Manufacturing Capacity Simulation at Primetals Technologies

Major Qualifying Project Submitted to the Faculty of

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ABSTRACT

The objective of this MQP was to provide Primetals Technologies with a better understanding of their current manufacturing floor capacity. The team created a capacity simulation focusing on horizontal machining centers, and the Roll Housing manufacturing process. The methods used were company data, axiomatic design, direct observations, and process simulation. The team approached the problem by a hierarchical problem solving method, by the development of a process simulation in Rockwell's ARENA® program. The team concluded that Primetals could know how their production system would respond under different changes in demand with a higher degree of accuracy. The team's financial analysis shed light on the cost to the company of making real time changes to the production schedule.

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1. INTRODUCTION

Primetals Technologies is a manufacturer of steel rolling mills that was formed as a result of a joint venture between Mitsubishi and Siemens in 2015 (Specht, 2016). Primetals processes include steel making, casting, rolling, milling, and turning of metals. The Primetals manufacturing plant located in Worcester, Massachusetts, formerly known as Morgan Construction, is world renowned for its manufacturing of steel machined products, which had existed for 130 years prior. Products that the Worcester plant specializes in includes the Morgan Vee No-Twist rolling mill.

1.1 PROBLEM STATEMENT

Primetals in Worcester operates as a job shop, fulfilling customized customer orders for steel rolling mills, along with their secondary business of manufacturing replacement parts. Due to the nature of customized orders, Primetals does not currently have an easy, efficient and accurate system of forecasting the costs and time to fill each order. This transcends into capacity and production planning issues that can result in long lead times and misinformed decisions, which has led to difficulty in the face of increasing competition. The use of a simulation tool will enable management to make better decisions such as effectively allocating resources and tracking progress on delivery commitments. Therefore, in their efforts in continuous process improvement, Primetals has sponsored this MQP with Worcester Polytechnic Institute. During the previous academic year, there was an MQP team at Primetals that was devoted to reducing the lead time of the production of the Roll Housing Assembly. For this year's MQP, the proposed project charter stated a goal of developing a simple computer model that reflects the changes necessary in the manufacturing department to respond to changes in customer demand.

1.2 PROJECT GOALS AND OBJECTIVES

The overall goal of this project was to develop a simple simulation modeling program that will show how to adjust the factory resources for optimal use of labor and production assets based on incoming changes in customer demand. The scope of the simulation encompasses solely the Roll Housing Assembly (RHA) Department and Horizontal Machining Centers (HMC) that make them in the manufacturing department. The team used axiomatic design to define the problem and develop an approach to the model. By using axiomatic design, the team was able to identify the customer needs, functional requirements, and design parameters of the model. Then the team observed data from the manufacturing floor and personal interviews. Next the team developed the simulation model using Arena. Once the model was established, the team performed an economic analysis of the current manufacturing process to evaluate the financial impact of the simulation model. The objectives included the ability to calculate standard allowable minutes (SAM) for the RHA and the HMCs along with determining global and local efficiencies.

1.3 PROJECT DELIVERABLES

The project deliverable was a computer model that simulates the impact of customer demand on the defined production processes.

1.4 PROJECT SCOPE

The team's simulation will be primarily focused on the Roll Housing Machining Assembly and the horizontal machining centers that produce them.

2. BACKGROUND

In order to fully find and develop a solution, the team conducted research at the project sponsor,

Primetals, the production lines within scope, simulation programs, and axiomatic design, which

are described in the following sections.

2.1 PRIMETAL'S TECHNOLOGIES

2.1.1 Morgan Construction Company

The location for this project took place at the Primetals Technologies facility in

Worcester, Massachusetts. Formerly known as Morgan Construction Company, this facility

specializes in the production of high-quality rolling mills which includes rod, section, and wire

rolling mills (Lean Process Improvement of Roll House Manufacturing, 2015). This project

specifically focused on the roll housing assembly and the horizontal machining centers. Morgan

Construction Company was founded in 1891 by WPI founder Charles Hill Morgan. For over a

century, Morgan Construction Company was a global leader in the manufacturing of high-

performing rolling mills. In 2008, Siemens/VAI acquired Morgan Construction Company,

increasing its share in the metal technologies industry (Siemens VAI, 2008).

2.1.2   Siemens AG/Siemens VAI Metal Technologies

Siemens AG is a German international conglomerate that offers a wide range of products

and services for almost every industry. Founded in Berlin, Germany in 1847 by Werner von

Siemens, Siemens is a global powerhouse in electrical engineering and electronics. The company

has 343,000 employees working across the globe to develop and manufacture products, design

and install complex systems and projects, and tailor a wide range of services for individual

requirements (Siemens AG, 2014). In the fiscal year of 2014, Siemens generated £78.5 billion

pounds in revenue with a net income of £5.5 billion pounds (Siemens AG, 2014). Siemens has

various business sectors that include power and gas, wind power and renewables, power generation services, energy management, building technologies, mobility, digital factory, process industries and drives, financial services, and healthcare.

Siemens/VAI Metal Technologies (SMT) was a vertically integrated business unit that led the way in the global metallurgical industry. The Siemens/VAI partnership was started in 1995 and is currently headquartered in Linz, Austria. Siemens/VAI's customer base, roughly around 500 customers, accounts for 70 percent of global steel production (Siemens VAI, 2015). Services previously offered had included plant construction, modernization of existing plants, and installation of integrated state-of-the-art production systems. Siemens/VAI Metal Technologies became defunct in 2015 after signing a deal to enter a joint venture with Mitsubishi Heavy Industries to provide plants, products and services for the metals industry. The joint venture is 51% owned by Mitsubishi, while the remaining stake is held by Siemens.

2.1.3 Mitsubishi

Mitsubishi was founded in 1870 by Yataro Iwasaki when he set up his own shipping company with three steamships chartered from his clan, the Tosa clan. The company continued to grow further when Yataro's son, Hisaya, assumed the presidency in 1893. Hisaya restructured the company to support increasingly diverse business operations. He set up divisions for banking, real estate, marketing, and administration, as well as for the original mining and shipbuilding businesses (Mitsubishi, 2015). The Mitsubishi Group is a National Multinational Enterprise with no parent company. It is the result of 40 individual companies that own substantial shares of the other 40 companies. Instead of a parent company exercising control of the subsidiaries, the three most important companies oversee the operations of the company as a

whole. These sister companies are Mitsubishi Bank, the Mitsubishi Corporation, and Mitsubishi Heavy Industries.

2.1.4 Primetals

Primetals is a firm based in London, UK formed as a result of a joint venture between Siemens VAI Metal Technologies and Mitsubishi Heavy Industries. The company specializes in engineering and plant construction for clients in the metals industry, both ferrous and nonferrous metals (Primetals, 2015). The combined company has a total of 9,000 employees worldwide in countries including China, India, The United States, and the United Kingdom. Primetals specializes in machining processes including ironmaking, steelmaking, continuous casting, hot rolling long, hot rolling flat, cold rolling, nonferrous rolling, processing, endless casting & rolling, and mini mills.

2.2 ROLL HOUSING ASSEMBLY & VALUE STREAM MAP

The Roll Housing is a crucial part to the Morgan Vee No-Twist mill. The Roll Housing is responsible for producing the proper size of the manufactured steel. The steel passes through a carbide roll connected to the pinion shafts which are all supported by the Roll Housing. The housing itself consists of a box and a front plate. There are different sizes of Roll Housings in order to make the Morgan Vee No-Twist mill more customizable for the customer. Therefore, there are different size roll houses to allow for the company to produce variable size steel. Due to the importance of this specific part, the Roll Housing was the focus of the 2014 WPI MQP team at Siemen's VAI (which is now Primetals Technologies.) The goal of their project was to increase productivity of the Roll Housing assembly. Therefore, they created a process map for the Roll Housing assembly, including all possible routings (Brofford et al, 2015).

The previous MQP team then translated the process map into a value stream map (VSM) for the Roll Housing assembly, in order to calculate the metrics needed for the VSM, the past team identified the most common part numbers using a Pareto Chart created from demand history. The Pareto Principle, or 80-20 rule, states that "20% of your customers represent 80% of your revenues" (Lavinsky 2014). The team used this principle to choose parts numbers that were responsible for 20% of the total order volume. Setup time, run time, and queue time were then determined for each part number using the following calculations (Brofford et al, 2015):

Formula	**Calculation**
Setup:	(Actual Setup)
Run:	(Actual Run) / (Yield)
Queue:	(Actual Start) n – (Actual Finish)n-1
N:	$(p-hat * (1-p-hat)) / ((ME / z)$ ^2) $Where: n = sample\ size, p-hat = estimation\ of\ p-value, ME = margin\ of\ error, z = z-score$

Using these calculations, the sample was determined by those data points that did not produce negative queue times, were not at the beginning of the process and were not outliers. From this sample, averages were determined for the 3 metrics. The above calculations were repeated for each work station (Brofford et al, 2015).

To make the VSM, the previous MQP team converted the process map to a VSM format and labeled each workstation with the name, number of workers, setup, run and queue time. Takt time was calculated using the following equations (Brofford et al, 2015):

$$(Total\ Hours)\ /\ (\#\ Pieces) = Takt\ Time$$

$$(Working\ Days\ Per\ Year) * (Hours\ Per\ Shift) = Total\ Hours$$

Lastly, material and information flow lines were added to the VSM. Material flow lines were determined by examining material movement. Information flow lines were determined by communications influencing forecasting, planning, and order fulfillment (Brofford et al, 2015).

