i.e. $MU = Scrap$), we analyzed this disparity through the cause and effect diagram method. This diagram was developed for this project through interviews, employees brainstorming and observation process. Refer to Figure 4.

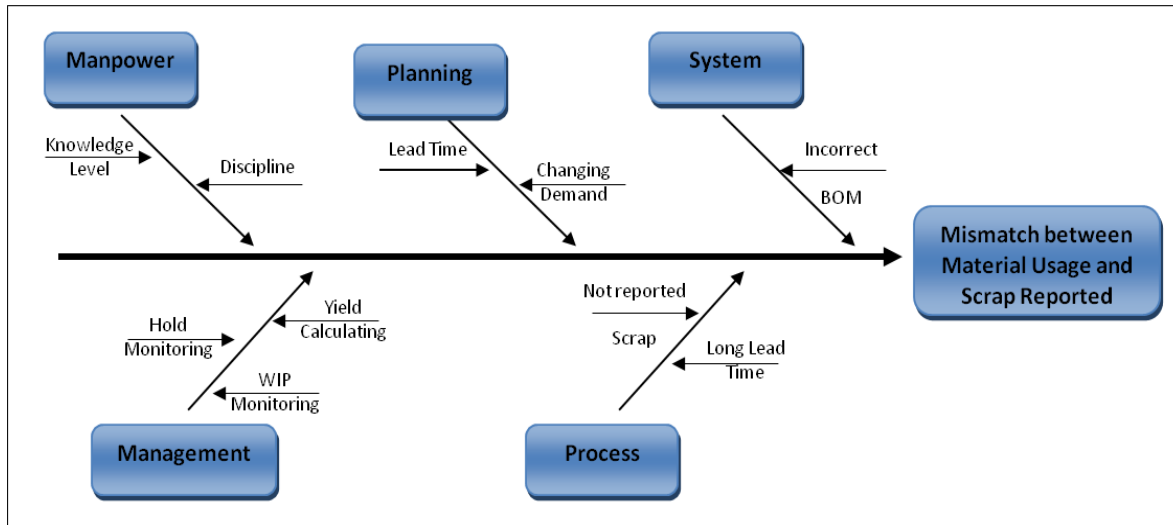


Figure 4. Mismatch between material usage and scrap cause and effect diagram

The cause and effect diagram presented in Figure 4 shows some of the elements identified as causes of mismatch between material usage calculated through backflushing and the scrap reported by engineering. It was found that of all the contributing factors the most relevant was the amount of work in progress which echoes the findings of Hassan Younies and Belal Barhem (2007) where they explained that “under the backflush system, entries are made only when the materials are transferred out, and any materials remaining in WIP are ignored.”

A secondary set of causes are employees' mistakes, change in demand, incorrect BOM, and lack of management monitoring in WIP and holds. Preliminary work has been done to address the lack of discipline to report transactions and incorrect BOM. The two were targeted before starting project analysis because the consequences of both were obscuring the real impact of the MU metric

and are independent of the inventory tracking system. In the following pages we would provide further explanation on both problems and the corrective actions that were accomplished:

- Discipline issues: high runners (product categorized as A and B) must be moved when a kanban card issues a signal (“move order” transaction, so called in the system). However, we found that it was very common to have high runners moved following a kanban signal, as well as moved as a result of a “push” command given by an operator (categorized as “inventory” in the system). This category (“inventory”) was supposed to be used to move parts type C (low runners). In our data collection and analysis development, we observed that around 25% of the items were moved also by “inventory” category. Hence, the part numbers were pushed and pulled to the shop floor. The entrance of materials without a kanban card signal results in an excess of inventory (in process inventory or assembled parts inventory) depending if they are backflushed or not. A high WIP level makes that material usage get bigger and it violates the principles of *Lean Manufacturing Philosophy*. It is well known that one of the two major forms of waste is work in process inventory (Rachna & Peter, 2003). In order to overcome this challenge we met with the owner of continuous improvement effort in the area and corrective measures were put in place. Nowadays, all part numbers are transacted by the “move order” category.
- BOM discrepancies: for an efficient implementation of backflushing it is important to have a correct BOM. If the BOM is not correct the quantities deducted will be altered. We identified some part numbers running with incorrect BOM. Although these part numbers do not belong to the area involved in this project (machine center), we advised the company about the inefficiency in backflushing due to having incorrect BOM.
- Inventory accuracy: another challenge identified was the match between the quantity they have in the floor at the beginning of the period (i.e. on-hand quantity), and what the computer system depicts as on hand quantity at the beginning of that period. Also, the

present on-hand quantity (current quantity, so-called in the system) must be equal to on-hand quantity for the next period. If these two values are not the same, the system will show on-hand quantities that are different to the physical quantity in the floor.

Recall the $MU_{i,h,t} = OH_{i,h,t} - OH_{i,h,t-1}$ currently in use at the company. The research on how the formula was calculated required several interviews. The reasons for the difficulty understanding the formula was not due to the arithmetic part of it, but the actual meaning and composition of each of the terms. The terms “on-hand” and “current” quantity received different interpretations depending on the relevant employee interviewed. Moreover, identifying the points where transactions were generated required considerable effort. In the way of understanding the formula and transactions, some of the comments received indicate misinterpretation and lack of knowledge from the personnel (dealing with the formula components on a daily basis) towards the components of such formula. For example, some of the testimonies received were:

- “the main problem in this situation is that the engineers need to know how many pieces are scrapped in the process,”
- “I do not understand how the Finance Department calculates material usage,”
- “the finance report is just a guide, the only way to know how many pieces you scrap is by going to the floor and count the pieces that are scrapped”.

To be able to understand the remarks, some part numbers were identified and analyzed from January through August 2010. These part numbers were selected because they:

- show positives and negatives material usage,
- are high runners,
- were pulled and pushed to the floor, and
- have material usage and scrap inconsistency.

Figure 5, shows variability of material usage in terms of value (i.e. money), month after month (January – August). As you can see, the data presented in the graph shows positives and negatives values; this variability causes confusion to the engineers. In addition, Figure 6 depicts the difference between material usage and scrap.

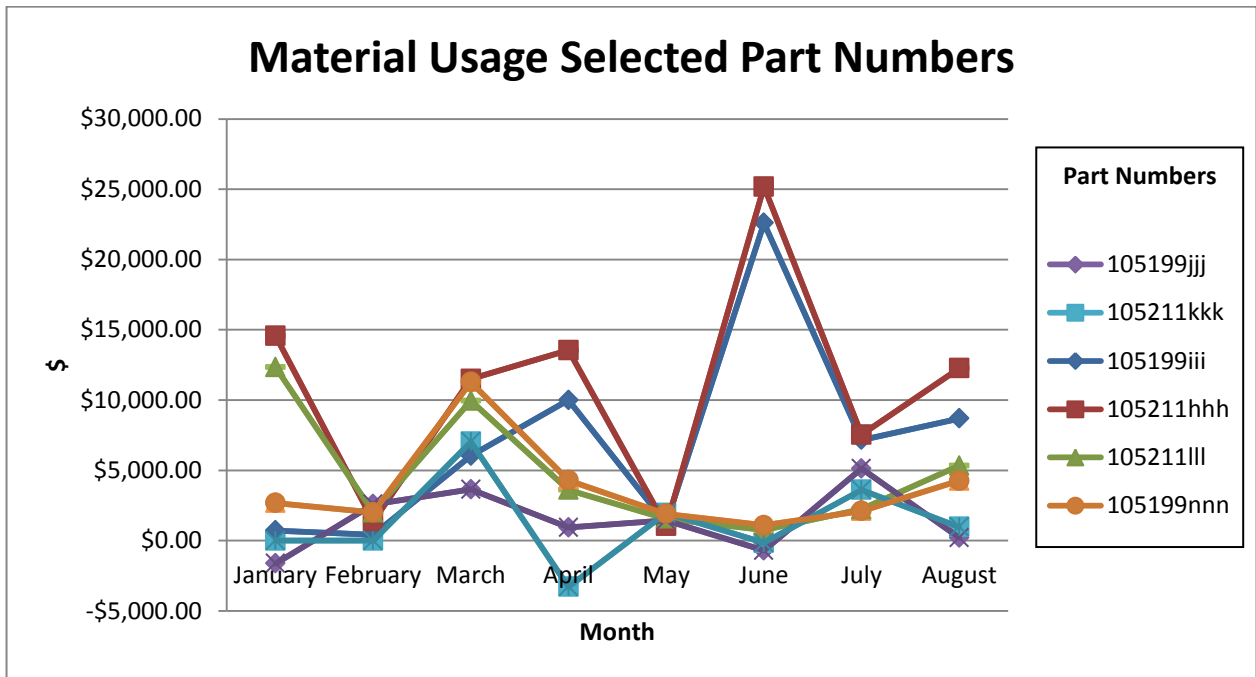


Figure 5. Material Usage Variability

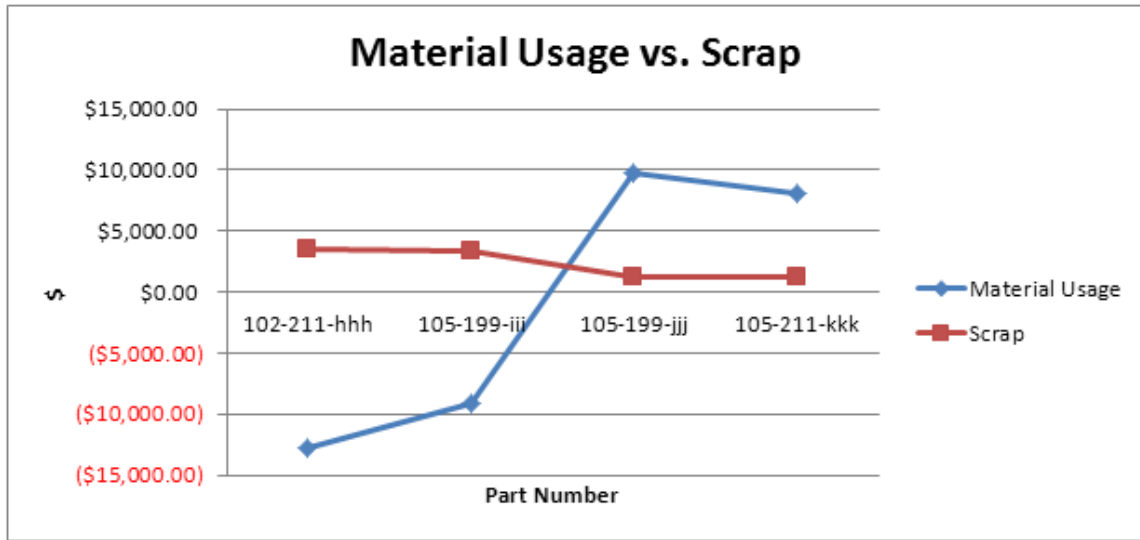


Figure 6. Material Usage vs. Scrap

Given that the current MU calculation is being questioned, labeled as “unreliable”, we decided to evaluate and propose a performance measure considering easiness of implementation, sustainability, and low percent of error. **Since it is not feasible to test its performance in the real system, a simulation model was developed capturing relevant system’s characteristics.**

4.2 THEORETICAL MODEL

A simulation model was constructed in order to understand the behavior of the real system over time. The use of simulation model permits to understand how the system operates and the “what if” analysis. The justification for using simulation in this project is due to the complexity of the system in terms of product variety. Also, the use of a computerized simulation model allows the analyzer to evaluate changes in parameters and their impact on the proposed measurements.

The methodological plan presented in this subsection followed some of the steps suggested by Banks et al., 2001 for a simulation study. The simulated model was constructed in ProModel[®] software package. This software was selected due to its availability at the Industrial Engineering Department and for the easiness of graphic animation, which permits verification and validation. Our model presents the actual situation at the machine center. Inputs model are shown in Figure 7. Data was gathered from *Transactional Historical Summary Report*, operators, managers, people related to the process, and historical data.

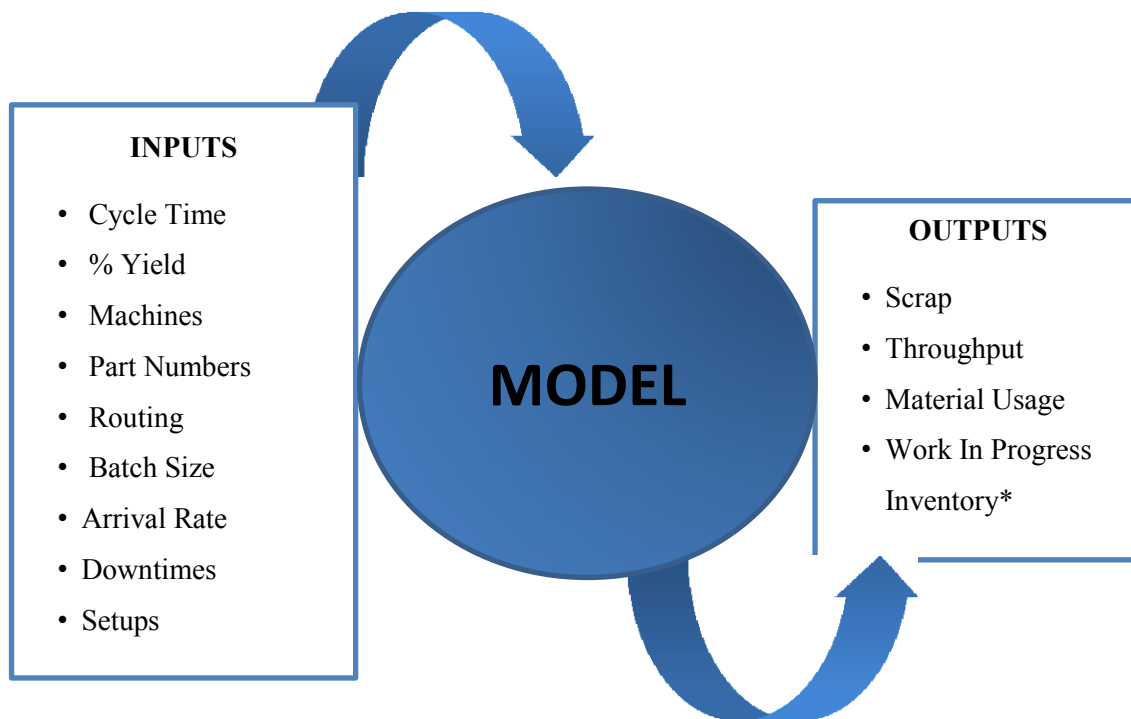


Figure 7. Input – Output Variables

Figure 7 presents all input variables that we introduced into the model and the output variables of the simulation model. We considered WIP inventory as an output in order to compare it with the proposed WIP estimated. The model developed considers the following assumptions:

- Inter-arrival rate is known.

- The first entity is created at time zero.
- Random job sequencing.
- There are three shifts of eight hours each. Breaks are taken at the same time by all employees. Each shift has 1.08 hrs. of inactivity due to breaks and allownces.
- Buffer infinite capacity.
- For any part number the order is always the same.
- Downtimes and setups are considered for each machine.
- No preemption. Once a batch of a specific part number is started in any machine, it will be processed in that machine until lot size will be completed without interruption of another part number.

4.2.1 Inputs Variables

Inputs variables were allocated as follows:

- % Yield: percent of yield will be settled calculating the average of one year yield collected from “Machine Center Yield Report” provided by the Engineering Department. Please refer to Table 3 for details.

Table 3. Percent of yield per process

Process	Oct10	Nov10	Dec10	Jan11	Feb11	Mar11	Apr11	May11	Jun11	Jul11	Aug11	Sep11	Oct11
	%	%	%	%	%	%	%	%	%	%	%	%	%
1	99.78	99.87	99.81	99.57	99.47	99.63	99.62	99.84	99.61	99.92	99.57	99.17	99.46
2,3,4	99.85	99.81	99.82	99.82	99.72	99.72	99.72	99.2	99.72	99.01	99.78	99.69	99.74
5	99.77	99.97	99.85	99.88	99.93	99.93	99.94	99.56	99.93	99.98	100	99.93	99.85
6	97.08	97.19	95.47	96.07	96.10	96.77	96.61	97.55	96.77	98.43	98.40	98.25	98.69

- Cycle Time: we used the average processing time given by the Engineering Department. We are assuming the same cycle time for all part numbers.
- Part numbers: all part numbers (family A and B) fabricated at the machine center were simulated. Refer to Table 4 for details.

Table 4. Entities used in the Simulation Model

Part Numbers Family A	Part Numbers Family B
AC_398	AH_402
AC_680	AH_404
AC_3906	AH_395
AC_399	AH_401
AC_400	AH_634
AC_397	AH_897
AC_518	AH_414
AC_7906	AH_178
AC_488	AH_179
	AH_734

- Routing: we have two different routings; one for each family. See Appendix E and F for details.
- Batch Size: the batch size used matches those used by the company. Refer to Table 5 for details.

Table 5. Lot Size per Entity

Entities Family A	Lot Size	Entities Family B	Lot Size
AC_398	1300	AH_402	650
AC_680	650	AH_404	650
AC_3906	650	AH_395	650
AC_399	650	AH_401	650
AC_400	650	AH_634	650
AC_397	650	AH_897	650
AC_518	650	AH_414	650
AC_7906	650	AH_178	650
AC_488	650	AH_179	650
		AH_734	650

- Arrival rate: arrival rate was settled using “Manufacturing Plan Report” and “Transaction Historical Summary” report.

4.2.2 Model Description



Figure 8. Model Conceptualization

Figure 8 graphically depicts the machine center area. The machines presented in the figure are not the real machines used in the company. The first transaction occurs because a kanban card signals. Raw material arrives to RM stock, then it is assembled in the first process (see number **1** in the figure) after that, the assembled parts receive different operations such as cleaning, inspections, molding etc. Each process generates a percentage of scrap (outcome of the simulation model). Quality holds are not modeling in our simulation because it is not within the scope of this project. When processes are completed, the parts are ready to be backflushed.

4.2.3 Model Verification

After we developed the simulation model we preceded with the verification process, i.e. confirm that we built the model right (Banks, 2001). This step attempted to find if the model works correctly in the computer. In order to answer the question: “is the conceptual model (assumptions on system components and system structure, parameter values, abstractions and simplifications) accurately represented by the operational model?” (Banks,2001), we used the following tools:

- Animation used to verify that the model emulates the current system.
- Trace element: detailed tracing of the model’s operation.

As we are dealing with a non-terminating system the simulation analysis must be made in a steady-state behavior. We used the replication method to estimate the standard deviation and mean. First, we made a long run to determine visually the truncation point (Figure 9) and then accomplished to discard observations that do not belong to steady-state.

