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Layout Improvement and Tool Change Optimization at Primetals

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Layout Improvement and Tool Change Optimization at Primetals

Major Qualifying Project Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

In Partial Fulfillment of the Requirements for the Degree of Bachelor of Science

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Abstract

The objective of this Major Qualifying Project (MQP) was twofold: to reduce setup and tool changeover times for products machined at Horizontal Machining Center 6 (HMC6), and to evaluate and improve the layout and flow of the Manufacturing Assembly Area 71 (A71M). The methods utilized include observations and interviews, axiomatic design, lean manufacturing, and linear programming. The team concluded that Primetals Technologies (Primetals) could more efficiently change tools on HMC6 and can save time on part assemblies at A71M. These changes at HMC6 and A71M can save Primetals an estimated 65-135 hours and 50-80 hours, respectively. A financial analysis of the report showed that lean implementation at A71M can save Primetals between $12,000 - $22,000 annually, and an optimized tool changeover process can save Primetals $57,000 - $126,000 per year.

Acknowledgments

We are grateful to the many individuals who contributed to the success of this MQP. In no particular order, thank you to our advisors, Walter Towner, Helen Vassallo, and Sara Saberi for your guidance. At Primetals, thank you to Bonnie Specht, Dan Gilbreath, Alberto Ortega Cerbon, A71M and HMC6 operators Brian Denis and Joe Barna, and all of Primetals Technologies for sponsoring and facilitating this project. Finally, thank you to Professor Andy Trapp for assistance with the linear programming model.

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Chapter 1: Introduction

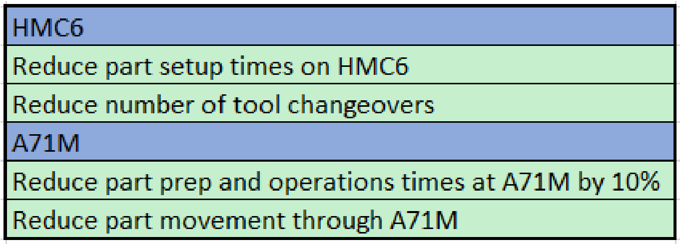
Primetals Technologies is a joint venture founded in 2015 between Mitsubishi and Siemens to deliver metallurgical solutions for companies worldwide (Primetals Technologies). The facility operates as a job-shop that produces customized, precisely machined new and replacement parts. Primetals partnered with Worcester Polytechnic Institute (WPI) to sponsor this MQP, which was completed in March 2018.

1.1 Problem Statement

Primetals produces a variety of customer specific parts for use in its Morgan Vee No-Twist Mill, of which a central component is the roll housing. The HMC6 and adjacent Manufacturing Assembly Area 71 constitute a critical work center in the small roll housing value stream, however both areas currently face production bottlenecks. At HMC6, part setup times are as high as 8 hours each, and the A71M area is backed up with parts going to and from HMC6. This bottleneck results in difficulty planning production and adapting to variable demand. As such, opportunities have been identified at both areas to reduce part setup (HMC6) and reduce part prep (A71M).

1.2 Project Goals & Objective

After an evaluation of the two areas, through observations and interviews with Primetals about their goals, we jointly established the following project targets as shown in Table 1.



HMC6
Reduce part setup times on HMC6
Reduce number of tool changeovers
A71M
Reduce part prep and operations times at A71M by 10%
Reduce part movement through A71M

Table 1: Project Goals Summarized by Area

In order to achieve these goals, we used a linear programming simulation and lean process improvement. At HMC6 the use of a linear programming model will reduce or eliminate the need for frequent tool changes. At A71M the implementation of lean will reduce wasted movement in the part preparation/cleanup operation. Completion will result in higher capacity at the work center and allow management greater flexibility to adapt to demand variability.

1.3 Project Deliverables

The project deliverables for this MQP include developing a new tool change schedule at HMC6 and an improved work layout at A71M, as well as a financial analysis of the impact of our solutions.