2.3 SIMULATION PROGRAMS

Simulation is the act or process of modeling real life activities without physically doing such acts. (Konrad, 2016) Simulation software models these processes through a set of mathematical equations. Once a process or operation can be reduced to a set of mathematical equations/ formulas, it can be simulated on a software. This enables one to view the type of changes or effects on a system that occur by changing some inputs. This can be used to make and evaluate decisions before performing them.

A model is a set of assumptions and approximations about how a system works. Essentially a model mimics reality. There are several types of models. The simple models are traditional math analysis such as queuing theory, linear programming and differential equations. Simulations are the more complex models. Models give the ability to manipulate processes virtually and perform the following: compress and expand time, control sources of validation, stop & review, restore system state, facilitate replication and control level of detail. A simulation analysis is conducted by modeling, simulating and then analyzing the systems. Simulation models can be characterized as deterministic or stochastic, and static or dynamic. Computers can be used to simulate via spreadsheets, typical for static models, simulation languages and lastly high-level simulators. (Konrad, 2016)

There are several steps for a simulation study: (Konrad, 2016)

1. Understanding the system
2. Identify the goals
3. Collect & analyze data
4. Formulate model representation
5. Translate into modeling software
6. Verify program
7. Validate model
8. Design experiment
9. Make runs
10. Generate insight

2.3.1   Other Capacity Planning Programs

Primetals currently uses a commonly available enterprise resources planning system called SAP for record accounting, order tracking, routings, and build of material workbooks. The software also has the ability to account for change over time per batched items while including setup times in hours. This software lacks specific inventory optimization options and other capabilities that the company would like. Primetals would like to have the ability to reduce queuing time within the factory, then implement the changes in real time.

The Production Scheduling Department is tasked with creating work dispatch lists (digital to-do lists) for assigned work. Such lists will contain data that allocate tooling, labor, machines and other resources. A few examples of production scheduling software include: TACTIC©, EnterpriseIQ Scheduling©, and Optessa©.

TACTIC has been developed by Waterloo Manufacturing to create dispatch lists based on live data from active machines and available labor. This software allows one to build detailed short term schedules, create long term plans, produce schedules and plans that consider capacity constraints from the inputted data, and evaluate what if analysis. Everything put into the system can be used to generate simulation alternatives to achieve customer and business needs.

Optessa is a production scheduling Software Company that has been around for 40 years. Its product is used by such companies as Ford and General Motors for production scheduling and planning: "These companies evaluated Optessa technology against both in-house developed legacy systems and solutions offered by other vendors in the planning and scheduling space" (Optessa, 2015). The software offers complete models that incorporate product data, BOMs, and routings, for labor and plant constraints the in turn reflect customer demand. Optessa's stochastic approach allows them to deliver solutions in real time.

Lastly EnterpriseIQ is a detailed planning software company. The program allows for "what if" analysis to determine availability of raw materials and parts on hand. It can integrate with sales modules to deliver more accurate forecasting. Additionally, this program can track active and projected work orders and create a production plan from the data. It tracks materials and assemblies by "manag[ing] all resources necessary to meet manufacturing demand, while maintaining lean inventory levels. It includes items manufactured internally and through third party vendors, as well as sub-assemblies" (IQMS, 2015).

2.4 AXIOMATIC DESIGN

Axiomatic Design is a systems design methodology originally discovered by Dr. Suh Nam Pyo at the Massachusetts Institute of Technology in the late 1970's (Towner, 2013) and then

subsequently published during the 1990's (Suh, 1990). This system entails using matrix methods to systematically analyze the transformation of customer needs into functional requirements, design parameters, and process variables. This method is based upon its use of design principles, or axioms, to govern the analysis and decision making process in developing high quality product or system designs. The two axioms which are used in this process are the independence axiom and the information axiom.

The independence axiom requires the independence of the functional requirements (FRs) that fulfill the customer needs. The information axiom is required to minimize the information content of the design in order to make it as simple and clear as possible. Between these two axioms, the problem is decomposed in a way that is mutually exclusive and completely exhaustive (Towner, 2013). For each FR created, there should be a correlating design parameter that may or may not affect multiple FRs. This process was useful to the team as the manufacturing system that was attempted to be replicated was complex with many machines within routings. By using this process, the team was able to make objective decisions about the project throughout the duration.

Some benefits from using this methodology can include but, are not limited to, providing metrics for progress and quality, removing non-productive iterations, reduced complexity, reduced costs, reduced design times, and providing a clear visual when deciding between different solutions to a complex problem (Towner, 2013). The use of Axiomatic Design in this project is a natural fit as this project requires the team to break down the process by which the capacity is affected by customer demand. By decomposing the larger issue into smaller more specific issues, it allows the team to better diagnose different effects that may result from solutions to each functional requirement on others. This process began when the team completed

a decomposition of the project in order to better understand the essential components that would be needed to be addressed.

3. MATERIALS & METHODOLOGY

Figure 1 below illustrates the methodology and materials used to design the simulation program that models the relationship between customer demands and production scheduling. Each of the three phases consumed about 7 weeks. This entire project was completed within three academic terms at WPI.

Initial Analysis & Diagnosis

Understand Primetals production planning process

- Interview manufacturing production scheduler
- On site observations
- Research on production planning process

Understand Roll Housing Assembly & Horizontal Machining Centers

- Review VSM from last year's MQP
- Identify bottlenecks
- On site Observations
- Identify critical elements
- Identify capacity

Design simulation program

Model relationship between customer demand and production scheduling

- Identify key inputs and outputs
- Create equations to model relationship

Choose program to execute simulation

- Populate program with current data

Test Program

Test to make sure it is executable with no errors

- Run several tests & simulations

Make sure program aligns with current production scheduling logic

- Present to scheduler and company
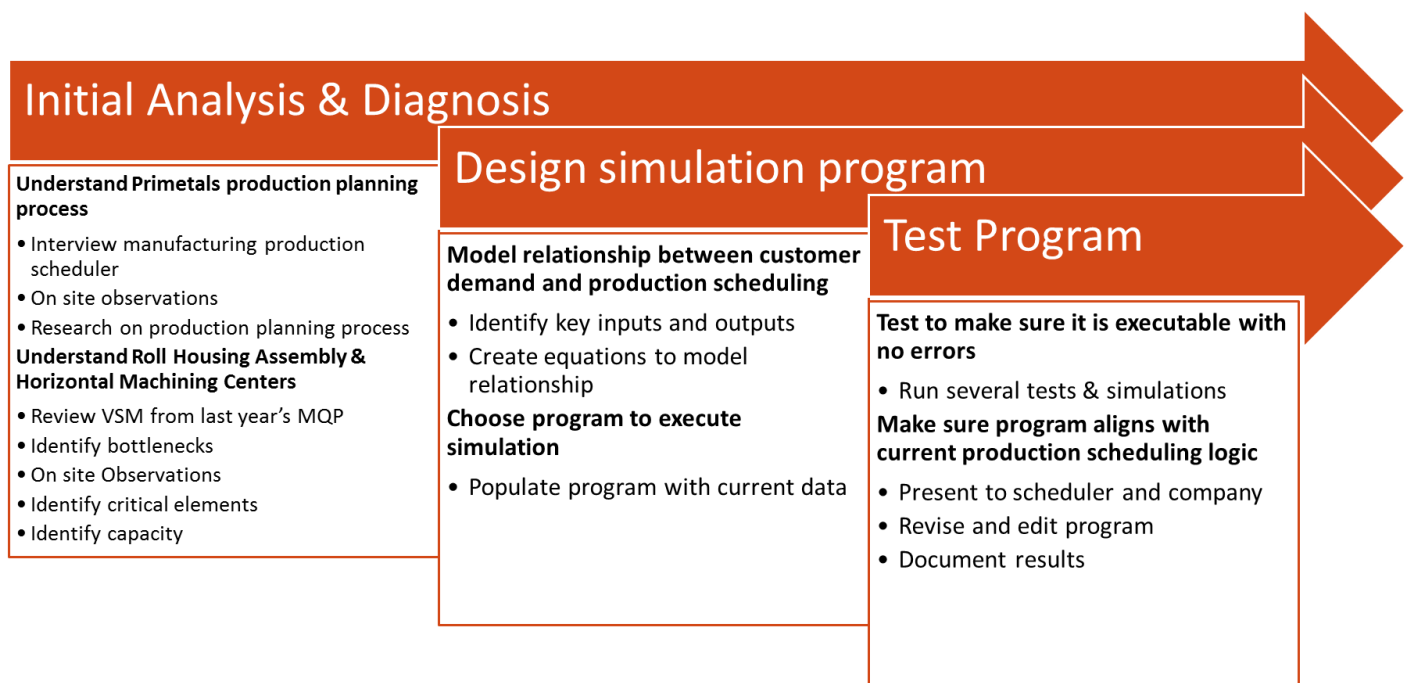- Revise and edit program
- Document results

Figure 1: Materials and Methodology (Authors, 2015)

3.1 INITIAL ANALYSIS AND DIAGNOSIS

The team started working on this project with some knowledge that had been transferred to the current team from the previous MQP team. However, the current team decided it would be best to gather some objective data and conduct independent observations directly as a team, in addition to previously received data. The team visited the Primetals facility in Worcester to speak with those who would be heavily involved with this project as well as those who may have information that could be beneficial to the team. The team began this process by taking a tour of the facility so that the team could get a general view of what operations were done in the facility and which processes the team would be focusing on with this project.