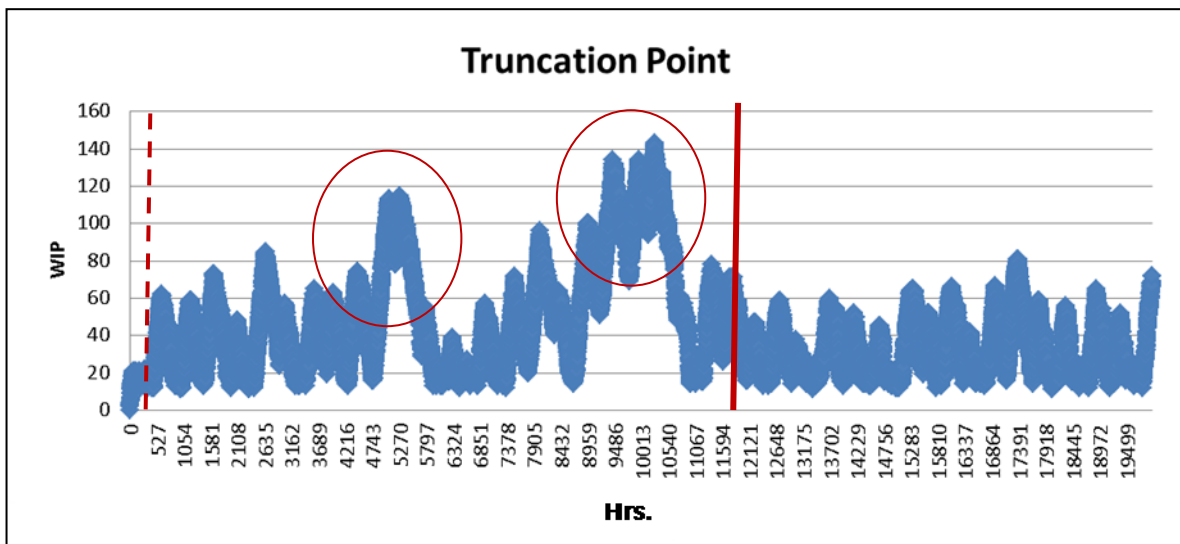


Figure 9. Truncation Point

The truncation determination for this model was a challenge. Mainly because the point should mean that the system is saturated and is in steady-state. If only saturation in the system is considered, the truncation point would have been less than 500 hours. However, the existence of coincidental downtimes at the simulation, occurring at 5200 and 9500 hours (see marks in circle in Figure 9), forced the simulated system out of the steady-state. The steady-state assurance was needed in order to validate the model since the system's real WIP, number of jobs completed and lead times were calculated in periods with no such prolonged and coincidental machine downtimes. However, it is known that in the history of the MC such situations have occurred.

To be able to validate the model the truncation point was then selected to be 12000 hrs. This time was determined after several runs; the truncation point was selected considering the higher time which WIP started to be stable. All observations before truncation point (i.e. transient point (refer to Pegden et al., 1995)) were discarded to minimize initial conditions bias. The data collected in the steady state period (i.e. after 12,000 hrs.) was used to our analysis.

Steady state observations were used to calculate the mean and standard deviation of the total jobs completed. Ten initial replications were performed using the default random numbers by ProModel©, thus we can assume classical statistic to our analysis.

The following equations were employed to calculate mean and standard deviation for jobs completed:

$$\bar{X} = \frac{\sum x_i}{n} \quad i = 1, 2, \dots, 10 \quad \text{and} \quad S = \sqrt{\sum \frac{(x_i - \bar{x})^2}{n-1}} \quad i = 1, 2, \dots, 10$$

The resulting vales where found to be $\bar{X} = 182,260 \text{ pcs}$ and $S = 22,334.96 \text{ pcs}$.

With the above metrics on-hand, we calculated the total number of independent replications (R) to have an error less or equal than 5% of real jobs completed using the following equation:

$$R \geq \left(\frac{t_{\alpha/2, R_0-1} S}{\epsilon} \right)^2 .$$

R_0 is an initial estimation of R . Banks et al. 2001 recommends R_0 to be at least 4; as mentioned before we used 10 initial replications. The $t_{\alpha/2, R_0-1}$ is the t -student statistic with $\alpha = 0.05$. Since the error allowed is five (5) percent of the real jobs completed, the number of replicates needed is

$$R \geq \left(\frac{t_{\alpha/2, 10-1} 22,334.96}{5\% \text{ Real CJ}} \right)^2 \geq 12.73 \approx 13$$

Even though, the calculation suggested 13 a total of 20 independent replications were used for the analysis.

4.2.4 Model Validation

A validation method is necessary to know if the simulation model is close enough to the real system in terms of total flow time. Validation is focused on three questions (Pegden, Shannon, & Sadowski, 1995):

- Conceptual validity: If the model represents the real world.
- Operational validity: If the “model- generated behavioral data characteristic of the real world system’s behavioral data”.
- Believability: If the ultimate user of the simulation model has confidence in it.

In order to validate our model, the total flow time of the real system was compared with the total flow time of the simulation model. Therefore, to obtain the total flow time of the computerized model we set in our model an attribute that recorded the input and the output transaction time. Then, the total flow time was calculated as the difference between those attributes. Furthermore, real flow time was obtained using manual reports which contained the date a batch entered to MC and the date it went out.

The statistic test used for the validation was “two Sample t”. This hypothesis test computes a confidence interval of the difference between two populations (real and simulated systems) means.

$$H_0: \mu_S - \mu_R = \delta_0 \text{ versus } H_1: \mu_S - \mu_R \neq \delta_0,$$

where μ_S and μ_R are the sample means and δ_0 is the hypothesized difference between the two sample means (i.e. zero).

In order to construct the confidence interval using “two sample t”, normality assumption must be met. We tested normality using Minitab statistical software. Kolmogorov – Smirnov test was selected because of the sample size of real data. Results were analyzed using p-value. Hypothesis testing statement is described below.

H_0 : Data is normally distributed

H_1 : Data is not normally distributed

With a 95 % of confidence we cannot reject H_0 . All P – values were greater than α ($\alpha = 0.05$). Appendix (H) shows P- value results and normal probability plots.

Confidence intervals results are shown in Table 6.

Table 6. Confidence Interval Results

Entity	N	Mean	Standard Deviation	95% Confidence Interval	P -Value
AC_398	20	9.68	1.17	(-2.277, 1.357)	0.581
_-398	9	9.22	2.28		
AH_402	20	12.69	1.76	(-5.13, 0.67)	0.122
_-402	13	10.46	4.67		

Since P - values are greater than α ($\alpha = 0.05$) we cannot reject H_0 . Thus, we can conclude that our model is close enough to reality.

4.2.5 Performance Measure Methodology

Before describing the different attempts we developed, a definition of the variables used in the model is appropriate.

MU period (t): is the period considered to calculate Material Usage (e.g. 5, 10, 20 days)

MU1_t: starting of MU period *t*

MU2_t: ending of MU period *t*

Input_{i,h,t}: material quantity entered to the MC area in a MU period *t* of raw material family *i* part number *h*

Output_{i,h,t}: material quantity that arrived to stock in a MU period *t* of raw material family *i* part number *h*

Δt : is the interval of time a lot remained in a MU period

We considered a fixed yield for all of the following attempts. Variability was introduced in the “Sensitivity Analysis” section.

a. Attempt: Constant Loss Rate

The following method assumed a constant material loss rate; WIP was estimated using the equation to determine the slope of a line with an alteration,

$$m = \frac{Y_2 - Y_1}{X_2 - X_1},$$

Where:

m: slope of the line i.e. rate of yield loss

Y₂: percent yield, 100%

Y₁: % of yield at the end of a period

(X₂ - X₁): Average Flow Time

Average flow time was calculated per part number in the simulation model. X_1 is an attribute assigned to record the time an entity arrived to the first process and X_2 when the entity arrived to the final stock point.

With a known value of m we calculated WIP as follows:

$$WIP_t = Input_{i,h,t} - Output_{i,h,t} - m * Input_{i,h,t} * MU_{period} \quad (4)$$

The expression $m * Input_{i,h,t} * MU_{period}$ in equation 4 represents the quantity lost in a MU period t .

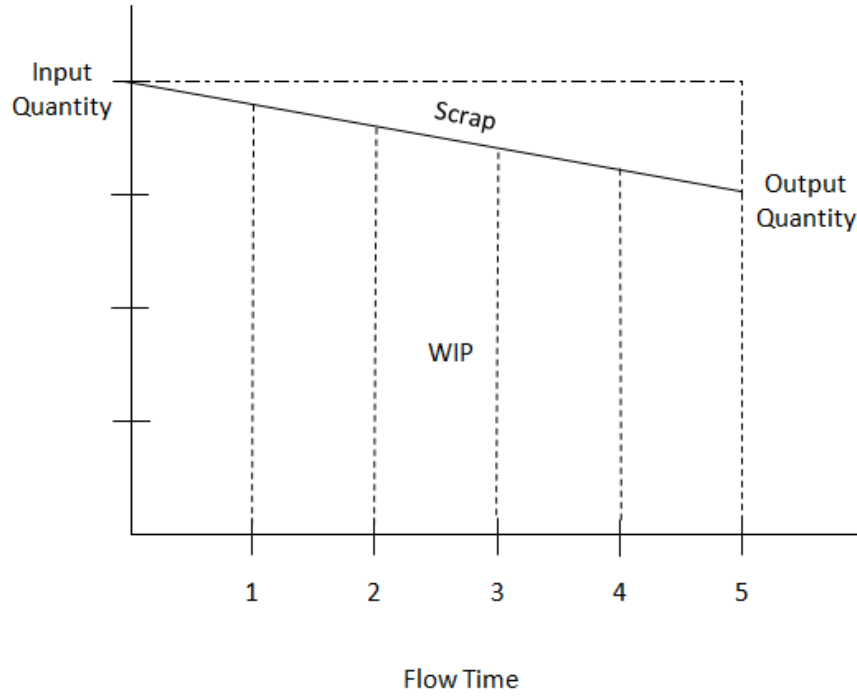


Figure 10. Performance measure graphic representation

This first attempt was not suited because this method presented an average absolute percent of error greater than 10%.

b. Attempt: Lot Case

In our second attempt we classified the lots in four cases:

Case 1:

If a lot was classified in the model as “Case 1”, the entrance of that lot (XI) to the MC area was in a MU period in the past.

$$X1 < MU1$$

$$X2 < MU2$$

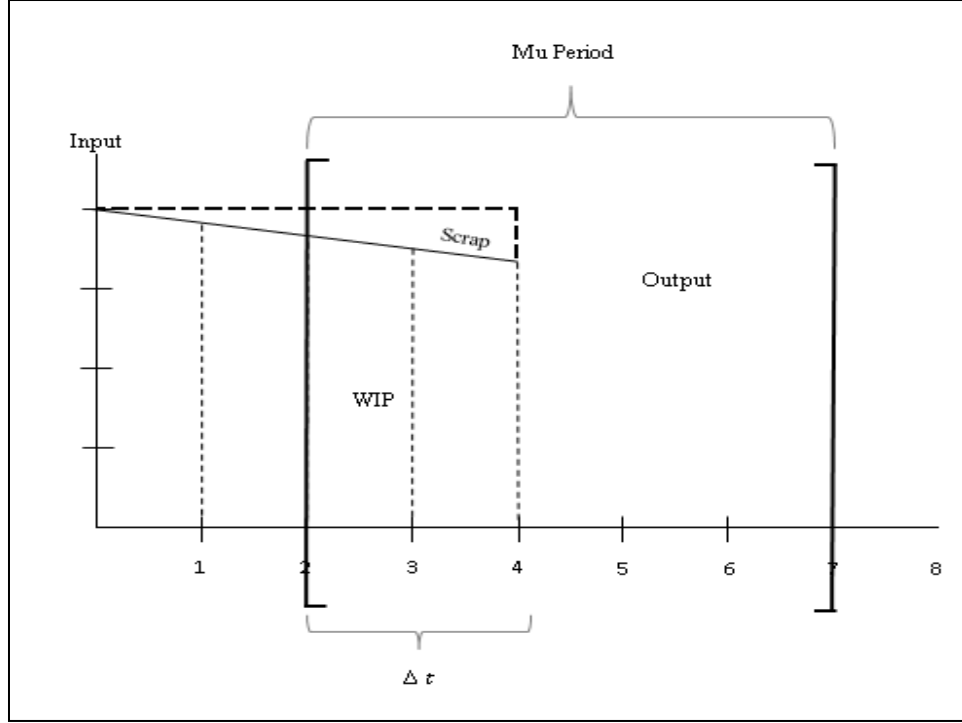


Figure 11. Case 1 Graphical Example

As shown in Figure 11, the entrance of the lot in that particular example occurs in time zero which is before MU period starting (number two in X axis). On the other hand, the exit of the lot occurs in time four and MU period ends in the seventh. As noticed, only the exit of the lot is within MU period.

Using the simulation output of the average time spent in each machine and its queue, a cumulative distribution of yield was estimated. Comparing Δt with flow time i.e. $(\Delta t / \text{flowtime})$, we determined the percentage that Δt represented. Thus, we knew how much scrap that lot produces. WIP was estimated using the following formula:

$$WIP_{t,h} = WIP_{i,h,t-1} + Input_{i,h,t} - Output_{i,h,t} - Scrap_{i,h,t} \quad (5)$$

Case 2:

This case has the characteristics that the incoming and outgoing transactions are made in the same MU period. Scrap and WIP were estimated as described in “Case 1”.

$$X1 \geq MU1$$

$$X2 \leq MU2$$

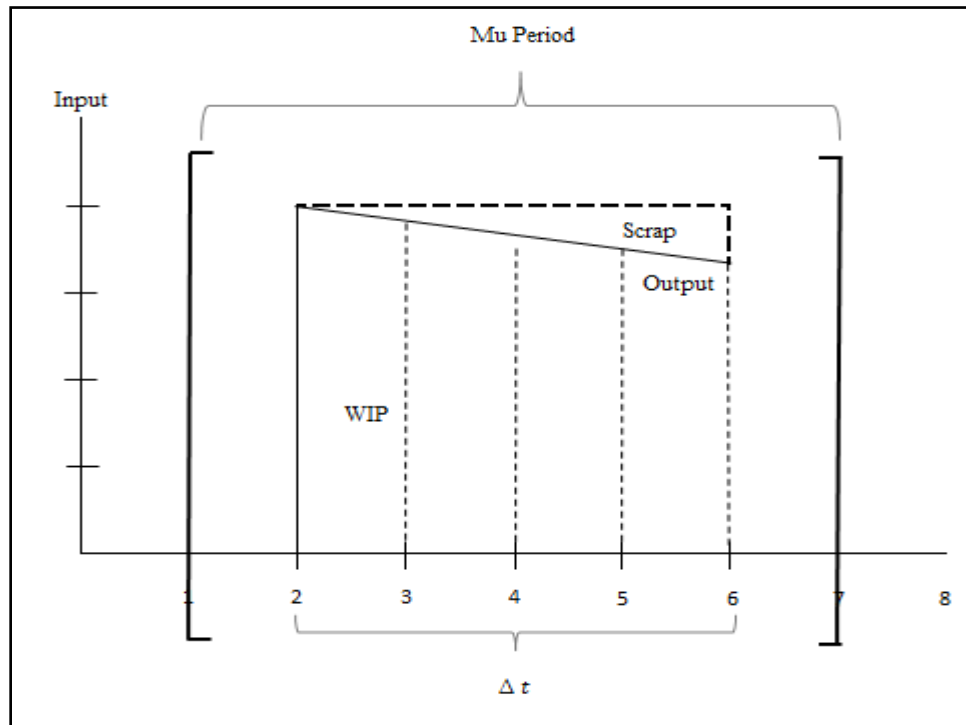


Figure 12. Case 2 Graphical Example

Figure 12 represents an example of a lot classified as case 2. In this case, the average flow time is similar to MU period and $\Delta t / \text{flowtime}$ was approximately to one.

Case 3:

In this case only the entrance of the lot occurs in the current MU period but the exit of that lot occurs in another period in the future. This case is contrary to “Case 1” where only the exit of the lot is within MU period.

$$X1 \geq MU1$$

$$X2 > MU2$$

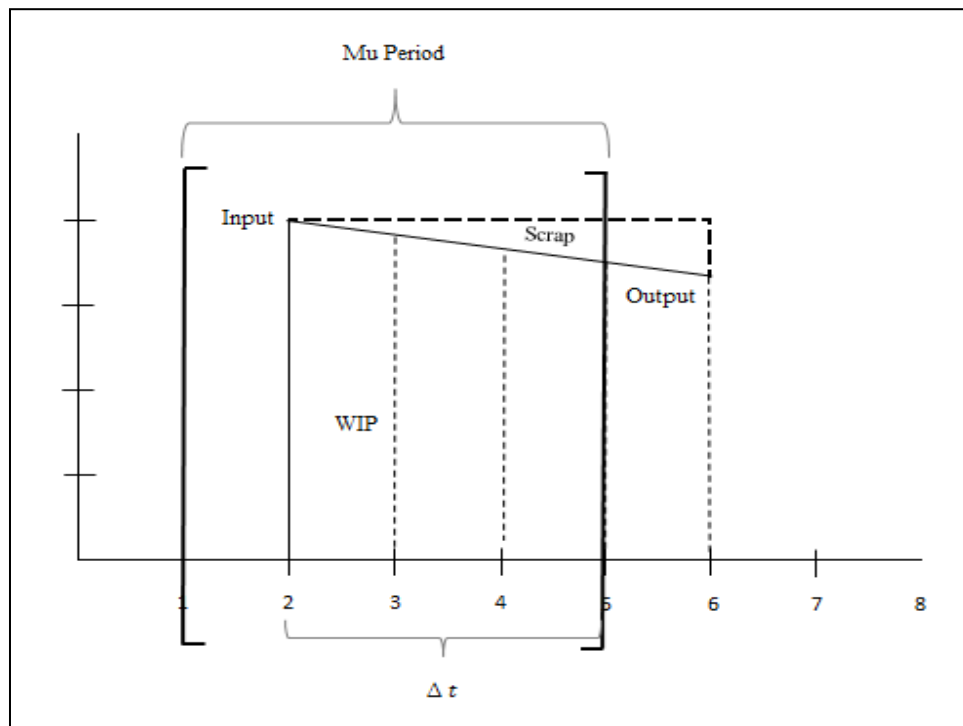


Figure 13. Case 3 Graphical Example

This case is graphically represented in Figure 13. As explained above, the exit of the lot in this example occurs after MU period ends.

Case 4:

This case has the particularity that the lots are WIP, thus

$$X1 < MU1$$

$$X2 > MU2$$

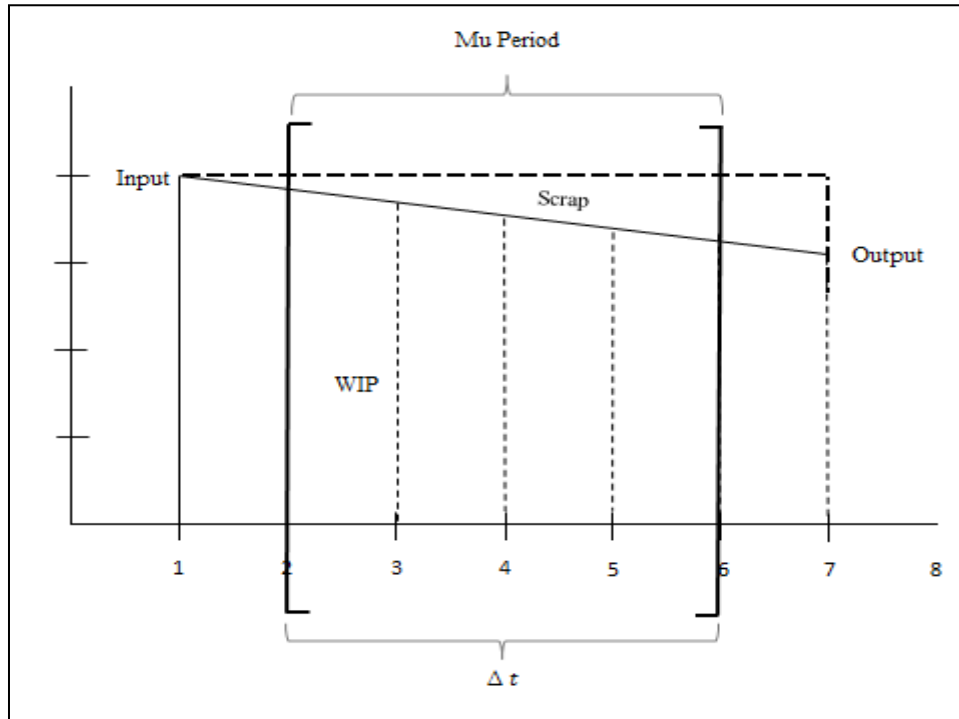


Figure 14. Case 4 Graphical Example

As shown in Figure 14, the entrance of the lot occurs in time 1 (before MU period starting) and the exit of the lot occurs at time 7 which is after MU period ending.