1.4 Project Scope

This project focused on HMC6 and A71M work areas, which are located adjacent to each other at Primetals. At the HMC6, the scope was contained to the part setup process, including part fixturing and tool changes. In the A71M area, the scope included the workers movements and organization of the area. Our proposed solutions can also be applied to other areas within the Primetals facility.

Chapter 2: Background

In order to understand the context of our project, we collected research on the history of Primetals (Primetals Technologies), axiomatic design (Brown 2013), lean manufacturing (Xuechang Zhu 2017), and linear programming (Ferguson n.d.).

2.1 Primetals History

Morgan Construction Company was founded in 1891 by Charles Hill Morgan. Morgan became a world leader in steel rolling and casting, in addition they developed a reputation for being innovative and having high quality products (Primetals Technologies n.d.). In 2008, Siemens acquired Morgan Construction, and the company became a part of Siemens VAI, whose discipline was steel and iron. On January 7th, 2015, Primetals Technologies was established as a joint venture between Siemens and Mitsubishi Heavy Industries. Mitsubishi is the majority owner of Primetals at 51%, while Siemens controls 49% (Primetals Technologies n.d.). Primetals is based in London, but has facilities located in China, India, US, and UK, as well as having over 9,000 employees worldwide. Primetals Technologies is currently the world leader in metallurgical plant solutions. Primetals works with both ferrous and non-ferrous metals and also specializes in 9 different machining processes (Primetals Technologies n.d.).

2.1.1 Morgan Vee No-Twist Mill

At Primetals the team worked with the 230, 160, and 150mm roll housings as well as the 8in copper mill roll housings. These products are machined and assembled in part at HMC6 and A71M. Shown in Figure 1 is the Morgan Vee No-Twist mill featuring the dark grey roll housings and the brass pinions. There are two major components that make up a finished part: the front plate and roll housing. Roll housings are essential as they store pinions and gears which are used in the mill. (Primetals Technologies n.d.).

Figure 1: Morgan Vee No-Twist mill

2.2 Axiomatic Design

Axiomatic Design (AD) is a system created to bring a scientific approach to design, and to ensure complete understanding of a problem or system. AD is an iterative look at what matters most within a system. The process is repeated until all parties are satisfied that the design accurately represents the components (Brown 2013)

The first step is to identify the top-level goal. Then, the decision maker identifies all of the functional goals that make up to the top-level goal. Each goal is further broken down until they are “mutually exclusive and collectively exhaustive” (Brown 2013). Each of these goals, or functional requirements (FRs), is paired with the physical action or item that represents that goal, known as the design parameters (DPs). The process is completed with a coupling matrix that combines all the FRs and DPs, with any interactions highlighted.

This systemized approach to design allows for common language across a team and a mutual understanding of the project goals and solutions. Further, following AD sheds light on the major issues in a process, aiding the problem definition phase (Brown 2013).

2.3 Lean Manufacturing

Lean manufacturing originally emerged from Toyota’s Production System (Xuechang Zhu 2017). At the core, lean is focused on prevention and elimination of waste through identification of activities that are non-value added. This is achieved through the implementation of one or more lean methods. Lean methods used in this project include 5S (Hirano 1996) and ergonomics (OSHA $afety Pays Program, 2013).

2.3.1 5S

5S is a lean manufacturing method that is most often implemented in manufacturing settings. The results of effective 5S include higher productivity, fewer defects, higher success rate for meeting deadlines, and a safer workplace atmosphere. 5S can be defined by five pillars in this order: Sort, Set in Order, Shine, Standardize, and Sustain. First, Sort primarily deals with removal of waste in a workspace. Second, Set in Order, aims to rearrange the required items for a workspace that remain after Sort. Shine is responsible for making sure a workspace is regularly cleaned to avoid saving labor from dirt and debris build ups. The fourth pillar, Standardize, differs from the first three pillars, as it ensures that the implementation of the first three pillars are done properly. Finally, Sustain, ensures longevity of 5S. There is high importance on this pillar, because if not properly sustained the implementation of the first four pillars will quickly go to waste (Hirano 1996).