The first course of action taken in this process was meeting with the sponsor to get a general idea of what the project scope would be. By doing so, the team was able to gain an understanding of what kind of data would need to be collected and what kind of metrics should be used in analyzing the results. After this meeting, the sponsor provided the team with data from their system that included cycle times for the machines, queue times, as well as other important data that would be analyzed. While examining the data, the team worked to identify the problems that were adversely affecting the production system. After analyzing the provided data, it was determined that the first goal would be to identify bottlenecks within the system that were interrupting the machining time and causing excessive lead times, as well as impacting the sales schedule. After attempting to identify these bottlenecks, the team decided to look at other factors that could affect the system attempting to take into account as many variables and different processes that could have an impact. By doing this, there were some external factors that were identified as possible problems. Ultimately, by analyzing the data and the current systems in place within the company, the team was able to compile a list of areas that had room for improvement and could possibly be addressed directly by this project's deliverable.

3.2 DESIGN SIMULATION PROGRAM

The team developed a simulation of a part of the manufacturing system using Arena®, by Rockwell Automation. The team chose this program because of its ease of accessibility and ability to animate a model to show how a part moves through the factory. The program also integrates the use live data via Excel sheets. In addition, Arena® produces many types of output data in the forms of: queue times, number of parts produced, and process times that will be helpful for production planning at Primetals. The team used part routings and other data provided by the sponsor to create the simulation. These routings provided the process times, and distribution of arrival times. The team first created the simulation a simple process within the factory, in order to ensure that just the model would be effective for the company. In order to create this simple model, the routing of one part was used. After the model was approved by the sponsor, the team created the full simulation using the routings for all the parts.

3.3 TESTING THE SIMULATION PROGRAM

Two simulation programs were designed; the first focused on specific machines such as the HMC 5 and the HMC6, and the second of the entire roll housing machining assembly. These models were to simulate a month's worth of work at Primetals for each machine. For the HMC5, the simulation program was set to run 20 hours per day, 30 days per month and was replicated 7 times within the program to provide a good average of the production times. The program produced results similar to that of Primetals actual production by using mathematical distributions along with the assigned routed hours per part and the specified work time exclusive of operator's schedule. The simulation is based on the time the machines are running, the work available/provided by the dispatch list and the times the factory is open. The results show how many jobs can be completed, excluding transfer or transportation time, and the use of operators available. Based on the project charter, and visual approval by the production scheduler, the

results of the simulation, including machine utilization, wait time, Work in Progress (WIP) and

process time are as accurate as then can be.

4. RESULTS

4.1 AXIOMATIC DESIGN

Axiomatic design was used to accurately define the problem to set the stage for the entire

project. This enabled the team to dissect the problem and develop a plan on how to approach the

solution. Once the team fully understood the problem statements and project scope from the

sponsor, the team was able to break down the requirements of the solution for good

communication between everybody. The team translated the functional requirements and design

parameters of the simulation program with the use of Acclaro® DFSS (Axiomatic Design

Solutions, 2016). Working through the axiomatic design decomposition provided clarity and

transparency between both the expectations of the sponsor and the team, ensuring that

throughout the entire process our work aligned with the sponsor's goals. Creating the coupling

matrix showed the interactions between the FR's and DP's, and ensured that all requirements of

the simulation program were met before submitting the final design to the sponsor. In addition,

axiomatic design directed the process in the sense that it provided clarity on what information the

team needed to know in order to be successful. Figure 2 shows the functional requirements the

#	[FR] Functional Requirements	[DP] Design Parameters
0	Model the impact of production loading on the RHA & HMCs	System for modeling the impact of production loading on the RHA & HMC
1	Show current load of manufacturing system	System for showing current load of manufacturing system
1.1	Input current load information into the simulation	System for inputing current load information into the simulation
1.2	Show efficiency of global production	System for showing efficiency of whole production
1.3	Shows efficiency of local processes	System for showing efficiency of individual processes
2	Show results of load changes on manufacturing system on RHA	System for showing results of load changes on manufacturing system
2.1	Shows how to manipulate current load schedule to satisfy changes in demand	System for showing how to manipulate current load schedule to satisfy changes in demand
2.2	Input customer demand	System inputting customer demand
3	Show total capacity (in house)	System for showing total capacity
3.1	Calculate standard allowable minutes (SAM) for each process	System for calculating SAM for each process
3.2	Show impact of outside vendors on total capacity	System for showing impact of outside vendors on total capacity
3.3	Identify bottlenecks	System for identifying bottlenecks

team developed using Axiomatic Design.

Figure 2: Functional Requirements of Axiomatic Design (Authors, 2015)

The original problem statement called for the team to create a simulation program that modeled the impact of production loading on the RHA and HMC's hence the top level functional requirement. Since the team aimed at building a simulation thus the design parameter calls for a system to perform the main functional requirement. Then team decomposed the main problem into three upper level FR's. The first FR is to show the current load of manufacturing system. The simulation needs to be able to mimic the current process and operations undergoing at Primetals and needs to be as accurate as possible. In order to fulfill this requirement sub FR's were created such as the ability to input current load information into the simulation. Subsequently for each functional requirement, the team needed a system that enables the requirements to occur which in turn is a design parameter. Hence, Arena® (Rockwell, 2016) was the software the team decided to use because it had the capacity to fulfill all of the design parameters. Arena® (Rockwell, 2016) enabled users to input current load information into the simulation and show the results of such inputs in terms of but not limited to efficiency, process time, queue time, machine utilization, non-value added and value added time. These were most of the sub-level functional requirements. Once the functional requirements and design parameters were defined, the team analyzed the coupling matrix that resulted as seen in Figure 3.
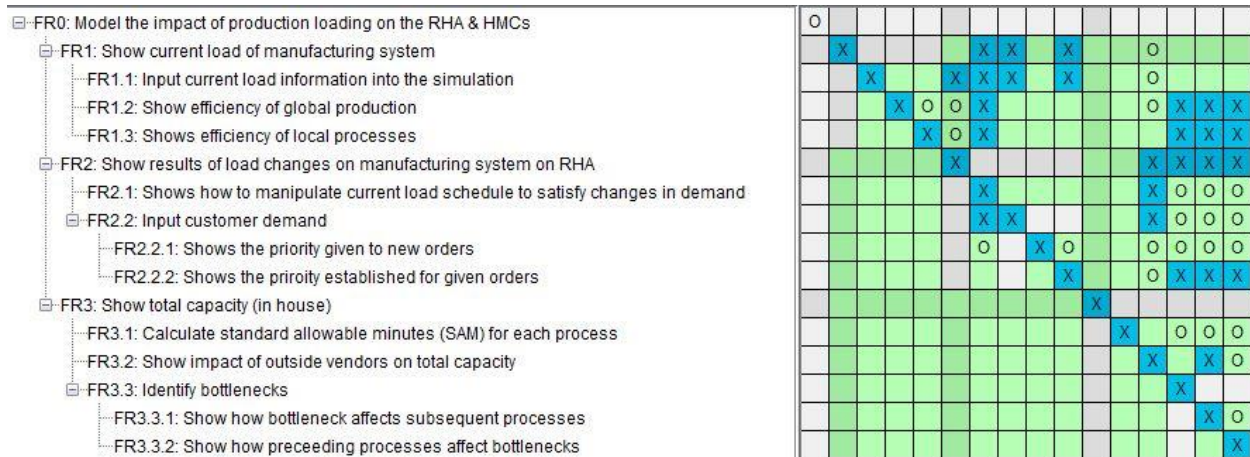
Figure 3: Coupling Matrix of the Axiomatic Design (Authors, 2015)

As can be seen above in the coupling matrix, X's and O's which indicate relationships between the FR's and DP's. An X indicates a direct relationship between the FR and DP which means that one directly impacts the other while an O indicates an indirect relationship between the two meanings that while they are related, one does not directly affect the other. The team used Axiomatic Design for its versatile facilitation of problem diagnosis. Every step taken to break down the functional requirements of the problem, led to the discovery of additional require steps. Within FR 2, there are 2 subsets: FR 2.1 and 2.1, however in FR3 there are 3 subsets FR3.1, 3.2 and 3.3. Unlike FR2, FR 3 had more meat to it, this is also seen in FR 3.3 which was later broken into 3.3.1 and 3.3.1. The change in FRs show the needed level of detail to properly define the parent FR per section.