The second attempt that was shown above also produces an average absolute percent of error greater than 10% (see results section for details). Since our objective is to have an estimate performance with a minimum error, these two attempts were rejected. A third attempt was necessary in order to satisfy the scope of the project.

c. Attempt: Lower and Upper Scrap

The third and last attempt we tried considers the estimate of an upper and lower bound on scrap. The upper and lower bounds on scrap were calculated as follows:

$$LowS_{i,h,t} = Output_{i,h,t} * 1 - Yield \quad (6)$$

$$UpperS_{i,h,t} = (Input_{i,h,t} - Output_{i,h,t}) * 1 - Yield \\ + LotsOut_{i,h,t} * LotSize - Output_{i,h,t} \quad (7)$$

The average scrap was calculated using a weighted average:

$$S_{i,h,t} = Wlow * LowS_{i,h,t} + Wupper * UpperS_{i,h,t} ,$$

the weights were found using the Microsoft Excel - Solver application . The objective function was to minimize the average percent of error

$$Average\ Percent\ of\ error = \frac{Real\ WIP - Estimated\ WIP}{Real\ WIP} * 100.$$

The estimate WIP inventory was calculated as follows:

$$WIP_{i,h,t} = WIP_{i,h,t-1} + Input_{i,h,t} - Scrap_{i,h,t} - Output_{i,h,t} \quad (8)$$

Using this method of estimate WIP we obtained an average percent of absolute error less than 3%. The results are illustrated on section 5. See Appendix (J) for detailed results.

4.3 SENSITIVITY ANALYSIS

In order to identify if our model is suited for systems with the characteristic of long lead time we run the model with different scenarios changing the following parameter:

Table 7. Variables to be vary

Variables	
% Yield Distribution	Uniform
	Triangular
	Normal
% Yield Values perMachine	95%
	99%
	99.99%
MU Calculation Period	$\frac{1}{2}$ Lead Time
	Lead Time
	2 Lead Time

***Lead Time: around 10 - 12 days**

5. Results

The results presented next consider variations in yield (probability distributions, mean and standard deviation) and MU period (1/2 lead time, lead time, twice lead time). The mean of the yield we show in the tables is the mean per machine considered in the MC area. The Table 10 presents the results regarding a fixed value of yield, variability is not considered in this case. Tables 8, 9 and 11 display the results using probability distributions (normal, uniform and triangular). Also, Table 13 depicts the results using triangular distribution with higher variability.

5.1 CONSTANT LOSS RATE

The following results are the outcomes from the first attempt (constant loss rate). These results considered a constant value of yield. As mentioned in section 4, this technique was not appropriate to estimate WIP inventory. This method overestimates scrap values, thus underestimating WIP inventory values. The following table shows the average absolute percent of error results, also minimum and maximum.

Table 8. Constant Loss Rate: Average Absolute Error Results

Mean	Minimum	Maximum
146.63%	93.33%	205.29%

As you can notice in Table 8, the results are very high, hence another attempt was required to reduce the absolute percent of error according to the target (i.e. $\varepsilon \leq 10\%$)

5.2 LOT CASE

The following results correspond to the second attempt (see section 4.2.5 for a detailed description). This method reduces the average absolute percent of error significantly. These results considered a constant value of yield. The MU calculation period was $\frac{1}{2}$ of lead time.

Table 9. Lot Case: Average Absolute Error Results

Mean	Minimum	Maximum
34.99%	30.86%	51.71%

Although results from Table 9 are significantly reduced, the average absolute percent of error is still greater than 10%. In order to find the best WIP inventory estimate a third attempt was necessary. The results of this attempt are shown next.

5.3 LOWER AND UPPER BOUND ON SCRAP

a. Fixed Yield

Table 10 shows the average absolute percent of error of the real WIP⁷ inventory and estimated WIP inventory. As previously mentioned these MU calculation periods represent $\frac{1}{2}$ of lead time (MU period = 5 days); lead time period (10 days); and twice lead time (20 days) approximately. The yield presented in this table corresponds to the complete processes yield.

⁷ Real WIP inventory refers to the WIP resulting in the simulation model.

Table 10. Fixed Value of Yield: Average Absolute Percent of Error Results

MU Period	Yield	Absolute Error
5 Days	0.95/0.94	1.161%
10 Days	0.95/0.94	1.175%
20 Days	0.95/0.94	1.182%

As presented in the table above, the error increases while MU period increase but the difference between MU period of five days and twenty days is not significant. Thus, we can conclude that our model is very accurate in estimating WIP inventory. The target of the company was to have an error less than 10%; the average percent of absolute error in this case (fixed yield) is less than 2%. The results presented in Table 10 are graphically depicted in Figure 15.

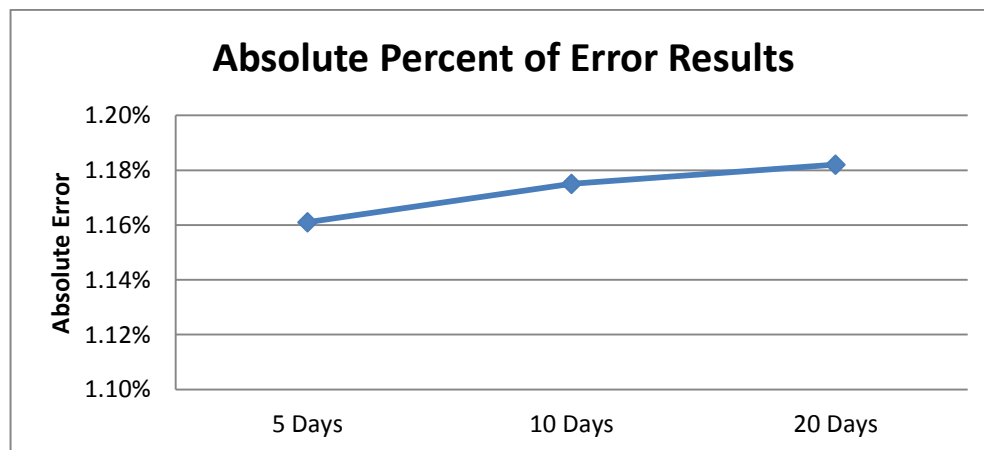


Figure 15. Fixed Value of Yield: Average Absolute Percent of Error

b. Yield Based on a Normal Distribution

The table below shows the results using normal distribution to generate the yield per machine (5 machines for family A, 6 machines for family B) in the simulation model. Three different values of mean were used keeping the same standard deviation. Because of the symmetry of the normal and the uniform distribution, high variability was not suited to test. In order to analyze if the variability has an impact in the estimation of WIP we used triangular distribution (see Table 13).

Table 11. Average Absolute Percentage Error Using Normal Distribution

MU Period	Parameters		Absolute Error
	Mean	Sigma	
5 Days	0.95	0.0001	4.66%
	0.99	0.0001	0.93%
	0.9999	0.0001	0.21%
10 Days	0.95	0.0001	4.25%
	0.99	0.0001	0.92%
	0.9999	0.0001	0.21%
20 Days	0.95	0.0001	4.54%
	0.99	0.0001	0.92%
	0.9999	0.0001	0.20%

The average absolute percent of error using normal distribution to generate the yield decreases while yield becomes higher. We can notice that there is no big difference regarding among MU calculation period. Besides with a mean yield of 0.95 the error increase reasonably, it falls in the acceptable range for the company (i.e. $\epsilon \leq 10\%$). Table 11 depicts the results of the average percent of error while varying the mean of the yield and the MU period calculation. As

shown in the next figures the best values of error (i.e. lower values) are found within greater values of yield.

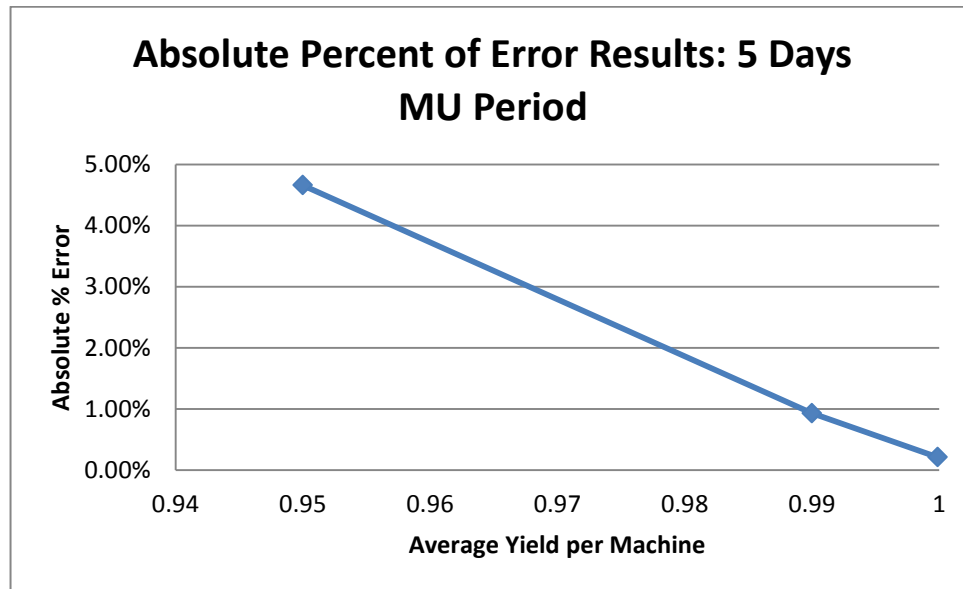


Figure 16. Average Percent of Error Results: Yield Based on a Normal Distribution, 5 Days MU Period

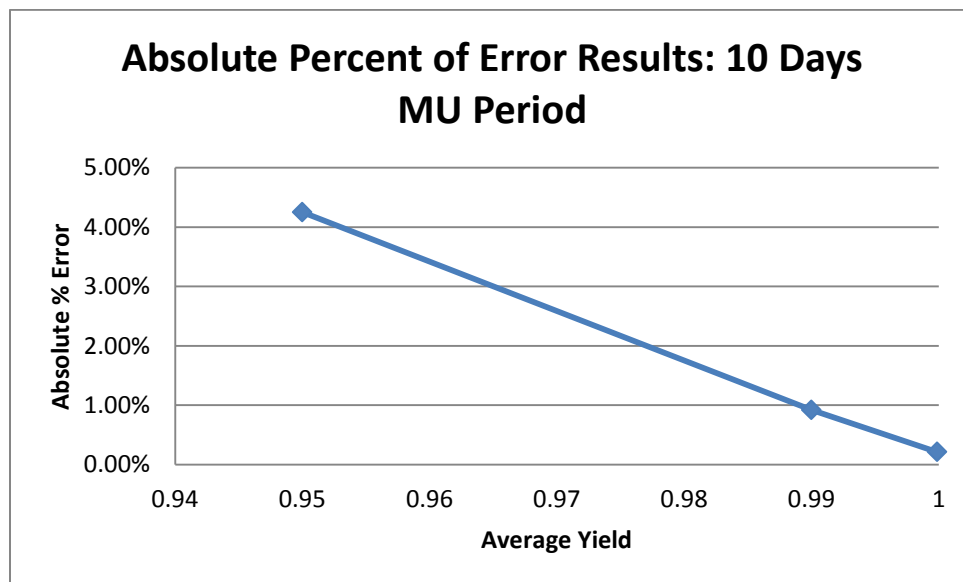


Figure 17. Average Percent of Error Results: Yield Based on a Normal Distribution, 10 Days MU Period

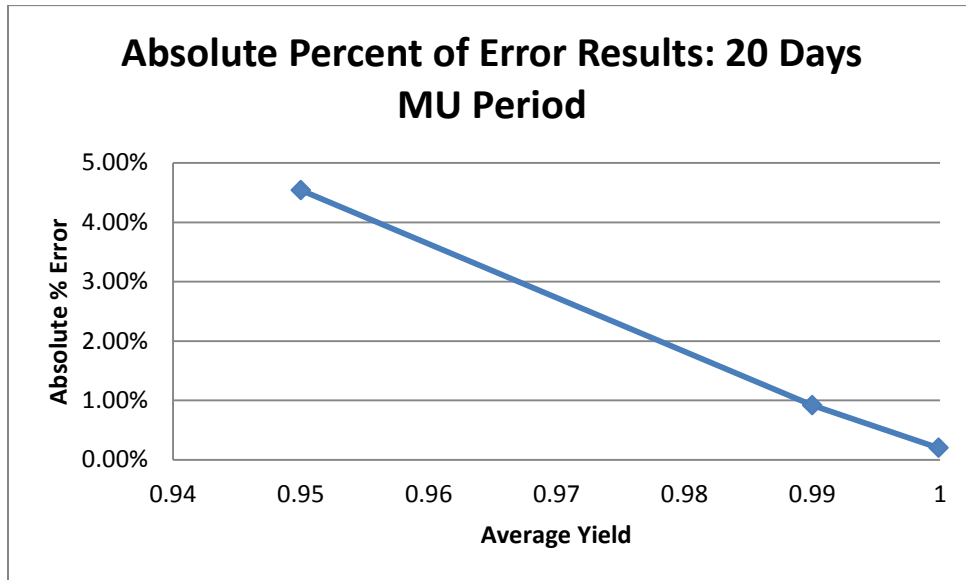


Figure 18. Average Percent of Error Results: Yield Based on a Normal Distribution, 20 Days MU Period

c. Yield Based on Uniform Distribution

The table below shows the results using the uniform distribution to generate the yield per machine in the simulation model. As explained before, three different values of mean were used.

Table 12. Average Absolute Percent Error Using Uniform Distribution

MU Period	Parameters			Absolute Error
	Mean	Min	Max	
5 Days	0.95	0.9498	0.9502	4.16%
	0.99	0.9898	0.9902	0.76%
	0.9999	0.9997	1.0000	0.20%
10 Days	0.95	0.9498	0.9502	4.72%
	0.99	0.9898	0.9902	0.76%
	0.9999	0.9997	1.0000	0.20%
20 Days	0.95	0.9498	0.9502	4.37%
	0.99	0.9898	0.9902	0.77%
	0.9999	0.9997	1.0000	0.29%

Using the uniform distribution, the lower values of the average absolute percent of error are found with MU period equal to five days. However, the results within MU periods are very close.

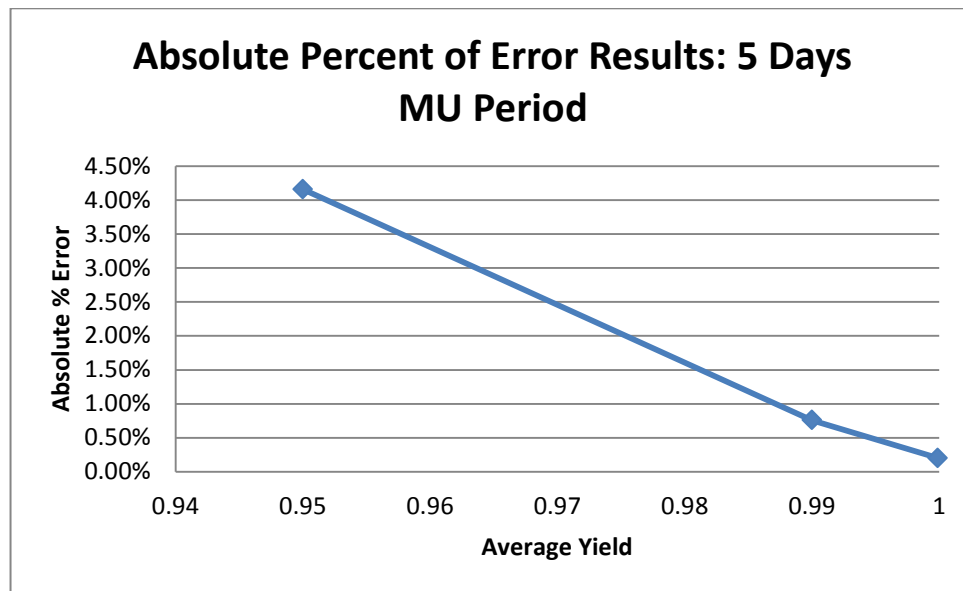


Figure 19. Average Percent of Error Results: Yield Based on a Uniform Distribution, 5 Days MU Period

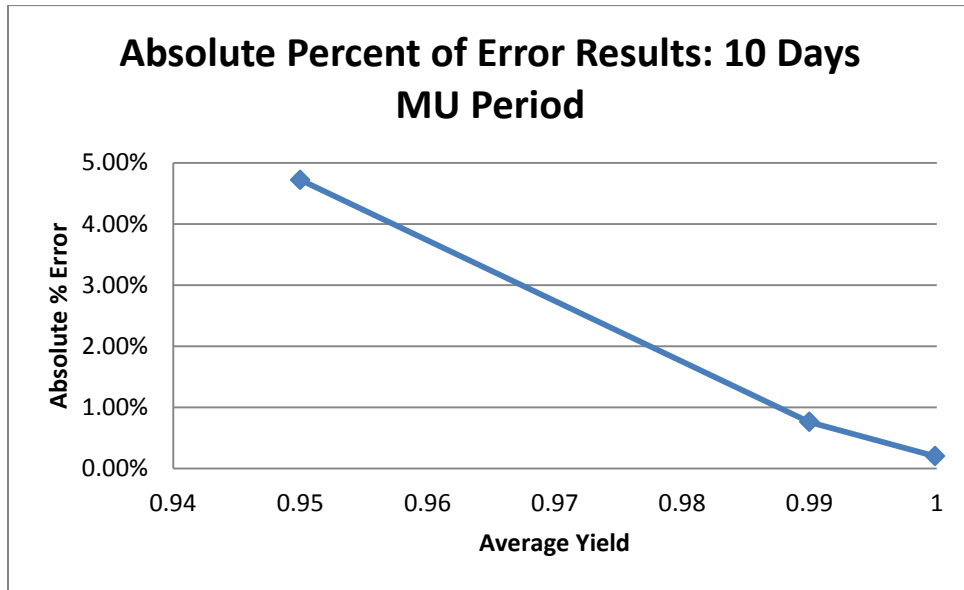


Figure 20. Average Percent of Error Results: Yield Based on a Uniform Distribution, 10 Days MU Period

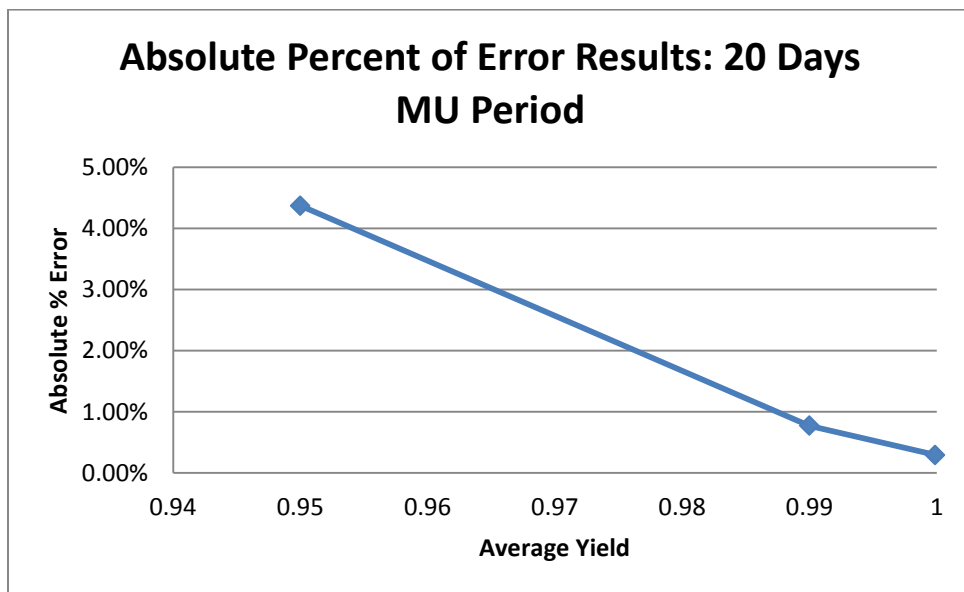


Figure 21. Average Percent of Error Results: Yield Based on a Uniform Distribution, 20 Days MU Period

d. Yield Based on Triangular Distribution

Table 13 depicts the results of the average absolute percent of yield using the triangular distribution to generate yield. In order to identify if the variability has an impact on the average absolute percent of error, we increase variability from 0.0001 to 0.042 with a mean of 95% of yield per machine. Because the yield is a value between 0 and 1, the triangular distribution allows us to configure it asymmetrically.