2.3.2 Ergonomics

Ergonomics is the practice of improving the balance between the physical demands of the workplace and the employees who perform the work. Given the differences in age, physical condition, strength, gender, and stature between every employee, ergonomics is crucial to reducing injury and fatigue. Ergonomics targets and searches for awkward postures, repetitive motions, forceful exertions, and constant stress throughout a workspace (OSHA $afety Pays Program, 2013). The goal of ergonomics is to eliminate or reduce these causes of discomfort and fatigue in every workspace. Implemented correctly, a worker's job should not endanger their current or future health.

2.4 Linear Programming & Optimization

According to UCLA's Thomas S. Ferguson, linear programming is "maximizing or minimizing a linear function subject to linear constraints" (Ferguson n.d.). In other words, linear programming is the practice of finding an optimal solution to an objective function, while satisfying the given constraints or requirements of the problem. Linear programming has an immense breadth of capabilities, including in industry or in a manufacturing environment. According to Fagoyinbo, "linear programming has proved useful in modelling diverse types of problems in planning, routing, scheduling assignment and design" and "mathematical methods [have been] developed to solve problems related to tactical and strategic operations" (Fagoyinbo et al. n.d.)

At Worcester Polytechnic Institute, coursework in linear programming is focused in Microsoft Excel (2016), including Excel's built in modeling system "Solver", as well as the open source add-in "OpenSolver" developed by constituents of the University of Auckland in New Zealand (OpenSolver 2018). For the scope of this project, all mentions of linear programming will be exclusively in reference to modeling conducted in Excel, using the aforementioned solving engines.

Further, linear programming follows a general order of defining first the objective function, then decision variables, and finally constraints. The objective function is the function that is dependent on the decision variables, which will in turn produce the value that will be maximized/minimized by the model. Objective functions are often supported by underlying functions contained within the model. Decision variables are the values that the model returns, which then equate to the optimal solution. Finally, constraints are the limiting factors/requirements of the model. Constraints can be inequalities, equalities, or more specific conditions such as binary (Ferguson n.d.).

Chapter 3: Methods

This project was completed in three phases of seven weeks each. It begins with a diagnosis of the problem, followed by development and implementation of a solution, and concluded by an analysis of that solution.

3.1 Problem Diagnosis

Problem diagnosis is separated into two parts: research preparation and specific data collection. During research preparation phase, our team focused on addressing general information concerning the project. Then we collected specific data about the production areas we were assigned to improve. With this information, we created the axiomatic design decompositions for each work area.

The first part of problem diagnosis focused on gathering information about Primetals and the project, developing a project charter to guide the completion of project goals, then diagnosing the project problems. The team gathered preliminary information by researching MQP work previously completed at Primetals then visited the facility for a tour and to meet with Primetals management. After several subsequent visits, a project charter was created and agreed to by all parties. This charter detailed the current state, problem, specific goals, scope, and timeline for the project (Appendix A).

For the second part, the project was divided between work at A71M and HMC6. Work at A71M focused on layout and flow of the area, and work at HMC6 focused on reducing part setup/tool changeover times. In order to determine inefficiencies, the team first noted the detailed steps that operators took in order to complete operations. However, these operations can take several hours, requiring the team to fill in knowledge gaps by discussing work with the operators. The team then developed a complete model of the system and to get insight into the operator’s perspective on the system. Involving the operators became critical to the success of developing a solution. Finally, the team applied axiomatic design to the collected material in order to identify critical areas of each process.

3.1.1 Axiomatic Design

Axiomatic design was applied in this project to expose flaws in each area. First, Primetals and the team discussed and identified the main Functional Requirements that we wanted to achieve. Each FR was broken down into sub FRs, these sub FRs are the components of each main FR. This method of breaking down and organizing each main FR led us to be able to focus on identifying areas to improve. From those FRs the team was able to form Design Parameters for each of these FRs (Appendix D & E).