4.2 MATHEMATICAL MODEL

In developing the simulation model, the team needed to create a mathematical logic basis for values assigned to entities for processing time inside the model while it was running. The team started by looking at current dispatch lists, a list of actual hours against routed hours dating back to 2013 and a project file created by one of the planners at Primetals. In doing this, the team

calculated the differences in actual times against routed hours for each individual machine. The

team encountered some difficulties in comparing hours between the project file and the dispatch

list due to numerous similarities in the descriptions of the order. By combining the operation

number and the order number into a new column labeled "Unique Identifiers", the team was able

to accurately compare processing time for every operation on every part. All differences in

processing times were compiled into lists sorted by machine then uploaded as a dataset to the

input analyzer application of Arena® (Rockwell, 2016). By creating these distributions, the team

was able to incorporate some heuristics currently used by the planners in their project files that

were unavailable from the original files. Some of these heuristics that are not taken into account

for the current calculated routed hours in the current SAP system include: extended set up times,

quality checks for specific orders, programming errors, and the knowledge of operating hours for

certain material types as well as certain types of orders from scheduling coordinators. The team

then used each of these distributions by adding them to the original routed hours the model

picked from the dispatch lists that were being used. By doing this, the simulation was able to

alter machining times to create a much more accurate simulation of the machining process within

the plant. The final results, in terms of hours, of this analysis for each machine are the following

distributions shown in Figure 4:

Machining Center	Distribution
HMC5	-4 + 79 * BETA(0.545, 1.25)
HMC6	-7 + WEIB(12.7, 2.08)
HH40	1 + WEIB(28.8, 1.19)
L74R	TRIA(-1, 1.4, 6.99)
A71M	-6 + 21 * BETA(5.73, 11.3)

WW3P	-2 + EXPO(8.74)

Figure 4: Machining Center Distributions

Distributions were created for each machine where there was a history of discrepancies between the routed hours and actual machine hours. The team decided that each machine needed its own distribution as the data collected for each machine was very dissimilar meaning if the team had created one distribution and applied it to the entire system, the resulting accuracy would have suffered greatly and would have been swayed greatly by the overall distribution. An additional feature of the input analyzer mentioned earlier is that it has the ability to create a graphical representation of the above distributions. By doing this, the team as well as the sponsor were able to visually see the distributions of each machines variation between routed hours and actual hours. The graphs of these distributions are located in Appendix C.

4.3 SIMULATION

Horizontal Machining Centers 5 & 6

One of the specific targets of this project was the horizontal machining centers (HMC). Specifically, the team simulated HMC5 and HMC6 as they are some of the more frequently utilized machines in the shop. The team also determined that the findings from data on these machines would will be most helpful to the production planner. There are two HMC5 machines and one HMC6. They each receive different parts and are only one step in the value stream thus each are treated as individual machines. Currently, the production planner receives a dispatch list of all the parts that need to be processed by an individual machine along with its planned hours, order number and material designation. However, the production planner uses their own heuristics to adjust the planned hours to a more reasonable and accurate process time. This is

illustrated in the project plan along with information such as the order and material number, routed hours and start/ finish date.

The Arena® Program is designed to read the order dispatch list for each machine, process the read data via a mathematical model/expression, and output actual machine run times. The outputted data closely matches real machine run times previously developed by the production planner. The simulation model illustrates the process of materials entering the system and being processed by a machine, given a certain amount of time. It then shows the total parts finished, number of parts that entered, the WIP, the queue times and the total production time for each given part. The parameters are adjusted to a typical work month as described by the production planner but can be further adjusted. The results are captured in a results sheet output from within the Arena® program, they also are exported into an excel spreadsheet labeled 'outputs'.

The basic template (Rockwell, 2016) for the simulation model is as follows:

1. Parts are created at a specific interval. Based on the average routed hours per part, set the models set to introduce a new part into the system every 15 hours in order to reduce queue time.

2. Parts are assigned the material number, order number and route number based on the dispatch list, which is read from an excel document labeled inputs.

3. Each part is processed by the machine at a certain process time. The process time is the routed hours plus the corresponding distribution for each machine(see Appendix A) to produce a process time similar to the adjusted time that the production planner usually makes.

4. When the part is completed by the machine, information such as the order number, material number, total processed time, and routed hours are exported to an excel sheet labeled 'outputs' and then exits the system.

This simulation replaces the process of the production planner applying personal judgment and only heuristics to calculate the adjusted routed hours for each part for the HMC5 and HMC6 machines.

Entire Manufacturing System

The Arena® simulation functions off of the data provided by the company. The program inputs the routes per order based stored route data. As new orders enter the system they are assigned their correct material number, which also associates the correct routing. The machine process time, and the next step in the production sequence are programed in within the part associated material number. All of this inputted data is easily visible in a display screen showing the layout of the factory (as shown in Appendix B) as orders move through it, wait in queues, and exit the system. The model is flexible enough to add additional routes and machines. Routes in the system can be simply modified to include more or less machines and process steps. Depending on order specific process times, machine queue times will vary. All data in the system can be easily seen and interpreted after the simulation run is complete.

4.4 MANUFACTURING PROCESS ANALYSIS

During the evaluation of the manufacturing process at Primetals, the team recognized that there are inefficiencies in the manufacturing process that are caused by factors external to the actual manufacturing process. The problem of bottlenecks within the system is not a centralized issue with one viable solution, but a problem that must be addressed on various fronts. These fronts expand across various departments and require a cross departmental effort in an

addressing and implementing solutions. When attempting to determine the root cause of what is hindering the manufacturing process of Primetals, the team determined the following factors; Tooling and programming (coding), queue times between machining centers, scheduling limitations, and excess WIP.

Primetals has a serious bottleneck within the process of coding the programs necessary for machining the various parts. Due to this delay in coding, orders are constantly pushed back resulting in late orders. This bottleneck is due to a constraint on the amount of programmers, and the process of requesting a programmer to code. When an order that has an upcoming deadline does not have the software needed to manufacture it, Primetals is forced to put work on to the shop floor that is not of the highest priority. Due to this, many parts being manufactured do not have buyers and result in an overstock of inventory. This unproductive labor also results in large WIP on the shop floor that hinders the ability of Primetals to complete orders that have a higher priority when the coding is finished.

Due to the layout of the manufacturing facility and sequences of the various parts manufactured, queue times of the parts manufactured range from one week to three months. This is due to the fact that the various parts manufactured require forklift drivers to physically move the parts between the machines across a shop that spans longer than a football field. Due to recent layoffs, machine operators have to spend more time moving products around the factory then they did before. This creates further bottlenecks due to loss of productivity when a machine is not running.

The team analyzed the financial impact that the bottlenecks described above cause on the entire manufacturing process. The main financial impact the team has identified is the resulting loss of sales revenue that occurs any time Primetals incurs when a deadline is not met. The team

determined that it would be out of scope to try to calculate individual financial losses in terms of loss of productivity and wasted time in queue. However, it made more sense to directly address the core cause of loss of revenue, which is incurred when orders are late.

4.5 FINANCIAL ANALYSIS

In analyzing the manufacturing process of Primetals, various financial details were provided to give insight into what steps within the manufacturing process contribute value and what steps create waste and delay the process. In analyzing any process, it is important to consider the financial details in order to improve profitability. When evaluating the Roll Housing Machining process, many inefficiencies and processes that did not create value to the final product have been observed.

Before machining can start, a manufacturing program needs to be generated. The trouble is, there is often a delay in programming and tooling for orders. This results in increased lead times over the entire process, further delaying orders. This aspect of the manufacturing process is beyond the scope of the model and project. However, it is a factor that the team had observed that greatly influences the entire machining process and would greatly reduce the overall lead time associated with most orders.

As a result of the delay in tooling and programming, a problem arises in regards to prioritization of jobs. There is a demand to have constant work on the machining floor regardless if the work is a priority order or a continuation of the spare parts sector of Primetals. Due to this decision. This further increases the lead time of the job and increases the probability that the job will be completed late.

When analyzing the roll housing machining process, a major component of the process involves physically the moving of materials from one machine to another across the manufacturing facility. Overhead cranes and forklifts are required to move the products around the factory floor. However, due to recent cutbacks in the workforce, the supply of dedicated material handlers has been greatly reduced resulting in an increased lead time for the various parts being manufactured. This is because dedicated machinists must leave their workstations to operate a forklift to move the materials they need to their workstation instead of dedicated material handlers being present to keep the moving of materials efficient. Because of this increased lead time, products are often left sitting around the factory waiting to be moved to the next machining center as the workers who could move said parts are running their assigned machine tools. This factor also relates back to how much WIP is on the machining floor at any given time. The more WIP on the machining floor, the more orders that are waiting to be moved. This results in longer lead times then necessary, increased non-value added time, and a higher probability that the product will be completed past deadline. There is also much risk associated leaving the products lying around the factory as this presents a greater risk that these products will be damaged.

As a consequence of the various factors that result in orders being late and accumulation of WIP, penalties, shipping fees, and inventory costs accumulate that result in a loss of profit. On many orders, specifically the custom orders, Primetals is obligated to pay a late delivery penalty. The percentage varies from contract to contract, but the common percentage is 0.1% of the equipment value per day (Specht, 2016). An example of how rapidly this penalty accumulates is the penalty associated with a No Twist Mill. A No Twist Mill costs two million dollars, so a $2,000/day penalty accumulates until the order is fulfilled (Specht, 2016). The original intentions

within our model were to provide a comparison between the current process occurring at Primetals and our suggested model to reduce the number of orders that were late. This was to be done by reducing the queue times of orders along with total time in the system. However, due to the various factors that can result in a late order including, engineering delays, material shortages, quality issues, lead times that are sold inside of what they actually are, etc., it is impossible to calculate and model all of the various factors that can result in an order being late.

There are also costs associated with expedited shipping. When expediting orders due to lateness or an attempt to have the order arrive on time, air freight must be used instead of ocean freight. While the cost of ocean freight is only concerned with weight, air freight is concerned with both volume and weight. A reasonable estimate for the cost multiplier of using air freight versus ocean freight is roughly six times greater the cost (B. Specht, personal communication, February 18th, 2016). An example of this is the cost to ship to China, who is a frequent customer of Primetals. When shipping the Roll Housing 150 MM Sizing Mill and the Roll Housing Machining Assembly, it would cost roughly $750 for both parts. However, when shipping the items using air freight, the cost would roughly be $4,100. Neither of these figures include fees, duties, and taxes which have to be paid regardless of how the item is shipped. Other costs to take into detail are the costs associated with WIP. Figure 5 outlines the total WIP and inventory

holding costs over 2015-2016.