Table 13. Average Absolute Percent Error Using Triangular Distribution

MU Period	Parameters			Absolute Error
	Mean	Min	Max	
5 Days	0.95	0.9498	0.9502	4.38%
		0.90	1.00	4.87%
	0.99	0.9898	0.9902	0.91%
	0.9999	0.9997	1.0000	0.63%
10 Days	0.95	0.9498	0.9502	4.37%
		0.90	1.00	7.68%
	0.99	0.9898	0.9902	0.91%
	0.9999	0.9997	1.0000	0.28%
20 Days	0.95	0.9498	0.9502	4.35%
		0.90	1.00	4.87%
	0.99	0.9898	0.9902	0.92%
	0.9999	0.9997	1.0000	0.60%

The highest value shown in the tables above is 7.68% which corresponds to MU period equal to 10 days (i.e. lead time) and high variability. This value is still acceptable for the company. As shown in the next figures the lower values of absolute percent of error are found in the greater

values of yield. In figures 22, 23, and 24, the points in circle represent the results for a high variability in the percent of yield.

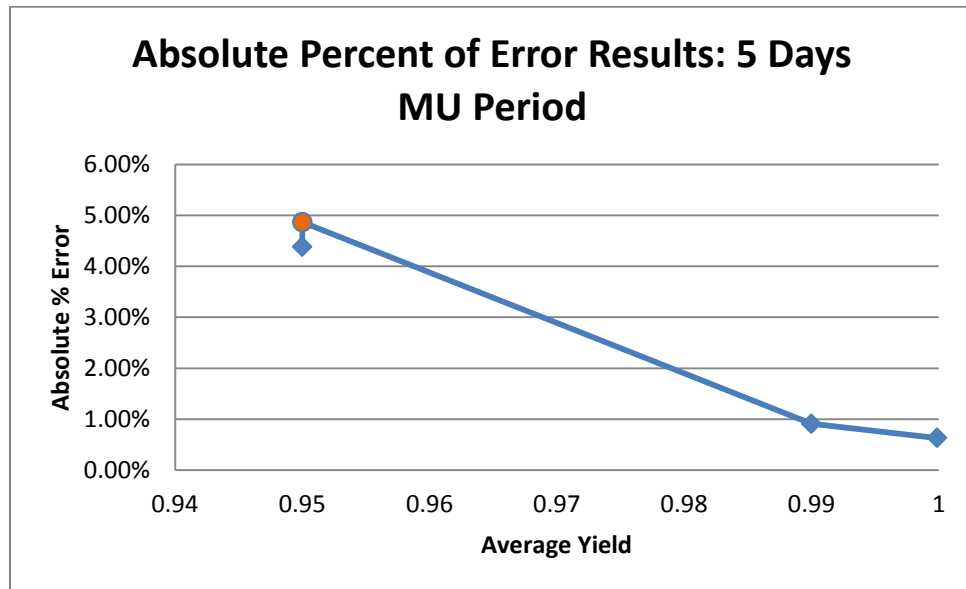


Figure 22. Average Percent of Error Results: Yield Based on a Triangular Distribution, 5 Days MU Period

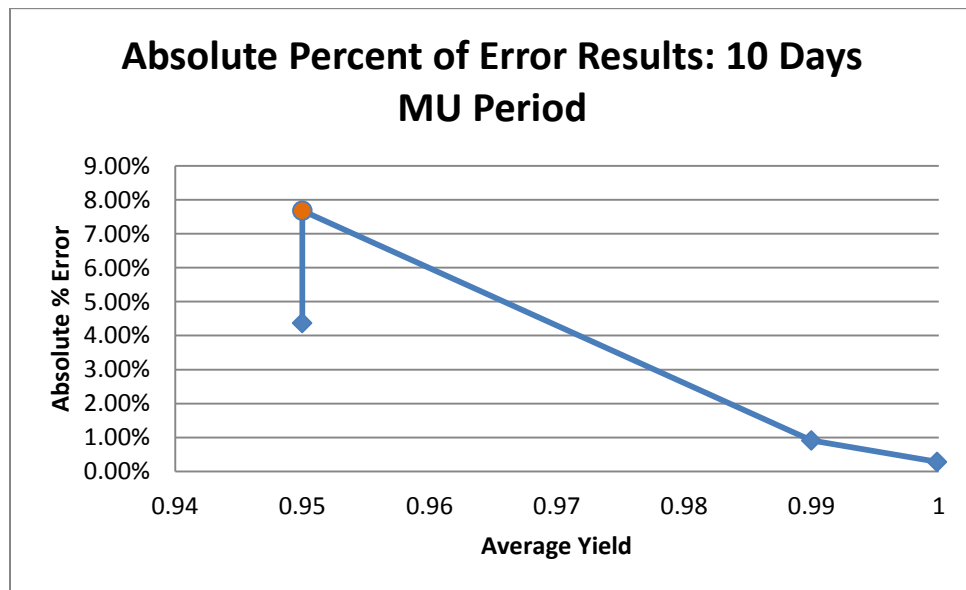


Figure 23. Average Percent of Error Results: Yield Based on a Triangular Distribution, 10 Days MU Period

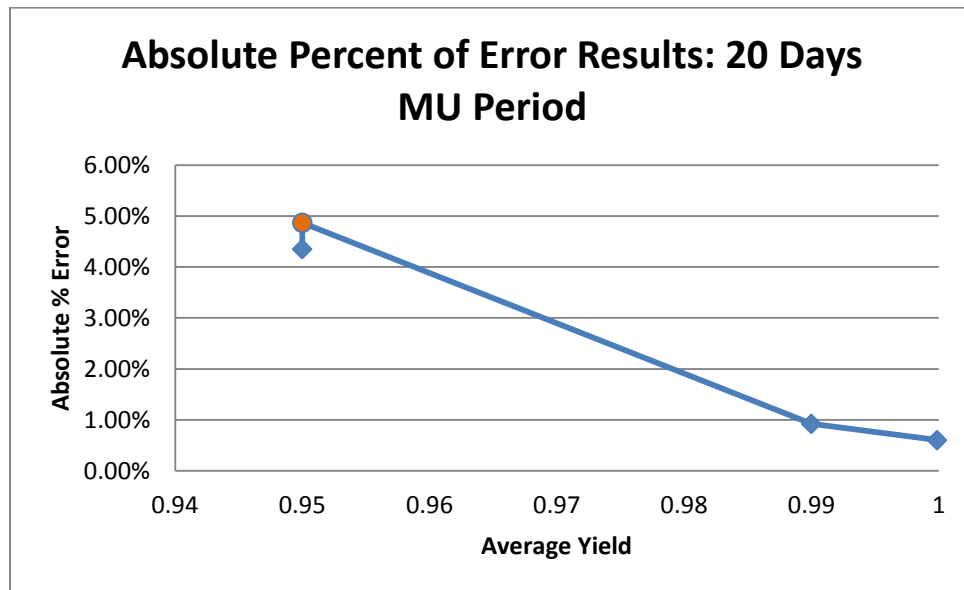


Figure 24. Average Percent of Error Results: Yield Based on a Triangular Distribution, 10 Days MU Period

Considering the average absolute percent of error presented in the tables above, we can conclude that our method to estimate WIP as a performance measure is appropriate to a system with the characteristics of long lead time, high variability and known average percent of yield. Implementation methodology is described in Appendix (K).

As shown in Table 13, the higher value of absolute percent of error is found when MU period is close to the lead time. The results support the literature description about when is appropriate to implement backflusing (i.e. lead time must be short, Bragss (2005)). Because the lead time is a controlled measure, an improvement of it will be advantageous for the company. The difference between the raw processing time and the total flow time observed in the company is around 8 days which means a difference of the 400%.

One of the most challenging phases in the project was the validation process due to inefficiencies in the manufacturing facility, such as downtimes. The frequent downtimes increase the total flow time causing work in progress inventory. Lean Manufacturing philosophy is centered

in the removal of any kind of waste (e.g. waiting, inventory). As the project site is called a “Lean Manufacturer”, a reduction of the lead time, idle machines and inventory is appropriate. In order to reduce these types of waste, an implementation of cellular manufacturing is recommended. Manufacturing cells minimize material handling times and workforce because machines are grouped closely together, working only a family or products with similar machining. Also, setups times are highly reduced or eliminated (White, 2000).

The method presented in this project can be useful to several departments within the company such as Engineering Department, Finance Department, Quality Department and Planning. As previously mentioned in this document, MU metric is not efficient when work in progress inventory exists. Therefore, this method will help engineers to monitor the performance of the floor (i.e. WIP and scrap) without increasing the number of transactions and avoiding an exhaustive counting. Also, Finance Department could implement this method in order to know how much they are losing due to the scrapped parts. In case of an accident an estimate of WIP results advantageous. If a perpetual inventory system is not performed, the method helps to estimate the total loss in order to claim to the insurance agent.

5.4 YIELD MONITORING

In previous sections we presented performance measures that accurately estimate the usage of material. To track the performance of the system is relevant for several departments within the company. However, it is crucial for Quality Department to know the yield of the process. Having a system that could easily monitor the yield (i.e. if it is stable or if it changes over the time) is convenient for this department. The system developed in this project allows yield monitoring, as long as a lot arrived to the final stock point. The following example shows the easiest way to calculate the real yield.

Table 14. Yield monitoring Example

Part_Number	Inputs (qty)	Outputs (qty)	Lots Out	Lots*Lot_Size	Yield
1	22100	20808	17	22100	0.9415
2	650	0	0	0	-
3	650	0	0	0	-
4	2600	1224	2	1300	0.9415
5	1300	1836	3	1950	0.9415
6	1950	612	1	650	0.9415
7	0	0	0	0	-
8	1300	0	0	0	-
9	0	0	0	0	-
10	19500	26273	43	27950	0.94
11	650	1222	2	1300	0.94
n12	0	0	0	0	-
13	1950	3055	5	3250	0.94
14	0	0	0	0	-
15	0	611	1	650	0.94
16	2600	2444	4	2600	0.94
17	0	0	0	0	-
18	650	611	1	650	0.94
19	0	0	0	0	-

Table 14 presents an example of a simulation output for 5 days MU period and fixed value of yield for each family type. The table shows each part numbers i , the quantity entered to the floor in the specified MU period t , the quantity that arrived to final stock, and the total lots that arrived to final stock. To calculate the yield the following formula should be performed:

$$Yield = \frac{Outputs_{i,h,t}}{LotsOut_{i,h,t}}$$

Noticed that the equation presented above is easy to achieve and the data are downloaded simply from the system.

5.5 PLANNING TOOL

The work in progress inventory is a metric useful for planning. The system presented in this project allows the planner to calculate the WIP inventory using the data downloaded from the system. The importance of knowing the WIP inventory is that it helps to identify stock-outs or excess of material for a particular part number. Also, inventory turnover which is a well-known indicator of the production performance within a “Lean” environment, can be easily calculated through WIP inventory. “Inventory Turn’s” formula facilitates the calculation of how many times, in a particular period the inventory is renewed; it’s reciprocal has an interpretation equivalent to average lead time of products in the system. The following table presents the output of the simulation model. A description of how to calculate the different performance measure is provided next.

Table 15. Planning Tool

Part_Number	Inputs (qty)	Outputs (qty)	Lots In	Lots Out	WIP (Lots)
1	23400	28152	18	23	24
2	1950	612	3	1	4
3	0	0	0	0	0
4	650	0	1	0	1
5	2600	3060	4	5	6
6	1300	0	2	0	2
7	0	0	0	0	0
8	0	0	0	0	0
9	650	612	1	1	1

Table 15 shows the output of the simulation model in Excel[®] for family type A, 5 days of MU period, and fixed yield. Work in progress inventory calculation was performed as follows:

$$WIP_{i,h,t} = LotsIn_{i,h,t} - LotsOut_{i,h,t} + WIP_{i,h,t-1}$$

The column called “Lots In” was calculated dividing the “Inputs” by the fixed lot size,

$$LotsIn_{i,h,t} = \frac{Input_{i,h,t}}{Lot_Size}$$

The “Lots Out” column is downloaded directly from the computer system; an explosion of the BOM is required to know the WIP inventory of raw material. After WIP inventory calculation, inventory turns is calculated as follows:

$$Inventory\ Turns = \frac{Yearly\ Total\ Lots\ Out}{Average\ WIP}$$

For the inventory turn calculation, in Table 15, a one year period (i.e. 44 weeks for simulation model purposes) was considered. The WIP inventory is the cumulative WIP since $t = 1$. Inventory turnover for this particular example was 28.21; this means that the MC area replaces the inventory 28.21 times a year. Thereby, average lead time is easy to calculate:

$$LeadTime = \frac{1}{Inventory\ Turnover}$$

In the example presented above the average lead time was 12.93 days which is within the lead time observed in the MC area.

6. Conclusions and Future Work

In conclusion, this project proposed a performance metric to overcome the inefficiencies of using material usage using a manufacturing facility as a case study. The system we were studying has the following characteristics:

- high product mix
- low volume demand
- long production flow time
- nonexistent WIP reporting

Traditional Material Usage as a performance measure do not represents a clear behavioral sight of the manufacturing area under study. We were able to attain an estimation of WIP inventory without increasing transactions.

In order to test if the WIP estimate was reasonable for this scenario, a simulation model was constructed using ProModel[®] simulation software. The model was validated through the real world scenario. After the validation procedure, we used simulated data to represent the manufacturing transactions in the MC area. Three attempts were made in order to find the best method to estimate WIP inventory with the minimum average absolute error.

The attempt based on lower and upper bounds on scrap attempt produced the minimum average absolute percent of error. With a known average value for yield, material input transactions, and material outcome transactions; the lower and upper bounds on scrap were estimated. A weighted average was calculated to estimate scrap, thus the estimate of WIP was possible. Several scenarios were developed with the purpose of identifying which parameters have a significant

impact (average absolute error greater than 10%) in our WIP inventory estimate. After conducting the sensitivity analysis presented in the Results section, we can conclude that our WIP estimate satisfy the company's target (i.e. $\varepsilon \leq 10\%$). Please refer to Appendix (I) to see the development of this method in detail.

Company's feedback

The model developed was presented to company's employees involved in the project. The feedback received was that "some of the employees that work in MC area had thought about different alternatives to accomplish an accurate material usage but they never implemented any of those". A brief explanation about the backflushing appropriateness was made in order to let them know the causes for the mismatch between material usage and scrap. The owner of continuous improvement effort was very interested in the literature found about the characteristics a process should have for a good implementation of backflushing. Since trace scrap is suggested in the literature, he explained "if we disciplined the employees, a transaction for scrap is preferred". The system developed in this project allows knowing the real scrap when a lot arrives to the final stock point. Therefore, if the scrap reported in the system by the employees is incorrect, a validation will be possible through the number of lots that arrived to stock. The model developed will then provide this validation tool. The planner of MC area was interested about the system. The feedback received was: "the system presented is a great tool. I can use it as a validation method".

Future Work

An immediate extension of this project is to implement the performance measures presented in the results section in the different departments (i.e. Finance Department, Quality Department, and Planning). As next step, this model can be extended considering variability in other inputs parameters. As a further extension, it can be applied to other systems with different characteristics as presented in this case study. Also, intermediate transactions can be added to identify if there is a

reduction in the average percent of error. Furthermore, this model could be further explored to test its sensitiveness, and if proven to be robust, it could be implemented as a tool to detect possible errors in the systems, such as incorrect BOMs.

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8. Appendices

A. GLOSSARY

- ABC inventory classification: is a method for dividing inventory into classifications, either by transaction volume or cost. Typically, category A includes that 20% of inventory involving 60% of all costs or transactions, while category B includes the next 20% of inventory involving 20% of all costs or transactions, and category C includes the remaining 60% of inventory involving 20% of all costs or transactions.
- Backflush: A term associated with an MRP system modification that offers and adaptation useful in lean manufacturing. APICS defines backflushing as the deduction from inventory records of the component parts used in an assembly or subassembly by exploding the bills of materials by the production count of assemblies produced.
- Cycle counting: The frequent, scheduled counting of a subset of all inventories, with the intent of spotting inventory record inaccuracies, investigating root causes, and correcting those problems.
- ERP (Enterprise Resource Planning): link information together across an entire organization in ways that make it much easier for upper management to have a more global picture of operations in almost real time.
- Floor stocks: Low-cost, high-usage inventory items stored near the shop floor, which the production staff can use it without a requisition and which are expensed at the time of receipt, rather than being accounted for through a formal inventory database.
- Flow Time: is the average time from release of a job at the beginning of the routing until it reaches an inventory point at the end of the routing.

- Job Shop manufacturing: frequently called batches. Parts are routed to different parts of the factory for processing steps, with relatively long lead times, high work in process inventories, and high utilization of work center capacities.
- Kanban: the goal of this system is to keep inventory moving through the manufacturing process with a lead time equal to processing time. Using kanban systems create a balance between inventory investment and material handling costs. In contrast to traditional manufacturing where components were assigned to a specific shop order; the advantage for the Lean manufacturer is that all material is available for use on any product immediately the product is demanded by the customer (i.e. rapid response time to the customer).
- Lead Time: a management constant indicating the time allotted for production of a part on a given routing.
- Lean Manufacturing: The National Institute of Standards and Technology define Lean Manufacturing as “A systematic approach to identifying and eliminating waste (non-value-added activities) through continuous improvement by flowing the product at the pull of the customer in pursuit of perfection.”
- MRP (manufacturing resource planning): is an integrated, computerized system for planning all manufacturing resources.
- One-piece-flow: one-piece flow means that parts are moved through operations from step-to-step with no WIP in between either one piece at a time or a small batch at a time.
- Pull: Refers to material flow discipline in which no one in a sequence of process steps produces anything until a downstream customer places an order for it.
- Scrap: faulty material that cannot be reworked.
- WIP (Work in process): any items being converted into finished goods or released from the warehouse in anticipation of beginning the conversion process.

- Work Order: in a manufacturing environment, a work order is converted from a sales order to show that work is about to be begin on the manufacture, building or engineering of the products requested by the customer.