3.2 Develop Solution

For the second phase of the project, we developed solutions at A71M and HMC6 Work focused on the organization and methods used to prepare parts at A71M, and in the part changeover operation at HMC6. The A71M area is used to prepare and clean parts that are machined on the HMC6. Observations and the axiomatic design matrix for each area helped identify challenges in the operations, then we developed solutions to the corresponding problems. In general, most solutions were implemented as they were developed, in collaboration with the operator of each area. This way testing could be done immediately, and appropriate changes could be made. In this section, we will detail the problems at A71M and HMC6, solutions to the problems, and implementation and implications of these solutions.

3.2.1 A71M

The primary problems that the team identified were a cluttered layout of the A71M area, an excess of unused tools and materials, disorganization of tools and supplies, and inefficiencies in the way that the A71M operator works on parts. We utilized the first pillar of 5S, Sort, to eliminate unused tools, cabinets, and materials. This addressed the second FR, having the right size tool library space required for A71M processes. The second pillar of 5S, Set in Order, was applied to organize the tools and supplies used to work on parts. This addressed the first FR, reduce time searching for elements. Then we used spaghetti diagrams to analyze the A71M operator's movements and reduce the number of steps required for working on each part. With this we addressed the third FR: reduce information for A71M processes. In addition, many of the changes that we made greatly improve the ergonomics of the area, reducing operator fatigue and risk of injury.

The first pillar of 5S, Sort, focuses on eliminating waste and unused materials in an area. By interviewing the operator and watching him work, we identified large items that could be removed completely. These included a large and unused cabinet, a large rack for crane straps, and metal bars in the center of the area, as shown in Figure 2. Next, we used red tagging to identify and remove tools and materials that were rarely or never used (Hirano 32). Red tagging involves placing a red tag on items that aren't used regularly, then moving them to a separate location to either be thrown out or returned in a better spot. Figure 3 shows the collected items that were red tagged.

Figure 4: Unused Cabinet, Metal Bar

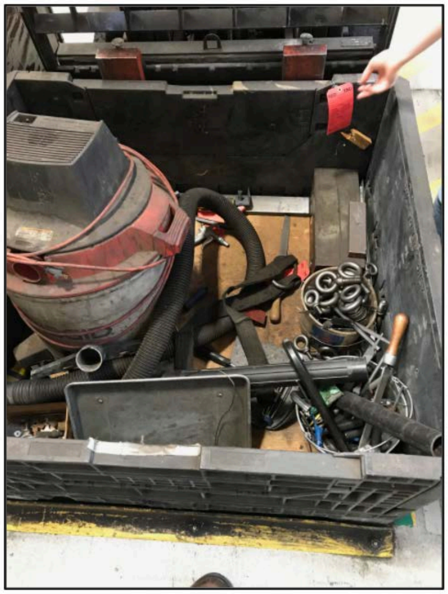


Figure 3: Red-Tagged Items

The next pillar of 5S, Set in Order, says to rearrange tools and materials in a clean, functional way. The operator uses the same set of tools and cleaning supplies for each part he works on, and they were strewn in messy drawers with no clear organization. Figure 4 shows one of the primary drawers used to contain many of the most important tools.

Figure 2: Disorganized Tools

Each time the operator needed a tool, he had to walk over to the drawer, bend down, and sift through to find the correct one. Our goal was to improve access to tools and reduce motion required to retrieve them. In collaboration with the operator, we looked at several options for moving walls called pegboards, that can be customized to hold the tools in an organized and accessible way. The pegboard chosen needed to be mobile and be organized many different ways to accommodate different tools. This would greatly reduce the time required to find each part and ensure that each part is easily accessible without bending. We developed the pegboard by creating iterative mock ups of what the final result could look like. As shown in Figure 5, we began with a cardboard template that we laid the tools and supplies on to determine how much space would be required. Then we placed the tools on a stationary pegboard that already existed at the station, and finally we purchased the permanent pegboard.