	WIP Balance (Thousand $)	Inventory Turnover Rate	Days Inventory Rate	Moving Average Of WIP (Thousand $)	Average WIP (Thousand $)	Average Inventory Holding Costs (Thousands $)
Jan-16	3,882	2.41	151	#N/A	4,083.8667	612.580
Dec-15	3,977			#N/A		
Nov-15	3,795			#N/A		
Oct-15	4,419			#N/A		
Sep-15	4,243			4,063		
Aug-15	3,926			4,072		
Jul-15	3,879			4,052		
Jun-15	3,788			4,051		
May-15	3,887			3,945		
Apr-15	3,976			3,891		
Mar-15	4,843			4,075		
Feb-15	4,586			4,216		
Jan-15	4,657			4,390		

Figure 5: Total WIP and Inventory Holding Costs (Authors, 2016)

For one, inventory holding costs are 15% of the total WIP. Given that Primetals has a turnover rate of 2.41, this translates into turning over their inventory every 151 days (1/2.41 x 365). This results in it taking 5 months for Primetals to sell its entire inventory. By calculating the rolling average using the interval of 5 months, and taking the average of these rolling averages, Primetals on average has over $4,000,000 of WIP at any given time. Given that Primetals has an inventory holding cost of 15%, they are spending $612,600 per month on average on holding costs. Besides the costs associated with WIP, there is a risk that the parts could be damaged or become obsolete due to changes in design.

Due to lack of data, including process and transfer times for various parts, an improved model of the entire manufacturing system to reduce WIP was beyond the scope of our project. The team was able to calculate maximum and average WIP and inventory holding costs for the part numbers that had the required information. However, as many parts did not have the

required data to create a proper simulation model, these parts were not taken into consideration and therefore result in an incomplete simulation. The simulation also does not take into account transfer times which greatly effect queues and WIP. The results the group was able to calculate regarding this information can be found in Figure 6 below.

Part #	Min	Max	Average WIP (30 days)	Max WIP ($)	Averege WIP ($)	Max Inventory Holding Cost	Average Inventory Holding Cost
10290451	-	7.000	0.781	$ 151,682	$ 16,930	$ 22,752	$ 2,539
10351978	-	39.000	14.761	$ 361,709	$ 136,902	$ 54,256	$ 20,535
10351979	-	31.000	11.494	$ 220,676	$ 81,822	$ 33,101	$ 12,273
10360689	-	3.000	0.326	$ 65,006	$ 7,064	$ 9,751	$ 1,060

Figure 6: WIP and Inventory information per part (Authors, 2016)

However, an improved model of the HMC5 to reduce WIP and inventory holding costs was possible. The group was supplied with a dispatch list to simulate the parts machined by the HCM5 along with the average prices associated with these parts. The team took an average value of all of the parts on the dispatch list allowing for the calculation of inventory holding costs and the total WIP costs. The number of WIP outputted by the two models was compared. The first model being a simulation of the current machining process of the HMC5 and the second simulation modeling our suggested process. This resulted in cost savings for inventory holding costs and WIP. The cost savings associated with this model are proof of concept that the full model, given more data, is capable of producing results that are applicable in cost savings. The

cost savings of our model of the HCM5 can be found in Figure 7 below:

Figure 7: Cost Savings (Authors, 2016)

When analyzing the overall cost savings associated with our model, other savings occur besides inventory holding costs that can be estimated, which our model provides. Reduction in late fees, expedited shipping costs, and a reduction of risk of damaged parts results in an estimated additional $2,000 savings per month along with the calculated $5,705. There will be an initial investment of $25,000 to purchase Arena and $12,000 to train an employee on its usage. Given these factors, Primetals can expect to save $91,037 over a 2 year span based on the capital recovery equation of A = P(A/P,i,n) which equals 24,000(A/P,10%,8) = 24,000(5.3349) =

$128,037. $128,037 minus the initial investment of $37,000 equals $91,037. Figure 8 below

shows the cost savings over 8 quarters.
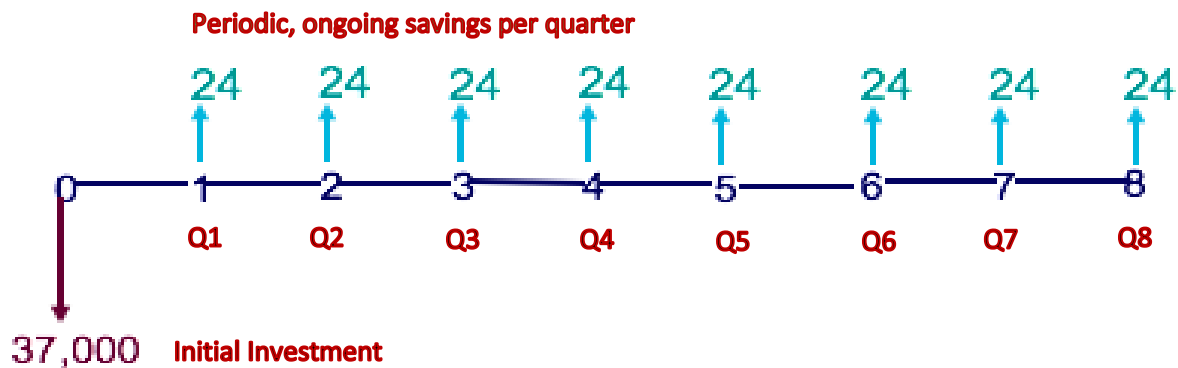
Figure 8: Cost Savings (Authors, 2016)

Given that this savings only accounts for the HCM5, it is expected that the savings across the

factory would be greater if more data is acquired to input into the simulation.

The current inefficiencies cause ongoing costs within the manufacturing process. One

factor that all of these inefficiencies influence is the reputation Primetals has within the

marketplace due to slipping delivery dates. Primetals can enhance its reputation further by

improving on time delivery and predictability of dates.

5. DISCUSSION

The first stage of research and understanding the process proved the most difficult because of the adjustments occurring at the company. A merger requires a huge company transformation including the culture and system. This led to many of the following issues the team had encountered below:

I. The team had the privilege to observe firsthand the challenges in merging organizations. A merger of sorts between the practices of Siemens against those practiced by Mitsubishi created a shift of operations and practices. Confusion arose between common terms and common measurements between the two systems. Therefore, the team attempted to make a common platform in order to compare the numbers between the systems and get a somewhat accurate baseline.

II. The lack of documentation presented a challenge. Sometimes it was difficult to retrieve data necessary for the project. Information such as the average transportation time or transfer time from one machine to another was not readily available. This hindered the ability to evaluate-non-value added time and prevented its inclusion in the simulation. Average set up time per each machine or job was not readily available as well.

III. Variability from manufacturing operations and human resources also presented other challenges. Another major issue that the team encountered was inaccurate data partially due to labor turnover at takt time of the merger. The team made certain observations that were accurate at the time when they were recorded but, as labor was relocated they became less accurate. The team attempted to adjust these changes

taking into consideration the labor changeover as best as they could, estimates were used.

The team encompassed many challenges but adapted to overcome them. The team used whatever data was accessible to develop the simulation program, and used the observations and interviews with company contacts to perform an analysis. To minimize delays, the team developed plans on how to address the problem. Once the team received the information, the team was able to quickly perform our analysis. The team observed firsthand how in the business world sometimes adjustments are necessary and the team adapted to changing circumstances as information was made available to the team.

6. RECOMMENDATIONS

Throughout this process the team also observed bottlenecks that impact the manufacturing process that are external to the physical process and beyond the scope of the project. Therefore, the team arrived at the following recommendations:

1. First, it is suggested that Primetals use simulation software like Arena® for their forecasting and planning needs. Arena® is relatively simple to use and allows users to manipulate different parameters such as the hours of operations, resources available, materials and route hours being inputted and the list continues. These features can provide Primetals insight on how to go about making changes in the production system without actually making those physical changes that could incur some cost and risk. Along with providing insights, the simulation program can allow users, especially the production planner, the possibility of completing certain jobs within a specific deadline, the number of jobs that can be completed and eliminates the manual labor associated with making these types of guesses. In addition to providing insights in regards to forecasting and planning, Arena® provides the ability to look at results and specific performance measures such as but not limited to queue time, value added time vs. non-value added time, transfer time (transportation), machine utilization, and average total time. These are parameters crucial for continuous improvement and can easily be recorded and documented. Also, the simulation program is able to read and write to Excel spreadsheets thus there is the ability to communicate with the simulation program and SAP software that is currently being used by Primetals. Excel sheets exported from SAP can be extracted and imported into the simulation program so that accurate and real information is being used. Then results can be extracted from the simulation program and be

documented and analyzed for future purposes. In conclusion, the team highly
recommends Primetals invest in Arena®.

2. Second, a set of heuristics need to be defined for the priority rule for jobs regarding
tooling, programming, scheduling work, and rules for machining. The team highly
recommends open lines of communication between the different departments including
production, manufacturing, quality, sales and human resources. After discussion, a
consensus of rules for which jobs are priority and require tooling and programming first
should be set. Also, there could be a rule on the amount of WIP that could be on the floor
and jobs that can be started to increase flexibility within scheduling. Lastly, there needs
to be rules for machining, which can be evaluated via the simulation program, on whether
some jobs should be batched or if the HMC5 should run on first-in-first-out among both
machines, or if each should continue to operate independently of each another and have
their own distinct dispatch lists. All of these heuristics will require the full collaboration
of various departments.