B. KANBAN CARD

Part Number: 0105-202-398	<i>Inside/Outside</i>
Location To: WOC-001-001	<i>Inside</i>
QTY: 1260	<i>Backflushing</i>
	<i>N/A</i>
Description: 4mm Formula Welded Cutter	
Route: Plasma -Straightening-Verification-Centerless-Knurling-Unison	
Raw Material P/N'S:	Raw Material Location:
0105-199-653	PB1-001-006
0105-211-373	PB1-001-005

C. TRANSACTION HISTORICAL SUMMARY REPORT

The screenshot displays the Oracle Applications interface for the Endoscopy Production Instance. The main window is titled "Run this Request..." and contains the following fields and buttons:

- Name:** Transaction historical summary
- Parameters:** (empty field)
- Language:** American English
- Buttons:** Copy..., Language Settings..., Debug Options
- At these Times...**
 - Run the Job:** As Soon as Possible
 - Buttons:** Schedule
- Upon Completion...**
 - ☒ Save all Output Files
 - Layout:** (empty field)
 - Notify:** (empty field)
 - Print to:** noprint
 - Buttons:** Help (C), Submit, Cancel

A "Parameters" dialog box is open in the foreground, showing the following configuration:

- Sort By:** Subinventory
- Selection Option:** Quantity
- Include Consigned:** No
- Rollback to this Date:** 30-APR-2010
- Category Set:** INVENTORY (Inventory Category Set)
- Categories From:** (empty field)
- To:** (empty field)
- Items From:** (empty field)
- To:** (empty field)
- Subinventories From:** RM BF (RAW MATERIAL BACKFLUSH)
- To:** RM BF (RAW MATERIAL BACKFLUSH)
- Source Type for Column One:** Inventory
- Source Type for Column Two:** Move order
- Source Type for Column Three:** Purchase order
- Source Type for Column Four:** Job or Schedule
- Buttons:** OK, Cancel, Clear, Help

D. MU EQUATION PROOF

$I_{i,h,t}$: “Inventory” category transactions for raw material family type i , part number h in period t .

This category is used to depict entry transactions for materials type “C” in the ABC⁸ classification.

$M_{i,h,t}$: “Move order” category transactions for raw material family type i , part number h in period t .

Category used to trigger A and B products, i.e. high runners.

$A_{i,h,t}$: Inventory Manual Adjustments for raw material family type i , part number h in period t . This variable results in the sum of “Other” category transactions, which is mostly used to indicate an entry of raw material purchased to another division, and “Account alias” category transactions. These adjustments can be classified as entry or output transactions depending on cycle counting auditing.

$JS_{j,t}$: “Job or schedule”⁹ category transactions of part number j in period t . Outputs are considered as transactions triggered from machine center to stock, indicating that an assembly or finished good is completed.

To be able to learn how many raw material part numbers $h \in \{i\}$ come out of the shop, the bill-of-material (BOM) information for each final product j is used. To be able to represent this function mathematically we define an analogous to the BOM, $F_{j,i,h}$ as,

$$F_{j,i,h} = \begin{cases} 1, & \text{if final product } j \text{ is composed of raw material } h \in i \\ 0, & \text{otherwise} \end{cases}.$$

Let

$$OH_{i,h,t} = OH_{i,h,t-1} + I_{i,h,t} + M_{i,h,t} + A_{i,h,t} - \sum_j JS_{j,t} \cdot F_{j,ikh} \quad \forall i, h$$

⁸ The company classifies ABC items based on volume. Items categorized as A are high volume parts; B medium volume and C, low volume.

⁹ Job or Schedule (output category variable) refers to final part number which is exploding in the BOM

Therefore

$$MU_{ih,t} = OH_{i,h,t-1} + I_{i,h,t} + M_{i,h,t} + A_{i,h,t} - \sum_j JS_{j,t} \cdot F_{j,i,h} - OH_{i,h,t-1} \quad \forall i, h$$

To simplify the notation, let

$$IN_{i,h,t} = I_{i,h,t} + M_{i,h,t} + A_{i,h,t} \quad \forall i, h$$

$$OUT_{i,h,t} = \sum_j JS_{j,t} \cdot F_{j,i,h} \quad \forall i, h$$

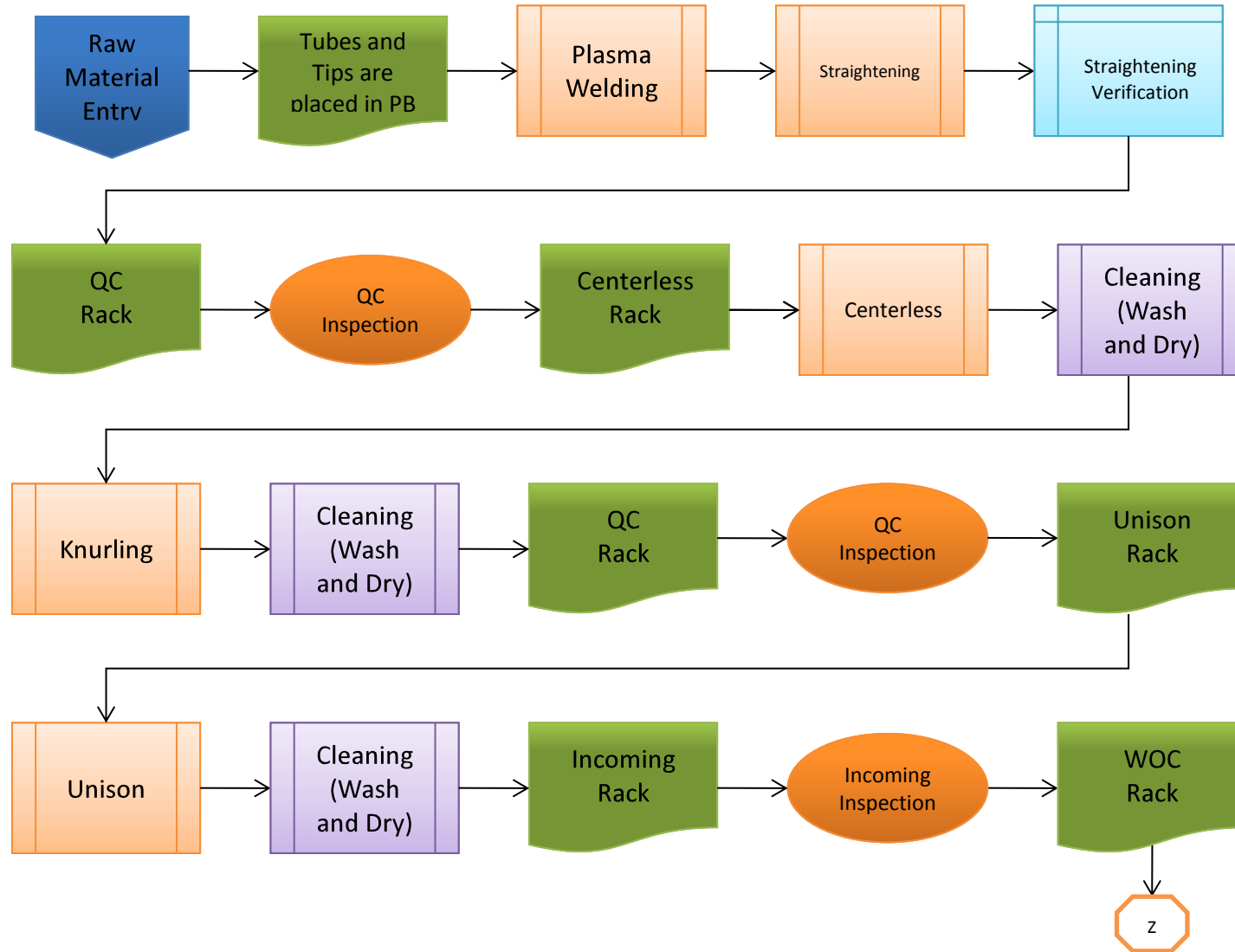
Thus

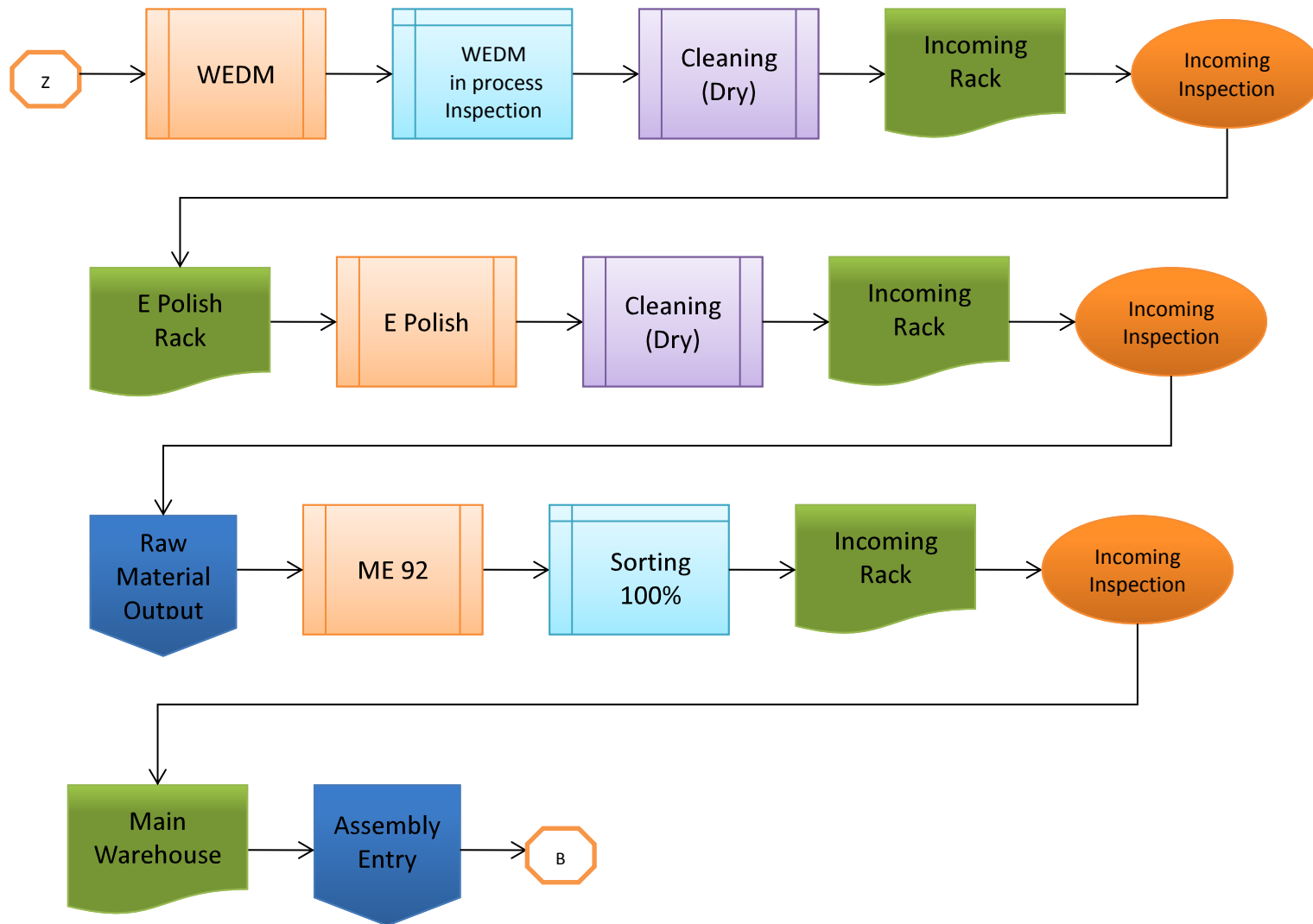
$$MU_{i,h,t} = OH_{i,h,t-1} + IN_{i,h,t} - OUT_{i,h,t} - OH_{i,h,t-1}$$

It follows that,

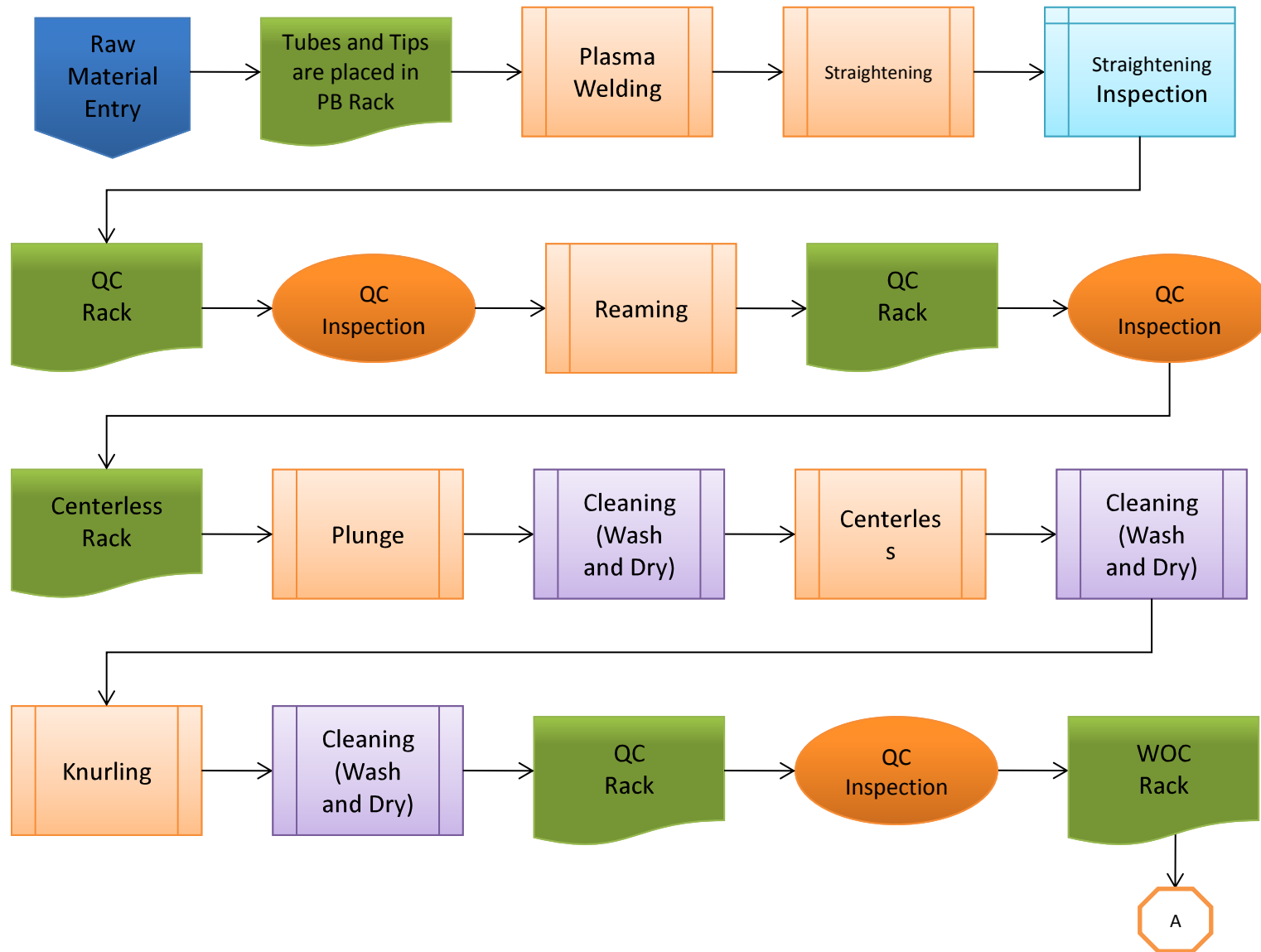
$$MU_{i,h,t} = IN_{i,h,t} - OUT_{i,h,t}$$

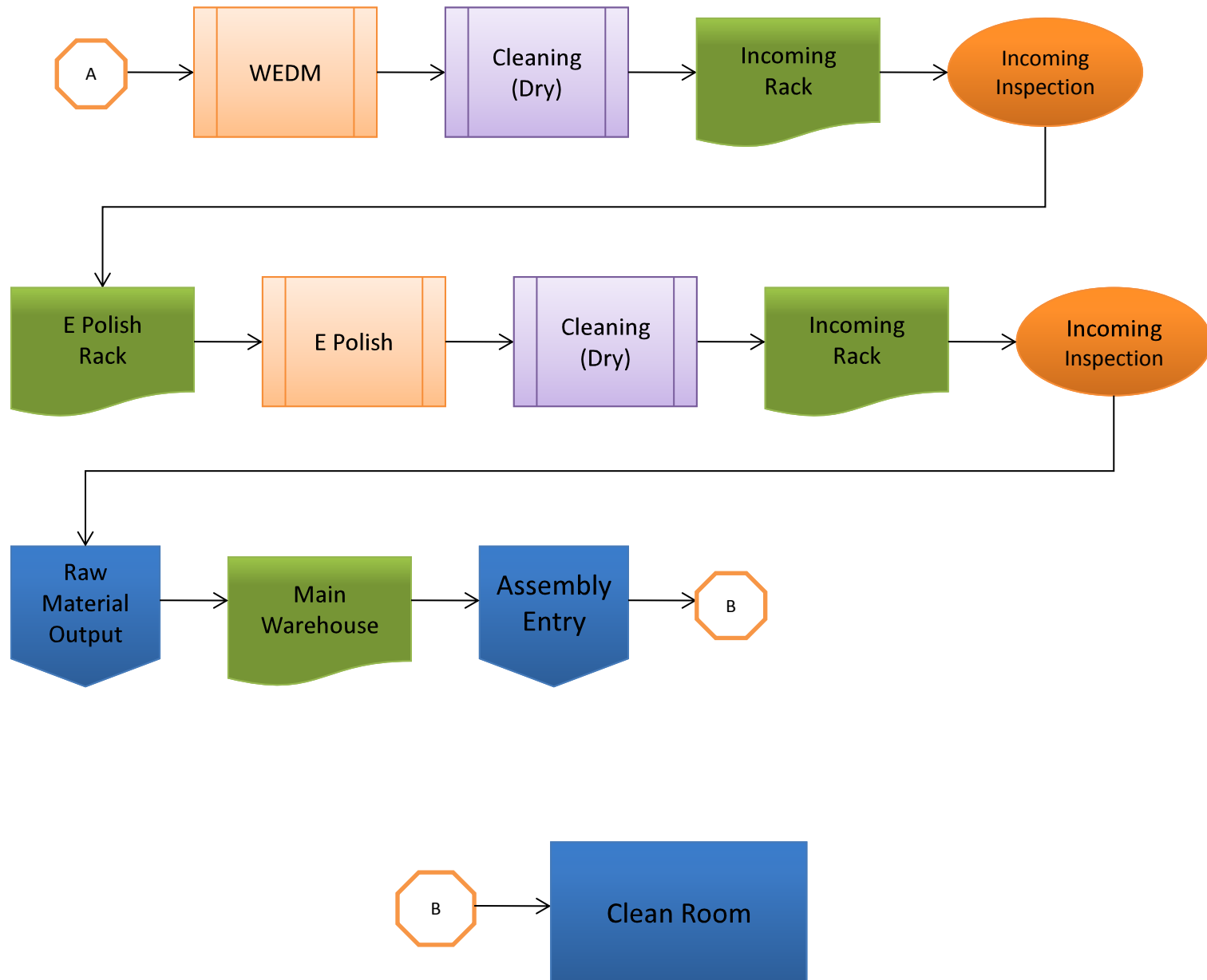
E. FAMILY TYPE A FLOW CHART





F. FAMILY TYPE B FLOW CHART





G. MANUFACTURING PLANNING SHEET

Week 1														
Monday	KB		Tuesday	KB		Wednesday	KB		Thursday	KB		Friday	KB	
AC_397	1	630	AC_400	1	630	AC_399	1	630	AC_398	4	5040	AC_518	2	1260
AC_398	4	5040	AC_397	1	630	AC_400	2	1260	AC_400	1	630	AC_398	4	5040
AC_399	1	630	AC_398	4	5040	AC_397	1	630	AC_397	1	630			
Total daily pcs		6300	Total daily pcs		6300	AC_398	3	3780	Total daily pcs		6300	Total daily pcs		6300
						Total daily pcs		6300						