3. The last alternative solution is to expand the use of SAP. SAP has the capability of
facilitating capacity planning and production planning similar to that of Arena®.
However, it will require a greater commitment to conduct the necessary training.

7. CONCLUSION

There were three major findings as a result of the project. The first is that Primetals can better understand their manufacturing capacity and capability by use of a simulation program like Arena®. After analyzing the current manufacturing process of the roller housing assemblies and the horizontal machining centers, the team developed a model using Arena® simulation software. Within the simulation program, the team was able to quantify heuristics into a mathematical distribution. These heuristics were typically inputted manually by the production planner. The simulation will allow the production planner to more easily forecast and strategically plan short term production runs for the HMC5 and HMC6 machining centers without the need to create them by hand. The team delivered the project goals by creating three simulation programs. One for the HMC5 center, one for the HMC6 center, and a final model for the roller house assembly manufacturing process.

The second major finding is that reducing shop floor headcount shifts value added work away from its high level employees, and reduces their efficiency. Machinists create the most value when running a machine, so any time spent doing material handling is time lost that could have been put towards production. In addition to creating a bottleneck of to-be-moved products, efficiency is also reduced due to programming constraints. The shop floor has a major bottleneck within the tooling and programming department. The tool part coding takes days to create. This can halt production if orders aren't planned out correctly. The company is then forced to put work on to the shop floor that is not of the highest deliverable priority. When the tooling and programming is ready, there then may be a lot of WIP on the machining floor interfering with the job. The risk with leaving WIP on the factory floors includes; increased chance of damage, crowding operator workspace, crammed isle-ways, and loss of products. This greatly influences

the entire machining process, and increases the overall lead time associated with most orders. Increasing the number of operators on the floor may cost more money up front, but could potentially save the company money in the long run. Third, a reasonable value of the inefficiencies in any production system can be quantified to understand the financial magnitude of the problem at hand.

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9. APPENDIX A – SIMULATION ONE HMC5 & HMC 6

PROCESS FOR HMC5 & HMC6

SIMULATION CODE FOR HMC5 AND HMC6
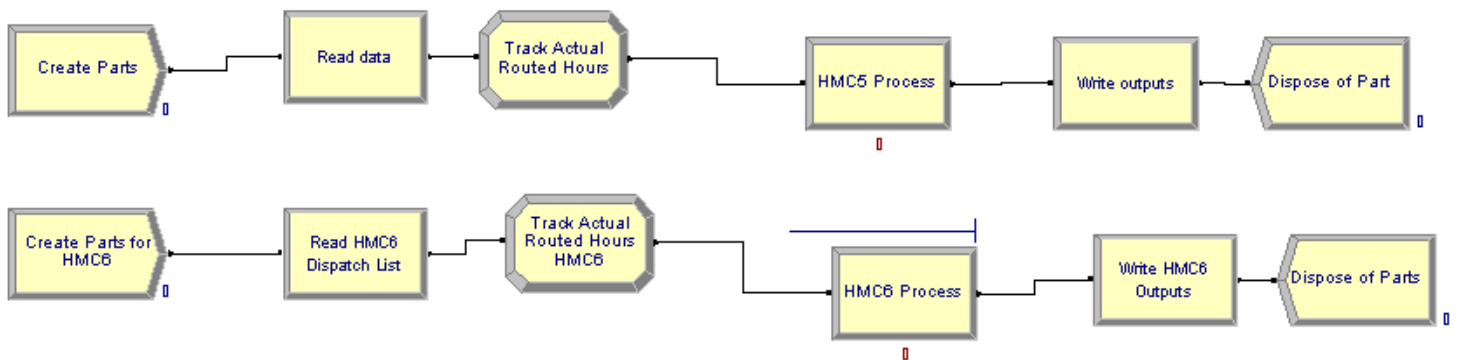
PARTIAL HMC5 & HMC6 RESULTS FOR DISPATCH LIST 02-01-16

Replications: 7   Time Units :   Hours

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HMC5 Process	11.6720	1.77	8.0909	13.2917	0.00	64.6776
HMC6 Process	26.8976	3.15	23.0952	31.3158	10.0000	65.0000

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HMC5 Process	2.3799	2.80	0.2649	8.9547	0.00	39.7441
HMC6 Process	125.86	37.69	70.6040	183.54	0.00	298.61

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
HMC5 Process	14.0519	3.91	8.4433	22.2036	0.00	64.6776
HMC6 Process	152.76	38.18	99.85	208.12	10.0000	323.21

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10. APPENDIX B – RHA MANUFACTURING PROCESS

ENTIRE RHA SIMULATION

MACHINE SHOP 5S AUDIT LOCATIONS

SIMULATION LOGIC FOR RHA MANUFACTURING PROCESS

Parts arrive → Assign Part Type and Sequence → Order Release Station → Start Sequence

STOR Station → Store part Part

two thousand Station → two thousand Process → Route from two thousand

A81P Station → A81P Process → Route from A81P

MM3B Station → MM3B Process → Route from MM3B

A71M Station → A71M Process → Route from A71M

A84M Station → A84M Process → Route from A84M

P837 Station → P837 Process → Route from P837

ARM1 Station → ARM1 Process → Route from ARM1

DD20 Station → DD20 Process → Route from DD20

Q34P Station → Q34P Process → Route from Q34P

CA1R Station → CA1R Process → Route from CA1R

DD4G Station → DD4G Process → Route from DD4G

VV5B Station → VV5B Process → Route from VV5B

F84W Station → F84W Process → Route from F84W

HMC4 Station → HMC4 Process → Route from HMC4

WW3P Station → WW3P Process → Route from WW3P

HH40 Station → HH40 Process → Route from HH40

HMC5 Station → HMC5 Process → Route from HMC5

WW6V Station → WW6V Process → Route from WW6V

WW4V Station → WW4V Process → Route from WW4V

Q34R Station → Q34R Process → Route from Q34R

Q34F Station → Q34F Process → Route from Q34F

HMC6 Station → HMC6 Process → Route from HMC6

L74R Station → L74R Process → Route from L74R

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RESULTS OF RHA SIMULATION

Category Overview
Values Across All Replications

Small Manufacturing System

Replications: 7   Time Units : Hours

Entity

Time

VA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 10290451	16.9380	1.89	13.9477	19.2408	5.0000	35.7980
Part 10351978	89.3991	5.74	79.2203	96.2359	74.5509	110.88
Part 10351979	51.9872	33.12	0.00	82.1082	0.00	85.4271
Part 10360689	16.6426	2.03	14.8743	21.4169	6.7956	36.0185

NVA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 10290451	0.00	0.00	0.00	0.00	0.00	0.00
Part 10351978	0.00	0.00	0.00	0.00	0.00	0.00
Part 10351979	0.00	0.00	0.00	0.00	0.00	0.00
Part 10360689	0.00	0.00	0.00	0.00	0.00	0.00

Wait Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 10290451	7.5038	3.11	3.7893	13.5833	0.00	49.0672
Part 10351978	237.76	137.50	27.2445	492.16	27.2445	492.16
Part 10351979	112.23	111.32	0.00	302.91	0.00	455.19
Part 10360689	10.3815	5.04	4.3750	18.0326	0.00	54.9051

Transfer Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 10290451	2.0000	0.00	2.0000	2.0000	2.0000	2.0000
Part 10351978	1.8333	0.00	1.8333	1.8333	1.8333	1.8333
Part 10351979	1.1905	0.75	0.00	1.6667	0.00	1.6667
Part 10360689	2.0000	0.00	2.0000	2.0000	2.0000	2.0000

Other Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 10290451	0.00	0.00	0.00	0.00	0.00	0.00
Part 10351978	0.00	0.00	0.00	0.00	0.00	0.00
Part 10351979	0.00	0.00	0.00	0.00	0.00	0.00
Part 10360689	0.00	0.00	0.00	0.00	0.00	0.00

Total Time

|	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 10290451	26.4418	3.85	19.7370	32.8378	7.0000	70.6153
Part 10351978	328.99	140.86	108.30	587.23	108.30	587.23
Part 10351979	165.41	133.46	0.00	376.83	0.00	525.68
Part 10360689	29.0241	4.23	22.8989	36.3913	11.0071	67.4268

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11. APPENDIX C – MATHEMATICAL MODEL

ORIGINAL DATA

Oper./Act	Order	Material	Material Description	Work cnt	System Status	PO	Cost Elem	Op. Qty	Yield	Act/Op.UoM	Actual sta	Act.finis	Routed Set u	Actual Set Up	Routed Ru	Actual Rur	Per Pc Act Ru	Differe
0005	1042118	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	01/08/2013	01/08/2013	0.000	0.000	1.000	0.000	0	-1.000
0010	1042118	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	HMC6	CNF CLSD PRT REL			1.000	1.000	PC	01/17/2013	04/10/2013	0.750	1.133	3.500	5.783	5.783	2.666
0005	1045739	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/05/2013	04/05/2013	0.000	0.000	1.000	1.083	1.083	0.083
0005	1045741	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/05/2013	04/05/2013	0.000	0.000	1.000	1.283	1.283	0.283
0005	1045734	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/06/2013	04/06/2013	0.000	0.000	1.000	1.133	1.133	0.133
0005	1045736	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/06/2013	04/06/2013	0.000	0.000	1.000	1.433	1.433	0.433
0005	1045737	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/06/2013	04/06/2013	0.000	0.000	1.000	0.800	0.8	-0.200
0005	1045738	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/06/2013	04/06/2013	0.000	0.000	1.000	1.150	1.15	0.150
0010	1045741	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	HMC6	CNF CLSD PRT REL			1.000	1.000	PC	04/06/2013	04/10/2013	0.750	2.017	3.500	9.301	9.301	7.068
0005	1045742	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/06/2013	04/06/2013	0.000	0.000	1.000	2.200	2.2	1.200
0005	1045743	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/06/2013	04/06/2013	0.000	0.000	1.000	2.100	2.1	1.100
0020	1042118	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/10/2013	04/10/2013	0.000	0.000	6.000	5.467	5.467	-0.533
0023	1042118	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/10/2013	04/10/2013	0.000	0.000	1.000	1.267	1.267	0.267
0010	1045734	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	HMC6	CNF CLSD PRT REL			1.000	1.000	PC	04/10/2013	04/10/2013	0.750	1.967	3.500	5.616	5.616	3.333
0020	1045741	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/10/2013	04/17/2013	0.000	0.000	6.000	7.767	7.767	1.767
0020	1045734	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/11/2013	04/11/2013	0.000	0.000	6.000	4.683	4.683	-1.317
0023	1045734	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/11/2013	04/11/2013	0.000	0.000	1.000	0.950	0.95	-0.050
0010	1045737	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	HMC6	CNF CLSD PRT REL			1.000	1.000	PC	04/11/2013	04/12/2013	0.750	0.567	3.500	3.500	3.5	-0.183
0010	1045739	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	HMC6	CNF CLSD PRT REL			1.000	1.000	PC	04/12/2013	04/25/2013	0.750	1.650	3.500	4.333	4.333	1.733
0010	1045738	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	HMC6	CNF CLSD PRT REL			1.000	1.000	PC	04/13/2013	04/13/2013	0.750	0.000	3.500	5.767	5.767	1.517
0005	1045824	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/13/2013	04/13/2013	0.000	0.000	1.000	1.100	1.1	0.100
0005	1045825	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/13/2013	04/13/2013	0.000	0.000	1.000	1.017	1.017	0.017
0010	1045736	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	HMC6	CNF CLSD PRT REL			1.000	1.000	PC	04/16/2013	04/16/2013	0.750	0.000	3.500	3.983	3.983	-0.267
0010	1045824	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	HMC6	CNF CLSD PRT REL			1.000	1.000	PC	04/16/2013	04/18/2013	0.750	1.500	3.500	2.633	2.633	-0.117
0023	1045741	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/17/2013	04/17/2013	0.000	0.000	1.000	1.017	1.017	0.017
0025	1042118	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	5000	CNF CLSD EODL PRT REL	X	61000010	1.000	1.000	PC	04/18/2013	04/18/2013	0.000	0.000	0.000	0.000	0	0.000
0030	1042118	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	Q34R	CNF CLSD PRT REL			1.000	1.000	PC	04/18/2013	04/18/2013	0.000	0.000	0.000	0.000	0	0.000
0025	1045734	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	5000	CNF CLSD EODL PRT REL	X	61000010	1.000	1.000	PC	04/18/2013	04/18/2013	0.000	0.000	0.000	0.000	0	0.000
0030	1045734	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	Q34R	CNF CLSD PRT REL			1.000	1.000	PC	04/18/2013	04/18/2013	0.000	0.000	0.000	0.000	0	0.000
0020	1045737	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/18/2013	04/19/2013	0.000	0.000	6.000	10.800	10.8	4.800
0020	1045738	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/18/2013	04/18/2013	0.000	0.000	6.000	7.384	7.384	1.384
0023	1045738	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/18/2013	04/25/2013	0.000	0.000	1.000	1.083	1.083	0.083
0010	1045825	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	HMC6	CNF CLSD PRT REL			1.000	1.000	PC	04/18/2013	04/20/2013	0.750	2.516	3.500	8.984	8.984	7.250
0005	1045826	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/18/2013	04/18/2013	0.000	0.000	1.000	0.483	0.483	-0.517
0005	1045827	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/18/2013	04/18/2013	0.000	0.000	1.000	0.533	0.533	-0.467
0005	1045908	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/18/2013	04/18/2013	0.000	0.000	1.000	0.533	0.533	-0.467
0023	1045737	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/19/2013	04/19/2013	0.000	0.000	1.000	1.633	1.633	0.633
0020	1045739	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/19/2013	04/25/2013	0.000	0.000	6.000	4.617	4.617	-1.383
0023	1045739	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/20/2013	04/20/2013	0.000	0.000	1.000	1.050	1.05	0.050
0020	1045824	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/20/2013	04/25/2013	0.000	0.000	6.000	9.433	9.433	3.433
0010	1045827	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	HMC6	CNF CLSD PRT REL			1.000	1.000	PC	04/20/2013	07/23/2013	0.750	0.783	3.500	3.934	3.934	0.467
0020	1045736	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/23/2013	04/27/2013	0.000	0.000	6.000	8.900	8.9	2.900
0020	1045825	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/23/2013	04/24/2013	0.000	0.000	6.000	6.717	6.717	0.717
0023	1045825	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/23/2013	04/23/2013	0.000	0.000	1.000	0.950	0.95	-0.050
0010	1045826	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	HMC6	CNF CLSD PRT REL			1.000	1.000	PC	04/23/2013	05/07/2013	0.750	1.350	3.500	8.633	8.633	5.733
0010	1045908	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	HMC6	CNF CLSD PRT REL			1.000	1.000	PC	04/23/2013	04/23/2013	0.750	0.000	3.500	4.917	4.917	0.667
0005	1046286	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/23/2013	04/23/2013	0.000	0.000	1.000	4.066	4.066	3.066
0023	1045824	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/24/2013	04/24/2013	0.000	0.000	1.000	1.550	1.55	0.550
0020	1045908	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/24/2013	04/24/2013	0.000	0.000	6.000	6.983	6.983	0.983
0023	1045908	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/24/2013	04/24/2013	0.000	0.000	1.000	0.850	0.85	-0.150
0035	1045734	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/25/2013	04/26/2013	0.000	0.000	4.500	9.317	9.317	4.817
0035	1042118	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/26/2013	04/26/2013	0.000	0.000	4.500	6.317	6.317	1.817
0023	1045736	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	A71M	CNF CLSD PRT REL			1.000	1.000	PC	04/26/2013	04/27/2013	0.000	0.000	1.000	8.116	8.116	7.116
0900	1042118	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	STOR	CNF CLSD PRT REL			1.000	1.000	PC	04/29/2013	04/29/2013	0.000	0.000	0.000	0.000	0	0.000
0900	1045734	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	STOR	CNF CLSD PRT REL			1.000	1.000	PC	04/29/2013	04/29/2013	0.000	0.000	0.000	0.000	0	0.000
0025	1045737	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	5000	CNF CLSD EODL PRT REL	X	61000010	1.000	1.000	PC	04/30/2013	04/30/2013	0.000	0.000	0.000	0.000	0	0.000
0025	1045738	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	5000	CNF CLSD EODL PRT REL	X	61000010	1.000	1.000	PC	04/30/2013	04/30/2013	0.000	0.000	0.000	0.000	0	0.000
0025	1045739	LRM 10290451	230 - ROLL HOUSING MACHINING ASSY	5000	CNF CLSD EODL PRT REL	X	61000010	1.000	1.000	PC	04/30/2013	04/30/2013	0.000	0.000	0.000	0.000	0	0.000