Week 2														
Monday	KB		Tuesday	KB		Wednesday	KB		Thursday	KB		Friday	KB	
AC_488	1	630	AC_399	1	630	AC_399	1	630	AC_399	1	630	AC_398	4	5040
AC_680	1	630	AC_400	1	630	AC_400	3	1890	AC_400	1	630	AC_488	1	630
AC_398	4	5040	AC_398	4	5040	AC_398	3	3780	AC_398	4	5040	AC_2400	1	630
Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300

Week 3														
Monday	KB		Tuesday	KB		Wednesday	KB		Thursday	KB		Friday	KB	
AC_398	5	6300	AC_400	1	630	AC_399	1	630	AC_398	4	5040	AC_518	2	1260
			AC_397	1	630	AC_400	2	1260	AC_399	1	630	AC_398	4	5040
			AC_398	4	5040	AC_397	1	630	AC_400	1	630			
Total daily pcs		6300	Total daily pcs		6300	AC_398	3	3780	Total daily pcs		6300	Total daily pcs		6300
						Total daily pcs		6300						

Week 4														
Monday	KB		Tuesday	KB		Wednesday	KB		Thursday	KB		Friday	KB	
AC_488	1	630	AC_399	1	630	AC_400	2	1260	AC_399	1	630	AC_398	4	5040
AC_680	1	630	AC_400	1	630	AC_398	4	5040	AC_400	1	630	AC_488	1	630
AC_398	4	5040	AC_398	4	5040				AC_398	4	5040	AC_400	1	630
Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300

Week 1														
Monday	KB		Tuesday	KB		Wednesday	KB		Thursday	KB		Friday	KB	
AH_401	1	630	AH_404	1	630	AH_402	7	4410	AH_402	7	4410	AH_897	2	1260
AH_402	9	5670	AH_401	1	630	AH_404	2	1260	AH_404	2	1260	AH_402	8	5040
			AH_402	8	5040	AH_401	1	630	AH_401	1	630			
Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300

Week 2														
Monday	KB		Tuesday	KB		Wednesday	KB		Thursday	KB		Friday	KB	
AH_734	1	630	AH_404	1	630	AH_402	8	5040	AH_414	1	630	AH_402	8	5040
AH_402	9	5670	AH_401	1	630	AH_404	1	630	AH_404	1	630	AH_734	1	630
			AH_402	8	5040	AH_401	1	630	AH_402	8	5040	AH_404	1	630
Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300

Week 3														
Monday	KB		Tuesday	KB		Wednesday	KB		Thursday	KB		Friday	KB	
AH_2402	10	6300	AH_404	1	630	AH_404	2	1260	AH_402	8	5040	AH_897	1	630
			AH_401	1	630	AH_401	1	630	AH_404	2	1260	AH_401	1	630
			AH_402	8	5040	AH_402	7	4410				AH_402	8	5040
Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300

Week 4														
Monday	KB		Tuesday	KB		Wednesday	KB		Thursday	KB		Friday	KB	
AH_488	1	630	AH_402	9	5670	AH_404	2	1260	AH_399	1	630	AH_402	8	5040
AH_680	1	630	AH_404	1	630	AH_402	8	5040	AH_404	1	630	AH_734	1	630
AH_398	4	5040							AH_402	8	5040	AH_404	1	630
Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300	Total daily pcs		6300

H. NORMAL PROBABILITY PLOTS

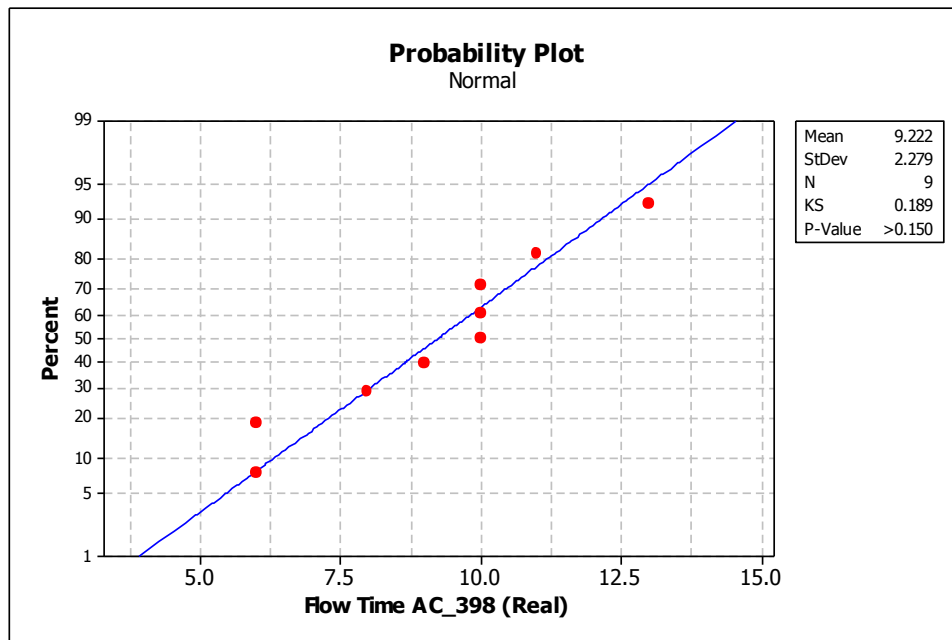


Figure 25. Probability plot for AC_398 (Real Data)

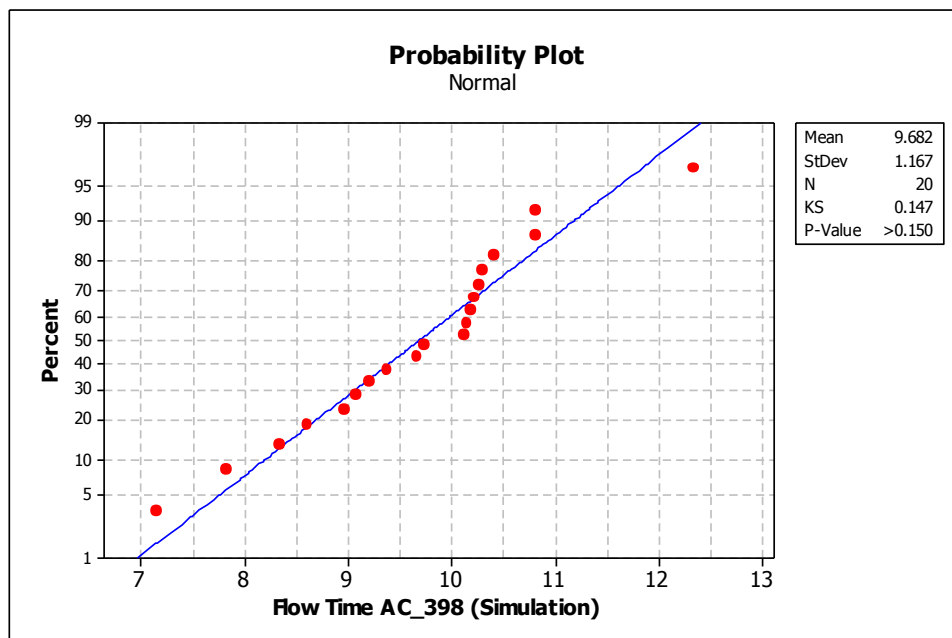


Figure 26. Probability plot for AC_398 (Simulated Data)

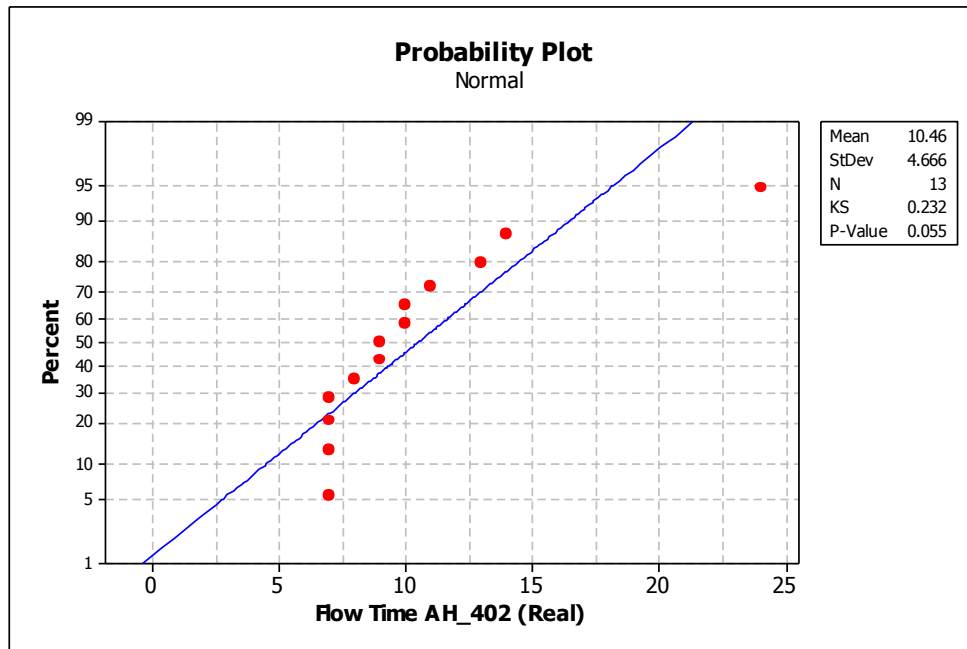


Figure 27. Probability plot for AH_402 (Real Data)

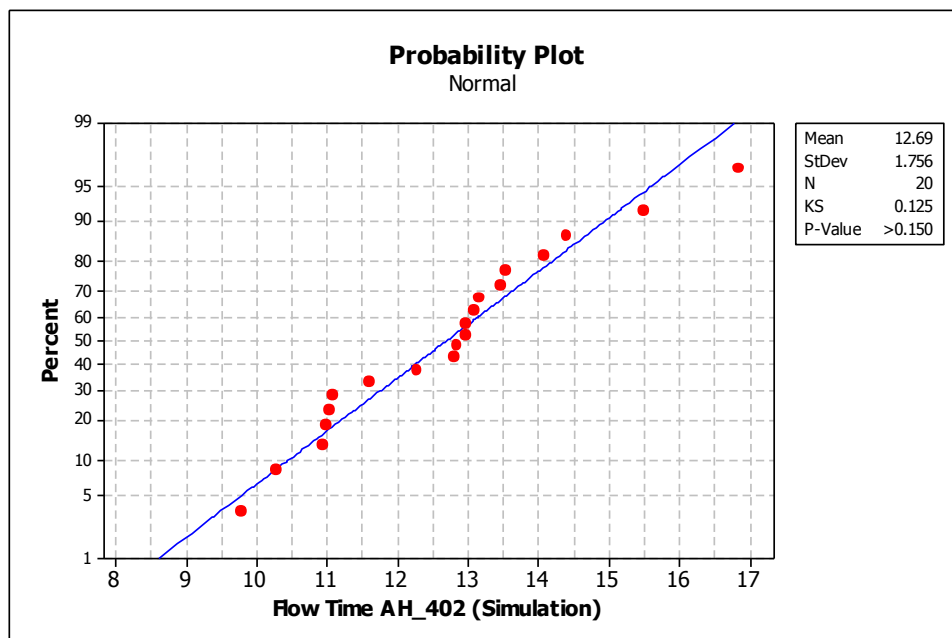


Figure 28. Probability plot for AH_402 (Simulated Data)

I. PROMODEL CODES

```
*****
*                                     *
*                                     * Formatted Listing of Model: *
*                                     *
*C:\Users\alma.sagredo.RemoteDesktop\Dropbox\SIMULACIONSCENARIOS\Min_Max\MC_MinMax_MOE.MOD *
*****
Time Units:      Minutes
Distance Units:  Feet
Initialization Logic: Week_Number = 0
```

```
*****
*                                     *
*                                     * Locations *
*                                     *
*****
```

Name	Cap	Units	Stats	Rules
Arrival_C	inf	1	Time Series	Oldest
Arrival_H	inf	1	Time Series	Oldest
P_C	1	1	Time Series	Rand,
P_H	1	1	Time Series	Rand,
Q_Ream	inf	1	Time Series	Oldest
Rea	1	1	Time Series	Rand,
Q_Insp	inf	1	Time Series	Oldest
Inspection	1	1	Time Series	Oldest
Q_Plun	inf	1	Time Series	Oldest
Plun	1	2	Time Series	Rand,First
Plun.1	1	1	Time Series	Rand,
Plun.2	1	1	Time Series	Rand,
Q_Cent	inf	1	Time Series	Oldest
Cent_C	1	1	Time Series	Rand,First
Cent_H	1	1	Time Series	Rand,
Q_Wash	inf	1	Time Series	Oldest
Wash	1	1	Time Series	Rand,

Q_Dry	inf	1	Time Series	Oldest
Dry	1	2	Time Series	Rand,First
Dry.1	1	1	Time Series	Rand,
Dry.2	1	1	Time Series	Rand,
Q_Kn	inf	1	Time Series	Oldest
Kn_C	1	1	Time Series	Rand,
Kn_H	1	1	Time Series	Rand,
Q_Uni	inf	1	Time Series	Oldest,First
Uni	1	2	Time Series	Rand,First
Uni.1	1	1	Time Series	Rand,
Uni.2	1	1	Time Series	Rand,
Q_Inco	inf	1	Time Series	Oldest
Incoming	1	1	Time Series	Oldest
WOC	inf	1	Time Series	Oldest
WEDM_C	1	1	Time Series	Rand,First
WEDM_H	1	1	Time Series	Rand,First
Q_Epol	inf	1	Time Series	Oldest
E_pol	1	1	Time Series	Rand,
QDry_WE	inf	1	Time Series	Oldest
Dry_WE	3	1	Time Series	Oldest,First
Dummy_Dry	inf	1	Time Series	Oldest
Dummy_WEDM	inf	1	Time Series	Oldest
Dummy_WIP	inf	1	Time Series	Oldest
Storage	inf	1	Time Series	Oldest
Dummy_for_contents	inf	1	Time Series	Oldest
Output_Recording	inf	1	Time Series	Oldest

			Series	
			Time	
OGP	1	1	Series	Oldest
			Time	
AFWOC	inf	1	Series	Oldest
			Time	
AFDRY	inf	1	Series	Oldest
			Time	
DummyAFDRY	inf	1	Series	Oldest
			Time	
CALC	1	1	Series	Oldest

 * Clock downtimes for Locations *

Loc	Frequency	First Time	Priority	Scheduled	Disable	Logic
P_C	T(10,20,30)day	15 day	99	No	No	Wait T(5,10,30) Min
	8 hr	6.92 hr	199	No	No	Wait 1.08 hr
P_H	T(10,20,30)	14 hr	99	No	No	Wait T(5,10,30) min
	8 hr	6.92 hr	199	No	No	Wait 1.08 hr
Rea	T(10,20,30) day	16 day	99	No	No	Wait 7 min
	8 hr	6.92 hr	199	No	No	Wait 1.08 hr
Inspecti	on 8 hr		199	No	No	Wait 1.08 hr
	2 hr	(null)	99	No	No	Wait 15 min
Plun	T(10,20,30)	10 day	99	No	No	Wait U(10,3)min
	8 hr	6.92 hr	199	No	No	Wait 1.08 hr
Plun.1	T(10,20,30)	10 day	99	No	No	Wait U(10,3) min
	8 hr	6.92 hr	199	No	No	Wait 1.08 hr
Plun.2	T(10,20,30)	10 day	99	No	No	Wait U(10,3) min
	8 hr	6.92 hr	199	No	No	Wait 1.08 hr
Cent_C						Wait T(10,15,45)
	T(10,20,30) day	20 day	99	No	No	Min
	8 hr	6.92 hr	199	No	No	Wait 1.08 hr
Cent_H						Wait T(10,15,45)
	T(10,20,30) day	19 day	99	No	No	min
	8 hr	6.92 HR	199	No	No	Wait 1.08 hr
Wash	14 hr		99	No	No	Wait 17 min
Kn_C	T(20,30,40) day	12 hr	99	No	No	Wait T(5,20,40)min
	8 hr	6.92 hr	199	No	No	Wait 1.08 hr
Kn_H	T(20,30,40) day	15 hr	99	No	No	Wait T(5,20,40) min
	8 hr	6.92 hr	199	No	No	Wait 1.08 hr
Uni						Wait T(20,45,65)
	T(20,40,60) day	30 day	99	No	No	min

Uni.1	8 hr	6.92 hr	199	No	No	Wait 1.08 hr
	T(20,40,60) day	30 day	99	No	No	Wait T(20,45,65) min
Uni.2	8 hr	6.92 hr	199	No	No	Wait 1.08 hr
	T(20,40,60) day	30 day	99	No	No	Wait T(20,45,65) min
Incoming	8 hr	6.92 hr	199	No	No	Wait 1.08 hr
	8 hr		199	No	No	Wait 1.08 hr
WEDM_C	3 hr	(null)	99	No	No	Wait 20 min
	U(3,0.5) day		99	No	No	wait T(5,7,10) min
WEDM_H	U(20,5) day	(null)	199	No	No	Wait T(20,100,310) min
	T(2,5,7) day		99	No	No	Wait U(20,5) min
E_pol	U(20,5) day	(null)	199	No	No	Wait T(20,100,310) hr
	8 hr		199	No	No	Wait 1.08 hr
OGP	8 hr		199	No	No	Wait 1.08 hr

Loc	Entity	Prior	Entity	Logic
P_C	ALL	ALL		Wait 15 min
P_H	ALL	ALL		Wait 15 min
Rea	ALL	ALL		Wait 15 min
Plun	ALL	ALL		Wait 20 min
Plun.1	ALL	ALL		Wait 20 min
Plun.2	ALL	ALL		Wait 20 min
Cent_C	ALL	ALL		Wait 20 min
Cent_H	ALL			Wait 20 min
Kn_C	ALL			Wait 30 MIN
Kn_H	ALL			Wait 15 min
Uni	ALL			wait 60 min
Uni.1	ALL			wait 60 min
Uni.2	ALL			wait 60 min
WEDM_C	ALL			Wait 15 min
WEDM_H	ALL			Wait 15 min
E pol	ALL			Wait 5 Min

 * Entities *

Name	Speed (fpm)	Stats
AC_398	150	Time Series
AC_680	150	Time Series
AC_3906	150	Time Series
AC_399	150	Time Series
AC_400	150	Time Series
AC_397	150	Time Series
AC_518	150	Time Series
AC_7906	150	Time Series
AC_488	150	Time Series
AH_402	150	Time Series
AH_404	150	Time Series
AH_395	150	Time Series
AH_401	150	Time Series
AH_634	150	Time Series
AH_897	150	Time Series
AH_414	150	Time Series
AH_178	150	Time Series
AH_179	150	Time Series
AH_734	150	Time Series
Revision_Cycle	150	Time Series
Dummy	150	Time Series
For_WIP	150	Time Series

 * Resources *

Name	Units	Stats	Res Search	Ent Search Path	Motion
Rea_OP	1	By Unit	Least Used	Oldest	Empty: 150 fpm Full: 150 fpm
Plun_OP	1	By Unit	None	Oldest	Empty: 150 fpm Full: 150 fpm
Cent_OP	1	By Unit	None	Oldest	Empty: 150 fpm Full: 150 fpm
WD_OP	1	By	None	Oldest	Empty: 150 fpm