This is a sample of the data the team used to create the distributions used for the model. In total, this list has actual hours and routed hours for jobs dating back to January 2013 and as recent as December 2015. This data was combined with some current dispatch lists as well as project files given to the team by a planner at Primetals.
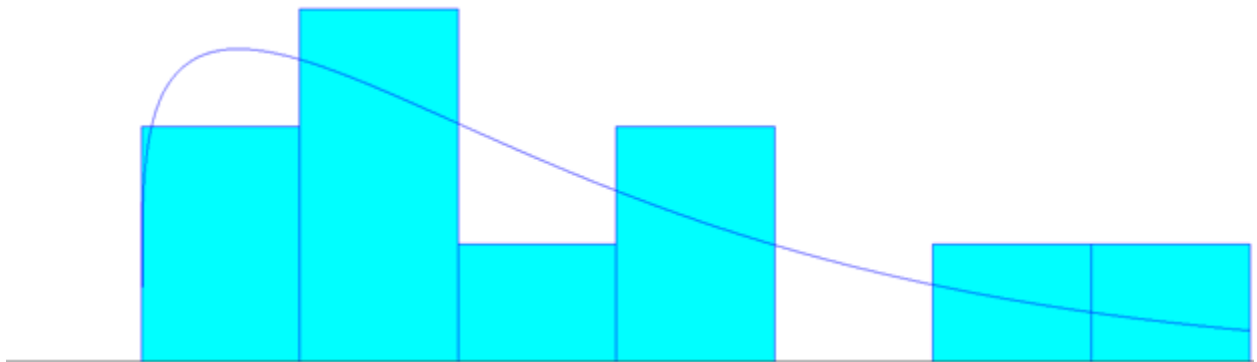
HMC5: -4+79*BETA(0.545, 1.25)
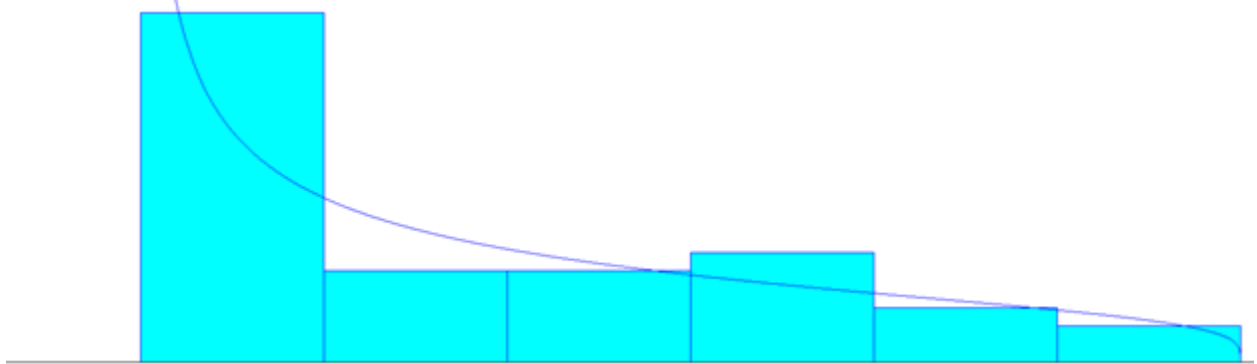
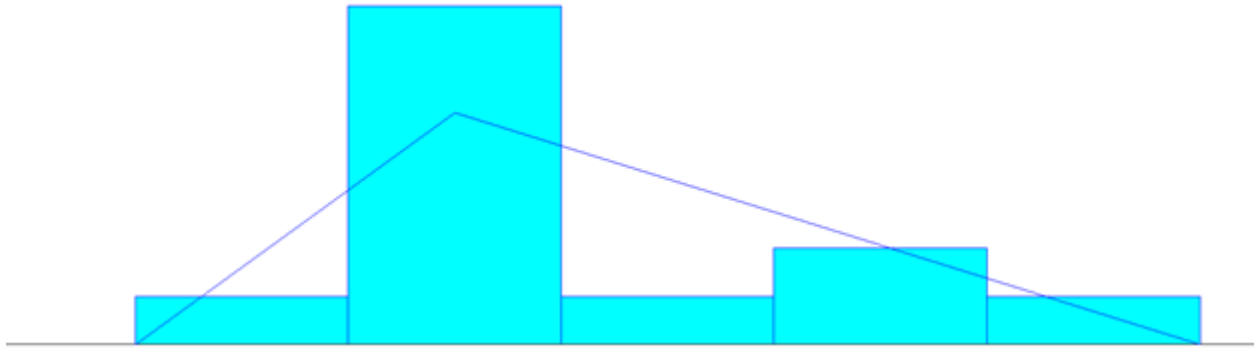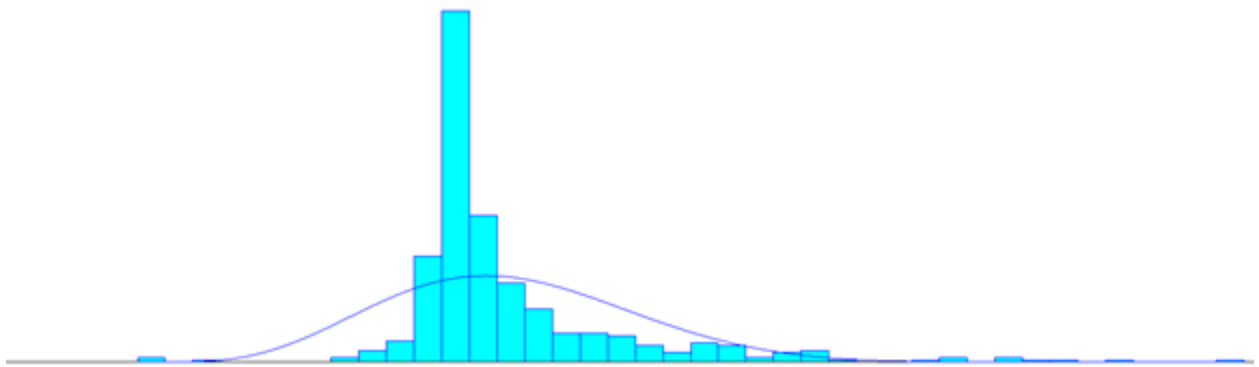**HMC6: -7 + WEIB(12.7, 2.08)**
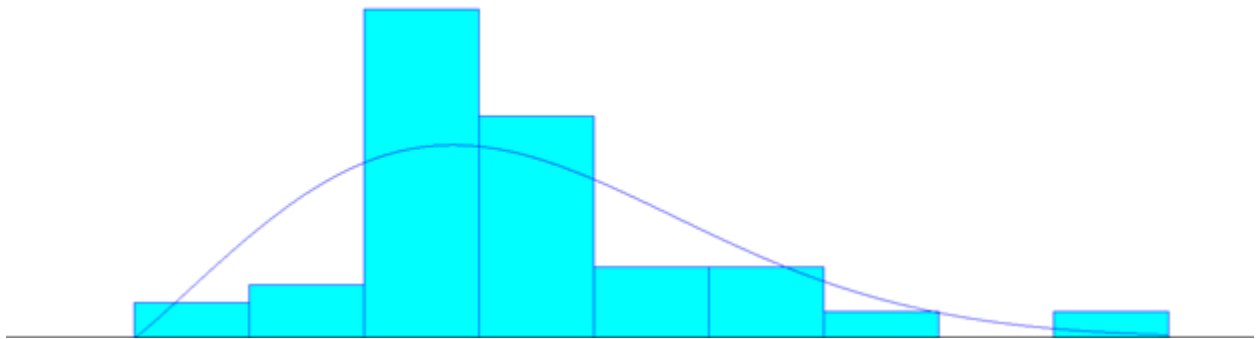
HH40: 1+ WEIB(28.8, 1.19)

L74R: TRIA(-1, 1.4, 6.99)

A71M: -6 + 21*BETA(5.73, 11.3)
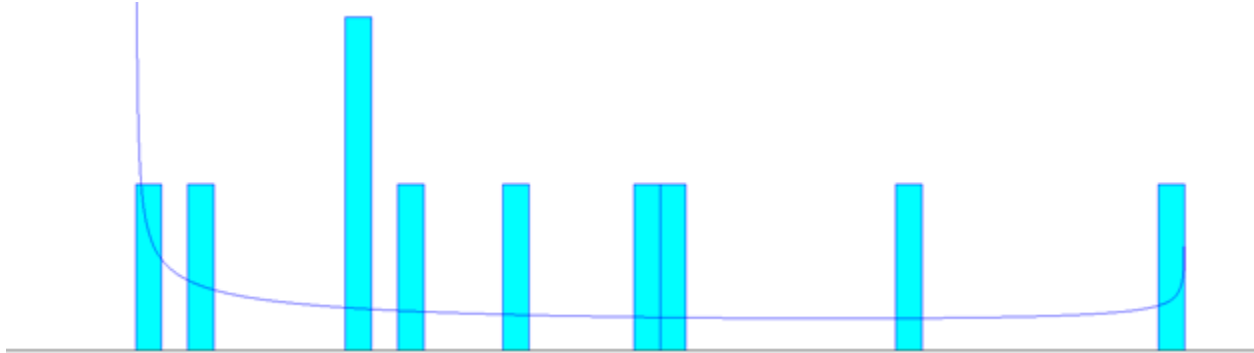

WW3P: -2+EXPO(8.74)
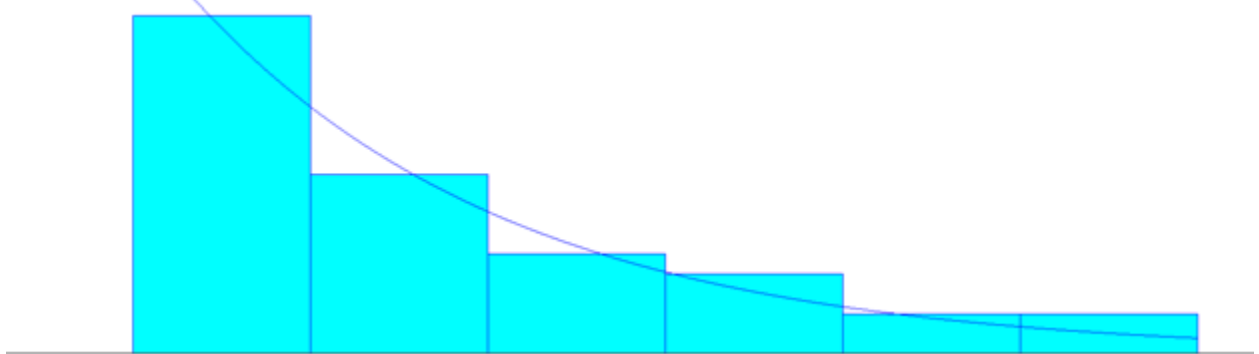
HH6S: -7 + 30*BETA(2.64, 1.55)

The above graphs are representations of differences between the actual run hours of machines and the current routed hours for operations within SAP. These graphs were generated with the best fit function in the input analyzer application. As can be seen above, each machine had very different data that led to a variety of distributions. The team used this in order to adjust the routed hours that the Arena simulation pulled from the excel files provided to the team by Primetals.