		Unit			
				Full: 150 fpm	
Kn_OP	1	By Unit	None	Oldest	Empty: 150 fpm
				Full: 150 fpm	
Uni_OP	1	By Unit	None	Oldest	Empty: 150 fpm
				Full: 150 fpm	
WEDM_OP	2	By Unit	None	Oldest	Empty: 150 fpm
				Full: 150 fpm	
Epol_OP	1	By Unit	None	Oldest	Empty: 150 fpm
				Full: 150 fpm	

 * Clock downtimes for Resources *

Res	Frequenc y	First Time	Priorit y	Schedule d	Nod e	Lis t	Disabl e	Logic
Rea_OP	8 hr	6.92 hr	199	No			No	Wait 1.08 hr
Plun_OP	8 hr	6.92 hr		No			No	Wait 1.08 hr
Cent_OP	8 hr	6.92 hr		No			No	Wait 1.08 hr
WD_OP	8 hr	6.92 hr		No			No	Wait 2 hr
Kn_OP	8 hr	6.92 hr		No			No	Wait 1.08 hr
Uni_OP	8 hr	6.92 hr		No			No	Wait 1.08 hr
WEDM_O								
P	8 hr	6.92 hr		No			No	Wait 2 hr
Epol_OP	8 hr	6.92 hr		No			No	Wait 1.08 hr

 * Processing *

		Process	Routing		
Entity	Location	Operation	Blk	Output	Destination Rule Move Logic
ALL	Arrival_C				
		#Assembly_Type = 1: entities types 1 arrive to this location			
		wait 0.0001 sec			
		Route 1			
		#Assembly_Type = 1 entities GO TO Dummy_WIP location			
		1	ALL	Dummy_WIP	FIRST 1


```

ALL      Arrival_H
        #Assembly_Type = 2: entities types 2 arrive to this location

        wait 0.0002 sec

        Route 1

        #Assembly_Type = 2 entities GO TO Dummy_WIP location
        1  ALL      Dummy_WIP  FIRST 1  MOVE FOR U(1,0.25) MIN

ALL      Dummy_WIP
        If Assembly_Type = 1 Then
        {
        Route 1
        }
        Else

        {
        Route 2
        }

        1  ALL      P_C      FIRST 1
        2  ALL      P_H      FIRST 1

ALL      P_C

        #local variables
        int ArrivalQty      #Variable to record lot size
        Real DepartureQty    #Variable to record lot size after yield loss
        real DeltaT          #Attempt 2 variable

        #Attribute named "Process" to identify the location
        Process = 1

        #Attribute to save the time an entity "X" arrive to this location
        wait 0.002
        Entrada = CLOCK(HR)

        LotIn = Lot_Size    #attribute that save the lot size

        INC Estimate[19*(Week_Number-1)+ENT(Entity()),7],1 #exporting data to Excel

        #Case 3 (Attempt 2)

        DeltaT = MUend*24 - Entrada
        AccumDeltaT = AccumDeltaT + DeltaT

        #DeltaT Case 3 & 2
        INC Estimate[19*(Week_Number-1)+ENT(Entity()),13],DeltaT #exporting data to
                                                                    Excel

        #Exporting total entries in a defined period of time (MU period)
        INC Estimate[19*(Week_Number-1)+ENT(Entity()),8],1
        INC Results[19*(Week_Number-1)+ENT(Entity()),5],Lot_Size
        #Exporting Delta T used on the attempt 2
        INC Estimate[19*(Week_Number-1)+ENT(Entity()),6], AccumDeltaT

        #Number of Cases 3
        INC Estimate[19*(Week_Number-1)+ENT(Entity()),11],1

```

```

#Registrating the quantity of units that arrived to this location of entity ()
#This data is exported to Excel within the Array named "Results"
INC Results[19*(Week_Number-1)+ENT(Entity()),3], Lot_Size
INC Estimate[19*(Week_Number-1)+ENT(Entity()),5], Lot_Size

#ArrivalQty is a local variable that save the initial size of the lot
ArrivalQty = Lot_Size

#Processing time imported from excel
wait Info[Ent(Entity()),2] min
#DepartureQty is a local variable that save the lot size after machining

DepartureQty = Lot_Size* Yield

#The lot size for the next process will be equal to the departure quantity

Lot_Size = round(DepartureQty)

#S local variable that represents scrap. The result is exported to excel
S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S
Dec Results[19*(Week_Number-1)+ENT(Entity()),5],S
ROUTE 1 #indicating where to go

```

ALL	P_H	<pre> 1 ALL Q_Insp FIRST 1 MOVE FOR U(1,0.25) MIN int ArrivalQty Real DepartureQty Real DeltaT Process = 12 Entrada = CLOCK(HR) LotIn = Lot_Size INC Estimate[19*(Week_Number-1)+ENT(Entity()),7],1 INC Estimate[19*(Week_Number-1)+ENT(Entity()),8],1 INC Results[19*(Week_Number-1)+ENT(Entity()),5],Lot_Size #Case 3 DeltaT = MUend*24 - Entrada AccumDeltaT = AccumDeltaT + DeltaT Case = 3 INC Estimate[19*(Week_Number-1)+ENT(Entity()),6], AccumDeltaT #DeltaT Cases 3 & 2 INC Estimate[19*(Week_Number-1)+ENT(Entity()),13],DeltaT #Number of Cases 3 INC Estimate[19*(Week_Number-1)+ENT(Entity()),11],1 INC Results[19*(Week_Number-1)+ENT(Entity()),3], Lot_Size INC Estimate[19*(Week_Number-1)+ENT(Entity()),5], Lot_Size ArrivalQty = Lot_Size </pre>
-----	-----	---

```

wait Info[Ent(Entity()),3] min

DepartureQty = Lot_Size* Yield
Lot_Size = round(DepartureQty)

S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S
Dec Results[19*(Week_Number-1)+ENT(Entity()),5],S

ALL      1  ALL      Q_Insp  FIRST 1 MOVE FOR U(1,0.25) MIN
ALL      Q_Insp    1  ALL      Inspection FIRST 1 MOVE FOR U(1,.25) MIN
ALL      Inspection Wait 3 min
          #Process 1 => P_C
          #Process 12 => P_H
          #Process 2 => Rea
          #Process 5 => Kn

          #If lot comes from an specific process or location then go to...

          If Process = 1 Then
          {
          Wait Info[Ent(Entity()),4] min

          ROUTE 1
          }
          ELSE

          If Process = 12 Then
          {
          Wait Info[Ent(Entity()),4] min
          ROUTE 2
          }

          ELSE

          If Process = 2 Then
          {

          Wait Info[Ent(Entity()),6] min

          ROUTE 3

          }
          ELSE

          IF Process = 51 Then
          {

          Wait Info[Ent(Entity()),14] min

          Route 4
          }
          ELSE
          If Process = 52 Then
          {
          Wait Info[Ent(Entity()),14] min

```

Route 5
}

1	ALL	Q_Cent	FIRST 1 MOVE FOR U(1,0.25) MIN
2	ALL	Q_Ream	FIRST 1 MOVE FOR U(1,0.25) MIN
3	ALL	Q_Plun	FIRST 1 MOVE FOR U(1,0.25) MIN
4	ALL	Q_Uni	FIRST 1 MOVE FOR U(1,0.25) MIN
5	ALL	WOC	FIRST 1 MOVE FOR U(1,0.25) MIN

ALL	Q_Ream	1	ALL	Rea	FIRST 1 MOVE FOR U(1,0.25) MIN
ALL	Rea				

#indicating the process attribute
Process = 2

#getting a resource
GET Rea_OP
#time spending setting up the lot
Wait 10 min

int ArrivalQty
Real DepartureQty

ArrivalQty = Lot_Size

#Releasing the resource
FREE Rea_OP

wait Info[Ent(Entity()),9] min

DepartureQty = Lot_Size* Yield
Lot_Size = round(DepartureQty)

S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S
Dec Results[19*(Week_Number-1)+ENT(Entity()),5],S

	ROUTE 1	1	ALL	Q_Insp	FIRST 1 MOVE FOR U(1,0.25) MIN
ALL	Q_Plun	1	ALL	Plun	FIRST 1 MOVE FOR U(1,0.25) MIN
ALL	Plun	Process = 3			

GET Plun_OP

Wait 7 min

int ArrivalQty
Real DepartureQty

ArrivalQty = Lot_Size

FREE Plun_OP

wait Info[Ent(Entity()),8] min

DepartureQty = Lot_Size* Yield
Lot_Size = round(DepartureQty)

S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S

Dec Results[19*(Week_Number-1)+ENT(Entity()),5],S

	ROUTE 1	1	ALL	Q_Wash	FIRST 1	MOVE FOR U(1,0.25) MIN
ALL	Q_Wash	1	ALL	Wash	FIRST 1	MOVE FOR U(1,0.25) MIN
ALL	Wash					

GET WD_OP

Wait 8 min
int ArrivalQty
Real DepartureQty

ArrivalQty = Lot_Size

If Process = 3 Then
{

FREE WD_OP

Wait Info[Ent(Entity()),12] min

DepartureQty = Lot_Size
Lot_Size = round(DepartureQty)

S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S

ROUTE 1
}

ELSE
IF Process = 51 THEN
{
FREE WD_OP

Wait Info[Ent(Entity()),11] min

DepartureQty = Lot_Size
Lot_Size = round(DepartureQty)

S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S

```

Route 1
}
ELSE

If Process = 52 Then
{

FREE WD_OP

Wait Info[Ent(Entity()),12] min

DepartureQty = Lot_Size
Lot_Size = round(DepartureQty)

S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S

Route 1
}
ELSE
{
FREE WD_OP

Wait Info[Ent(Entity()),11] min

DepartureQty = Lot_Size
Lot_Size = round(DepartureQty)

S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S

ROUTE 1
}

```

```

1 ALL Q_Dry FIRST 1 MOVE FOR U(1,0.25) MIN

ALL Q_Dry Accum 3
#Display "Contents ", CONTENTS(Q_Dry)

1 ALL Dummy_Dry FIRST 1

ALL Dummy_Dry
#Location created to group entities.
GROUP 3 #number of entities to be grouped

1 ALL Dry FIRST 1

ALL Dry

GET WD_OP

Wait 8 min

```

```

int ArrivalQty
Real DepartureQty

ArrivalQty = Lot_Size

DepartureQty = Lot_Size
Lot_Size = round(DepartureQty)

If process = 3 Then
{

FREE WD_OP

Wait Info[Ent(Entity()),15] min

S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S

}
Else

{
FREE WD_OP

Wait Info[Ent(Entity()),13] min

S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S

}

```

```

1 ALL AFDRY FIRST 1

```

```

ALL AFDRY

```

```

UNGROUP #ungrouping entities

```

```

Route 1

```

```

ALL AFDRY
Route 1

```

```

1 ALL DummyAFDRY FIRST 1
ALL DummyAFDRY

```

```

If process = 3 Then
{

```

```

ROUTE 1
}
Else

```

```

If Process = 41 OR Process = 42 Then
{
ROUTE 2

```

```

}
ELSE

```

```

If Process = 6 Then

```

```

{
ROUTE 4
}
ELSE

```

```

{
ROUTE 3
}

```

		1	ALL	Q_Cent	FIRST 1	MOVE FOR U(1,0.25) MIN
		2	ALL	Q_Kn	FIRST 1	MOVE FOR U(1,0.25) MIN
		3	ALL	Q_Insp	FIRST 1	MOVE FOR U(1,0.25) MIN
ALL	Q_Cent	4	ALL	Q_Inco	FIRST 1	MOVE FOR U(1,0.25) MIN

```

If Assembly_Type = 1 Then

```

```

{
Route 1
}

```

```

Else

```

```

{
Route 2
}

```

		1	ALL	Cent_C	FIRST 1
		2	ALL	Cent_H	FIRST 1

ALL	Cent_C	Process = 41
-----	--------	--------------

```

GET Cent_OP

```

```

Wait 7 min

```

```

int ArrivalQty
Real DepartureQty

```

```

ArrivalQty = Lot_Size

```

```

FREE Cent_OP

```

```

wait Info[Ent(Entity()),5] min

```

```

DepartureQty = Lot_Size* Yield
Lot_Size = round(DepartureQty)

```

```

S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S

```


Dec Results[19*(Week_Number-1)+ENT(Entity()),5],S

1 ALL Q_Wash FIRST 1 MOVE FOR U(1,0.25) MIN

ALL Cent_H Process = 42

GET Cent_OP

Wait 7 min

int ArrivalQty
Real DepartureQty

ArrivalQty = Lot_Size

FREE Cent_OP

wait Info[Ent(Entity()),5] min

DepartureQty = Lot_Size* Yield
Lot_Size = round(DepartureQty)

S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S

Dec Results[19*(Week_Number-1)+ENT(Entity()),5],S

1 ALL Q_Wash FIRST 1 MOVE FOR U(1,0.25)

MIN
ALL Q_Kn

If Assembly_Type = 1 Then

{
Route 1
}

Else

{
Route 2
}

1 ALL Kn_C FIRST 1
2 ALL Kn_H FIRST 1

ALL Kn_C int ArrivalQty
Real DepartureQty

Process = 51
GET Kn_OP

Wait 7 min

ArrivalQty = Lot_Size

```

FREE Kn_OP

wait Info[Ent(Entity()),7] min

DepartureQty = Lot_Size* Yield
Lot_Size = round(DepartureQty)


S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S

Dec Results[19*(Week_Number-1)+ENT(Entity()),5],S

Route 1      1  ALL      Q_Wash   FIRST 1  MOVE FOR U(1,0.25) MIN

ALL      Kn_H      int ArrivalQty
Real DepartureQty

Process = 52

GET Kn_OP

Wait 7 min

ArrivalQty = Lot_Size

FREE Kn_OP

wait Info[Ent(Entity()),7] min

DepartureQty = Lot_Size* Yield
Lot_Size = round(DepartureQty)

S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S

Dec Results[19*(Week_Number-1)+ENT(Entity()),5],S

Route 1      1  ALL      Q_Wash   FIRST 1  MOVE FOR U(1,0.25) MIN

ALL      Q_Uni      1  ALL      Uni      FIRST 1

ALL      Uni      Process = 6

GET Uni_OP

wait 10 min

int ArrivalQty
Real DepartureQty

ArrivalQty = Lot_Size

FREE Uni_OP

```

```

wait Info[Ent(Entity()),10] min

DepartureQty = Lot_Size* Yield

Lot_Size = round(DepartureQty)

S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S

Dec Results[19*(Week_Number-1)+ENT(Entity()),5],S

                                1  ALL      Q_Wash   FIRST 1  MOVE FOR U(1,0.25) MIN

ALL      Q_Inco                1  ALL      Incoming  FIRST 1

ALL      Incoming      int ArrivalQty
                        Real DepartureQty

                        ArrivalQty = Lot_Size
                        DepartureQty = Lot_Size

                        Wait 10 min

                        Lot_Size = round(DepartureQty)

                        If Process = 6 Then
                        {
                        Wait 15 min
                        S = ArrivalQty - Lot_Size
                        INC Results[19*(Week_Number-1) + (Entity()),6],S

                        Route 1
                        }
                        ELSE
                        If Process = 71 OR Process = 72 Then
                        {
                        Wait 25.2 min
                        S = ArrivalQty - Lot_Size
                        INC Results[19*(Week_Number-1) + (Entity()),6],S

                        Route 2
                        }
                        ELSE

                        If Process = 8 Then
                        {
                        Wait 10.2 min
                        S = ArrivalQty - Lot_Size
                        INC Results[19*(Week_Number-1) + (Entity()),6],S

                        Route 3
                        }

                                1  ALL      WOC      FIRST 1  MOVE FOR U(1,0.25) MIN

```

2	ALL	Q_Epol	FIRST 1	MOVE FOR U(1,0.25) MIN
3	ALL	Storage	FIRST 1	MOVE FOR U(1,0.25) MIN

ALL WOC

If Entity() <= 9 Then #indicating which route to take according to the entity type

{

 Route 1

 }

 Else

 {

 Route 2

 }

1	ALL	WEDM_C	FIRST 1
2	ALL	WEDM_H	FIRST 1

ALL WEDM_C

 int ArrivalQty

 Real DepartureQty

 Process = 71

 GET WEDM_OP

 Wait 7 min

 ArrivalQty = Lot_Size

 DepartureQty = Lot_Size* Yield

 Lot_Size = round(DepartureQty)

 FREE WEDM_OP

 WAIT Info[Ent(Entity()),16] min

 S = ArrivalQty - Lot_Size

 INC Results[19*(Week_Number-1) + (Entity()),6],S

 Dec Results[19*(Week_Number-1)+ENT(Entity()),5],S

1	ALL	QDry_WE	FIRST 1
---	-----	---------	---------

ALL WEDM_H

 Process = 72

 GET WEDM_OP

 Wait 7 min

 int ArrivalQty

 Real DepartureQty

 ArrivalQty = Lot_Size

 DepartureQty = Lot_Size* Yield

 Lot_Size = round(DepartureQty)

FREE WEDM_OP

Wait Info[Ent(Entity()),17] min

S = ArrivalQty - Lot_Size

INC Results[19*(Week_Number-1) + (Entity()),6],S

Dec Results[19*(Week_Number-1)+ENT(Entity()),5],S

1 ALL QDry_WE FIRST 1

ALL QDry_WE 1 ALL Dry_WE FIRST 1

ALL Dry_WE int ArrivalQty
Real DepartureQty

ArrivalQty = Lot_Size

DepartureQty = Lot_Size

Lot_Size = round(DepartureQty)

If Process = 71 OR Process = 72 Then

{

Wait Info[Ent(Entity()),20] min

S = ArrivalQty - Lot_Size

INC Results[19*(Week_Number-1) + (Entity()),6],S

Route 1

}

ELSE

{

Wait Info[Ent(Entity()),20] min

S = ArrivalQty - Lot_Size

INC Results[19*(Week_Number-1) + (Entity()),6],S

Route 2

}

1 ALL OGP FIRST 1 MOVE FOR U(1,0.25) MIN

2 ALL Q_Inco FIRST 1 MOVE FOR U(1,0.25) MIN

ALL OGP Wait 5 min

If Ent(Entity()) = 1 Then

{

Wait (264*U(12.5,2.5)) sec

}

Else

{

Wait (132*U(12.5,2.5)) sec

}

1 ALL Q_Inco FIRST 1 MOVE FOR U(1,0.25) MIN

ALL Q_Epol 1 ALL E_pol FIRST 1

ALL E_pol Process = 8

Get Epol_OP

Wait 10 min

int ArrivalQty
Real DepartureQty

ArrivalQty = Lot_Size
DepartureQty = Lot_Size
Lot_Size = round(DepartureQty)

IF Assembly_Type = 1 THEN
{
Free Epol_OP
Wait Info[Ent(Entity()),18] min
S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S

Route 1
}
ELSE

{
Free Epol_OP
Wait Info[Ent(Entity()),19] min
S = ArrivalQty - Lot_Size
INC Results[19*(Week_Number-1) + (Entity()),6],S
Route 1
}

ALL 1 ALL QDry_WE FIRST 1
Storage Real DeltaT

Wait 0.08 hr

#Exporting to a column in Excel the entities that arrived to Storage
Estimate[19*(Week_Number-1)+ENT(Entity()),1] = Ent(Entity())

#Number of lots that arrived to storage
INC Estimate[19*(Week_Number-1)+ENT(Entity()),3], 1
Dec Results[19*(Week_Number-1)+ENT(Entity()),5],Lot_Size

#Variable that saves the time an entity arrived to storage
Salida = CLOCK(HR)
#calculating total flow time
FlowTime = Salida - Entrada

#Saving Flow Time for each part number and exporting to excel
INC Estimate[19*(Week_Number-1)+ENT(Entity()),2], FlowTime

#Actual WIP counter
DEC Estimate[19*(Week_Number-1)+ENT(Entity()),7], 1

#Calculating parameters used on attempt 2: Case 2
If Entrada >= MUstart*24 Then

```

{
DeltaT = Salida - MUend*24

Inc Estimate[19*(Week_Number-1)+ENT(Entity()),6], DeltaT

#Counting the number of Cases 2 in an specific MU period
INC Estimate[19*(Week_Number-1)+ENT(Entity()),10],1

#Counting the number of Cases 3 in an specific MU period
DEC Estimate[19*(Week_Number-1)+ENT(Entity()),11],1

#DeltaT 3&2
INC Estimate[19*(Week_Number-1)+ENT(Entity()),13],DeltaT
INC Estimate[19*(Week_Number-1)+ENT(Entity()),16],muend*24-entrada+DeltaT
}
Else
#Case 1
{
If Entrada < MUstart*24 Then

DeltaT = Salida - MUend*24

INC Estimate[19*(Week_Number-1)+ENT(Entity()),6], DeltaT
INC Estimate[19*(Week_Number-1)+ENT(Entity()),9],1
DEC Estimate[19*(Week_Number-1)+ENT(Entity()),12], 1

#DeltaT 1&4
INC Estimate[19*(Week_Number-1)+ENT(Entity()),14], DeltaT
INC Estimate[19*(Week_Number-1)+ENT(Entity()),15],(MUend-MUstart)*24+DeltaT
}

#Saving entity output
INC Results[19*(Week_Number-1) + ENT(Entity()),4],Lot_Size

#Truncation Point = 12,000 hrs
If CLOCK(HR) > 12000 Then

#exporting flow time for each entity
INC LeadTime[z,ENT(Entity())],FlowTime

inc z
1 ALL EXIT FIRST 1
Revision_Cycle Output_Recording #dummy location used to indicate and increment Week Number
int i
int DeltaT
i = 1

INC Week_Number

MUstart = Clock(day)
MUend = MUstart + MUPeriod +0.005

While i <= 19 DO
{

```

```

#Saving Entity number in the first colum of "Results" array
Results[i+ 19*(Week_Number-1),1] = i
Estimate[19*(Week_Number-1)+i,1] = i
Results[i+(Week_Number-1)*19,2] = Week_Number

if week_number >=2 then
{
Estimate[19*(Week_Number-1)+i,4]=Estimate[19*(Week_Number-2)+i,7]
Estimate[19*(Week_Number-1)+i,7]=Estimate[19*(Week_Number-2)+i,7]

Results[19*(Week_Number-1)+i,5]=Results[19*(Week_Number-2)+i,5]
}
#Exporting WIP to excel for each entity
Estimate[19*(Week_Number-1)+i,12] = Estimate[19*(Week_Number-1)+i,4]
Estimate[19*(Week_Number-1)+i,6] = Estimate[19*(Week_Number-1)+i,4]*((MUend
- MUstart)*24)
Estimate[19*(Week_Number-1)+i,14] = Estimate[19*(Week_Number-1)+i,4]*((MUend
- MUstart)*24)

INC i

}

wait 0.001      1  Revision_Cycle EXIT      FIRST 1

```

```

*****
*                               *
*                               *
*****

```

Entity	Location	Qty Each	First Time	Occurren ces	Frequency	Logic
AC_398	Arrival_C	4	0	inf	1 day	Assembly_Type = 1 Lot_Size = 1300
AC_680	Arrival_C	2	0	inf	U(10,2) day	Assembly_Type = 1 Lot_Size = 650
AC_3906	Arrival_C	1	0	inf	U(20,3) day	Assembly_Type = 1 Lot_Size = 650
AC_399	Arrival_C	1	0	inf	U(2,1) day	Assembly_Type = 1 Lot_Size = 650
AC_400	Arrival_C	2	0	inf	U(3,1)day	Assembly_Type = 1 Lot_Size = 650
AC_397	Arrival_C	1	0	inf	U(5,1) day	Assembly_Type = 1

AC_518	Arrival_C	1	0	inf	U(10,3) day	Lot_Size = 650 Assembly_Type = 1
AC_7906	Arrival_C	1	0	inf	U(20,5) day	Lot_Size = 650 Assembly_Type = 1
AC_488	Arrival_C	1	0	inf	U(15,5) day	Lot_Size = 650 Assembly_Type = 1
AH_402	Arrival_H	8	0	inf	1 day	Lot_Size = 650 Assembly_Type = 2
AH_404	Arrival_H	1	0	inf	U(2,1) day	Lot_Size = 650 Assembly_Type = 2
AH_395	Arrival_H	1	0	inf	U(54,12) day	Lot_Size = 650 Assembly_Type = 2
AH_401	Arrival_H	2	0	inf	U(2,1) day	Lot_Size = 650 Assembly_Type = 2
AH_634	Arrival_H	1	0	inf	U(20,3) day	Lot_Size = 650 Assembly_Type = 2
AH_897	Arrival_H	1	0	inf	U(10,2) day	Lot_Size = 650 Assembly_Type = 2
AH_414	Arrival_H	2	0	inf	U(2,1) day	Lot_Size = 650 Assembly_Type = 2
AH_178	Arrival_H	1	0	inf	U(7,2)day	Lot_Size = 650 Assembly_Type = 2
AH_179	Arrival_H	1	0	inf	U(6,1) day	Lot_Size = 650 Assembly_Type = 2
AH_734	Arrival_H	1	0	inf	U(20,2) day	Lot_Size = 650 Assembly_Type = 2
Revision_Cycle	Output_Recording	1	0	inf	MUPeriod day	Lot_Size = 650
Dummy	Dummy_for_constants	1	0	inf	1 hr	

 * Attributes *

ID	Type	Classification
Assembly_Type	Integer	Entity
Lot_Size	Integer	Entity
Process	Integer	Entity
Entrada	Real	Entity
Salida	Real	Entity
slope	Real	Entity
ScrapE	Integer	Entity
AccumDeltaT	Real	Entity
LotIn	Integer	Entity
AccumLotIn	Integer	Entity
Case	Integer	Entity

 * Variables (global) *

ID	Type	Initial value	Stats
Week_Number	Integer	0	Time Series
S	Integer	0	Time Series
For_Contents	Integer	0	Time Series
FlowTime	Integer	0	Time Series
z	Integer	1	Time Series
Dummy_1	Integer	0	Time Series
M	Integer	0	Time Series
MUstart	Real	0	Time Series
MUend	Real	MUPeriod	Time Series

* Macros *

#A macro is a place holder for an often used expression, set of statements and functions, or any text that might be used in an expression or logic field.

#MUPeriod Macro is used to change MU period calculation

#Yield is a macro used for the sensitivity analysis

ID	Text
MUPeriod	5
Yield	U(.95,.0003)

* External Files *

ID	Type	File	Name
Prompt			

(null)		C:\Users\alma.sagredo.Remote-Desktop\Dropbox\SIMULACION SCENARIOS\	
		\Scenarios\Min_Max\MU5\Perido(5),Yield-U(.95,.0003),ErrorAbsoluto.xlsx	

* Streams *

Stream #	Seed #	Reset
1	37	No

J. ATTEMPT: LOWER AND UPPER SCRAP SHEET RESULTS

Cum In	Cum Out	Cum Lots Out	Lower Scrap	Upper Scrap	Cum Average Scrap	Scrap	ESTWIP	Real WIP	Error
22100	12240	13000	717.4109	1293.3692	1228.927139	1228.927139	8631	8799	0.019085
1300	1224	1300	71.74109	76	75.5234845	75.5234845	0	0	
650	612	650	35.87054	38	37.76174225	37.76174225	0	0	
1950	1224	1300	71.74109	114.0978	109.3586484	109.3586484	617	633	0.025843
2600	2448	2600	143.4822	152	151.046969	151.046969	1	0	
650	0	0	0	38.0978	33.83516388	33.83516388	617	630	0.021961
650	612	650	35.87054	38	37.76174225	37.76174225	0	0	
650	612	650	35.87054	38	37.76174225	37.76174225	0	0	
650	612	650	35.87054	38	37.76174225	37.76174225	0	0	
15600	9776	10400	594.2733	940.1028	901.4090835	901.4090835	4923	5000	0.015482
1300	611	650	37.14208	78.51285	73.88401204	73.88401204	615	629	0.022073
650	611	650	37.14208	39	38.7921234	38.7921234	0	0	
2600	2444	2600	148.5683	156	155.1684936	155.1684936	1	0	
650	611	650	37.14208	39	38.7921234	38.7921234	0	0	
650	611	650	37.14208	39	38.7921234	38.7921234	0	0	
2600	1833	1950	111.4262	156.51285	151.4682588	151.4682588	616	650	0.053028
0	0	0	0	0	0	0	0	0	
650	0	0	0	39.51285	35.09188864	35.09188864	615	631	0.025502
650	0	0	0	39.51285	35.09188864	35.09188864	615	633	0.028581
48100	37944	40300	2223.974	2813.1736	2747.249986	1518.322847	7409	7571	0.02143
1300	1224	1300	71.74109	76	75.5234845	0	0	0	
650	612	650	35.87054	38	37.76174225	0	0	0	

3250	3060	3250	179.3527	190	188.8087113	79.45006288	1	0	
4550	3672	3900	215.2233	266.0978	260.4056174	109.3586484	618	631	0.021245
1300	1224	1300	71.74109	76	75.5234845	41.68832063	0	0	
1300	612	650	35.87054	76.0978	71.59690613	33.83516388	616	612	0.007195
650	612	650	35.87054	38	37.76174225	0	0	0	
650	612	650	35.87054	38	37.76174225	0	0	0	
35750	27495	29250	1671.394	2150.1285	2096.564439	1195.155356	6158	6319	0.02541
1950	1222	1300	74.28416	117.51285	112.6761354	38.7921234	615	629	0.021743
650	611	650	37.14208	39	38.7921234	0	0	0	
3250	3055	3250	185.7104	195	193.960617	38.7921234	1	0	
650	611	650	37.14208	39	38.7921234	0	0	0	
650	611	650	37.14208	39	38.7921234	0	0	0	
6500	4888	5200	297.1366	391.0257	380.5207645	229.0525056	1231	1242	0.008471
0	0	0	0	0	0	0	0	0	
650	611	650	37.14208	39	38.7921234	3.70023476	0	0	
650	611	650	35.81193	39	38.64329768	3.551409036	0	0	

Cum In: refers to the total number of pieces entered to the manufacturing area for each part number h of family type i in a MU period t .

$$CumIn_{i,h,t} = Input_{i,h,t} + InCum_{i,h,t-1}$$

Cum out: refers to the total number of pieces that arrived to stock for each part number h of family type i in a MU period t .

$$CumOut_{i,h,t} = Output_{i,h,t} + OutCum_{i,h,t-1}$$

Cum Lots Out: refers to the total number of lots that arrived to stock for each part number h of family type i in a MU period t .

$$CumLotsOut_{i,h,t} = (LotsOut_{i,h,t} + CumLotsOut_{i,h,t-1}) * LotSize$$

Lower Bound on Scrap: refers to the minimum quantity of scrap for each part number h of family type i in a MU period t .

$$LowerScrap_{i,h,t} = CumOut_{i,h,t} * (1 - yield)$$

Upper Bound on Scrap: refers to the maximum quantity of scrap for each part number h of family type i in a MU period t . Maximum scrap is calculated with the product of material usage accumulated (i.e. $CumIn_{i,h,t} - CumOut_{i,h,t}$) and % of scrap, plus the cumulative quantity wasted (i.e. $CumLotsOut_{i,h,t} - CumOut_{i,h,t}$)

$$UpScrap_{i,h,t} = (CumIn_{i,h,t} - CumOut_{i,h,t}) * 1 - yield + (CumLotsOut_{i,h,t} - CumOut_{i,h,t})$$

Cum Average Scrap: refers to the cumulative weighted average scraped pieces for each part number h of family type i in a MU period t .

$$CumScrap_{i,h,t} = \frac{Wmin * LowerScrap_{i,h,t} + Wmax * UpperScrap_{i,h,t}}{2}$$

Where:

$Wmin$: is optimum weighted assigned to the average minimum scrap with the objective to minimize the average absolute percent of error.

$Wmax$: is optimum weighted assigned to the average maximum scrap with the objective to minimize the average absolute percent of error.

Scrap: is the quantity wasted in a MU period t for each part number h of family type i .

$$Scrap_{i,h,t} = CumScrap_{i,h,t} - CumScrap_{i,h,t-1}$$

ESTWIP: WIP estimated through minimum and maximum scrap average for each part number h for each part number h of family type i in a MU period t .

$$ESTWIP_{i,h,t} = ESTWIP_{i,h,t-1} + Input_{i,h,t} - Output_{i,h,t} - Scrap_{i,h,t}$$

Real WIP: is the WIP inventory for each part number h for each part number h of family type i in a MU period t obtained through the simulation model.

|Error|: is the absolute percent of error calculated as follows,

$$\varepsilon = \frac{ESTWIP_{i,h,t} - RealWIP_{i,h,t}}{RealWIP_{i,h,t}}$$

K. WIP ESTIMATE IMPLEMENTATION METHODOLOGY

1. Create from Oracle Database System “Transaction Historical Summary” report with the following outcomes: Item, Description, Quantity, Move Order, Account Alias, Job or Schedule, Other, Current Quantity. Indicate the MU period calculation (i.e. rollback date). Also, download the same report with the accumulated quantity, the rollback date to be indicated is the date the inventory count was performed.

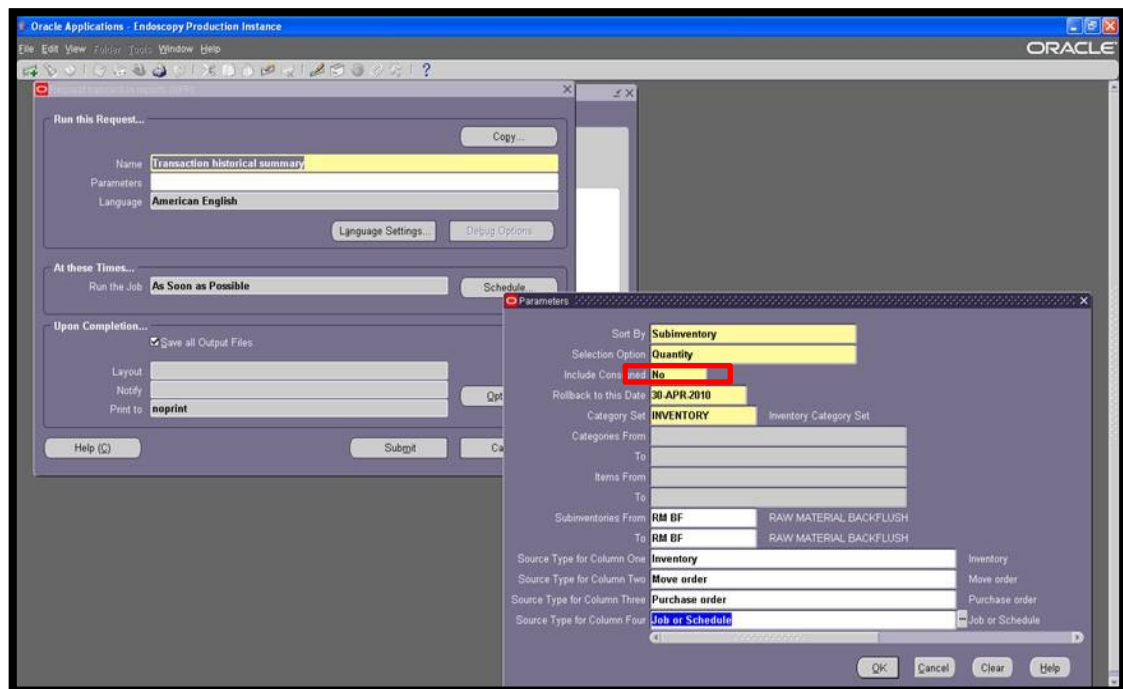


Figure 29. Transaction Historical Summary Oracle Window

- Export both report to Microsoft Excel. Filter the items to be analyzed. (File 1 and 2). The figure below presents the quantity values exported to excel. Two sheets of this will be required: one with th MU calculation period and the other with the accumulative period.

Jul full qty - Microsoft Excel

File Home Insert Page Layout Formulas Data Review View Developer

Clipboard Font Alignment Number Styles Cells

P18

1 PUERTO RICO MAIN Re port Date: TODAY

2 Sorted by Subinventory, Item Transaction Quantity Historical Summary Page: 1

3 Subinventories From RM BF To RM BF Value On: Start Date

4 Category Set: BUSINESS UNIT

5 Categories From: UNIT

6 To: UNIT

7

8

9 Subinventory: RM BF

10 1-Jul-10 Current

Item	Description	UOM	Quantity	Inventory	Move ord	Account	Job or Sched	Other	Quantity	MU
13	105211974 TIP HOUSING	EA	92,245.00	650	90,887.00	0	-79,804.00	0	103,978.00	11,733.00
14	105211973 TIP GRIND &	EA	145,747.00	0	92,213.00	0	-82,331.00	0	155,629.00	9,882.00
18	105199652 TUBE, HOUSING	EA	101,771.00	5,200.00	80,600.00	0	-79,003.00	0	108,568.00	6,797.00
20	105199651 TUBE, CUTTER -	EA	15,045.00	4,011.00	7,800.00	0	-5,501.00	0	21,355.00	6,310.00
21	105211976 CUTTER TIP	EA	12,539.00	0	11,700.00	0	-5,506.00	0	18,733.00	6,194.00
23	105211977 CUTTER TIP	EA	15,491.00	1,950.00	14,950.00	0	-10,994.00	0	21,397.00	5,906.00
24	105201568 TUBE, CUTTER -	EA	25,397.00	1,950.00	14,849.00	0	-10,957.00	0	31,239.00	5,842.00
25	105211978 TIP HOUSING	EA	10,513.00	0	15,600.00	0	-10,366.00	0	15,747.00	5,234.00
27	105199653 TUBE, CUTTER -	EA	149,496.43	26,650.00	59,800.00	0	-81,555.00	0	154,391.43	4,895.00
32	105211975 CUTTER TIP	EA	13,690.00	0	12,350.00	0	-8,820.00	0	17,220.00	3,530.00
39	105211980 TIP HOUSING	EA	18,310.00	0	14,300.00	0	-11,745.00	0	20,865.00	2,555.00
45	105201565 TUBE, HOUSING	EA	13,583.00	0	9,100.00	0	-7,137.00	0	15,546.00	1,963.00
46	105201566 TUBE, CUTTER -	EA	19,002.00	650	9,100.00	0	-7,796.00	0	20,956.00	1,954.00

Figure 30. Exported Report in Microsoft Excel Sheet

- Download from the system the report that contains all the transactions made to stock in the cumulative period. Export these outcomes to Microsoft Excel. Create a “Pivot Table” in Microsoft Excel with the data gathered in order to count the number of transactions made to stock (i.e. output) filtering the part numbers used in the MC area. (File 3)

Table 16. Pivot Table Number of Lots Transactions made to Stock

Row Labels	Count of Transaction Quantity
105199259	26
105199379	2
105199444	4
105199453	21
105199667	2
105199669	3
105199943	6
105199946	1
105199965	3
105199968	1
105199974	14
105199977	5
105199980	3
105199989	1
105200004	1
105200007	1
105200023	3
105200026	1
105200029	4
105200765	1
105206190	1
105206205	1
105206208	1
Grand Total	106

4. Merge these three files and create a unique file with the columns indicated in appendix (J).
5. Filter the part numbers used in the machine center and create the following columns: Lower Scrap, Upper Scrap, Cum Average Scrap, Scrap, ESTWIP. Apply the formulas described in appendix (J).