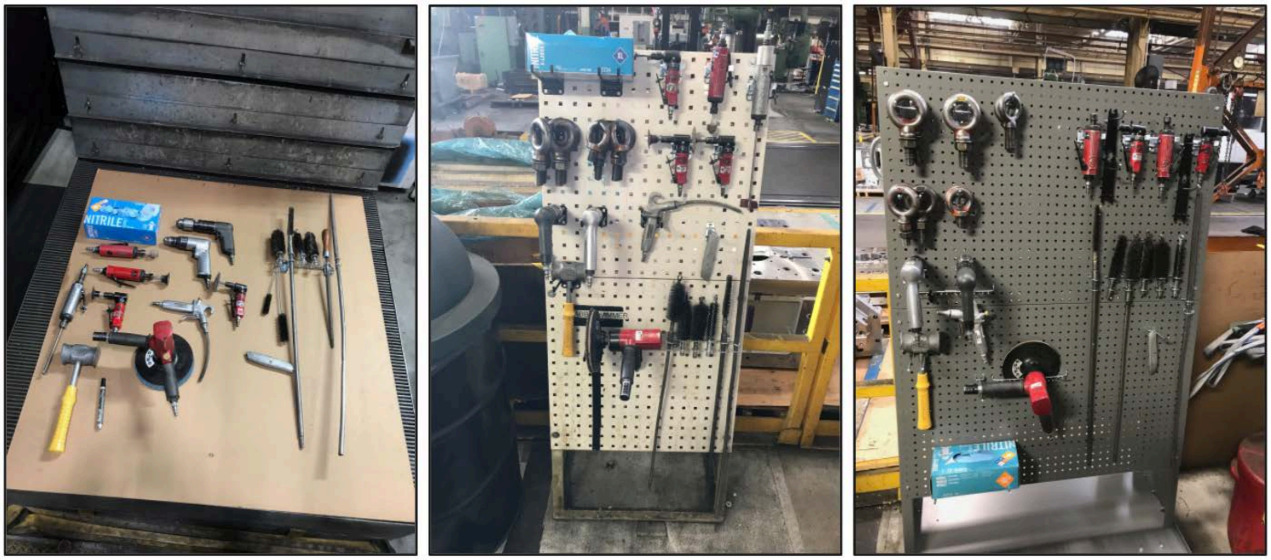


Figure 5: Creation of the Pegboard

This final design includes space on both sides and is on wheels. This allows the operator to bring the tools to the work location, reducing trips to and from the drawers. Finally, the organized layout greatly increases the ergonomics of the area (OSHA $afety Pays Program, 2013). The operator no longer needs to spend time bent over searching for the correct tool. In addition to the pegboard, we reorganized the cleaning supplies that the operator uses. This was done with foam board, which is placed in the cabinet. Then spaces are cut into the foam corresponding to the shape of each item to be placed there. This ensures that items are returned to the correct locations every time, and also indicates whether there is something missing. The before and after of this work is shown in Figure 6. These changes, the pegboard and foam board, significantly reduce time spent searching for supplies while working on parts.

Figure 6: Cabinet re-design with foam board

Finally, the team focused on identifying non-value-added work in order to reduce information and steps required in the work processes for each part at A71M. For this the team created spaghetti diagrams based on the operators and parts movements around the area. By taking detailed observations of each movement the team traced the paths of both the operator and the part. Reducing these movements is critical in order to reduce information and steps required for each part. During the part prep process the operator must use a crane multiple times to move the part, out of all the operator’s steps finding, retrieving and using the crane took the most amount of time. This crane services several other workstations, so there are often delays caused by waiting for access to the crane. After creating spaghetti diagrams with the observations, the team was able to identify and eliminate steps and crane usages in the process. Shown in Figure 7 are before and after spaghetti diagrams, where the right photo shows the reduction of non-value-added work. These reductions yield significant improvements to the time spent working on each part.

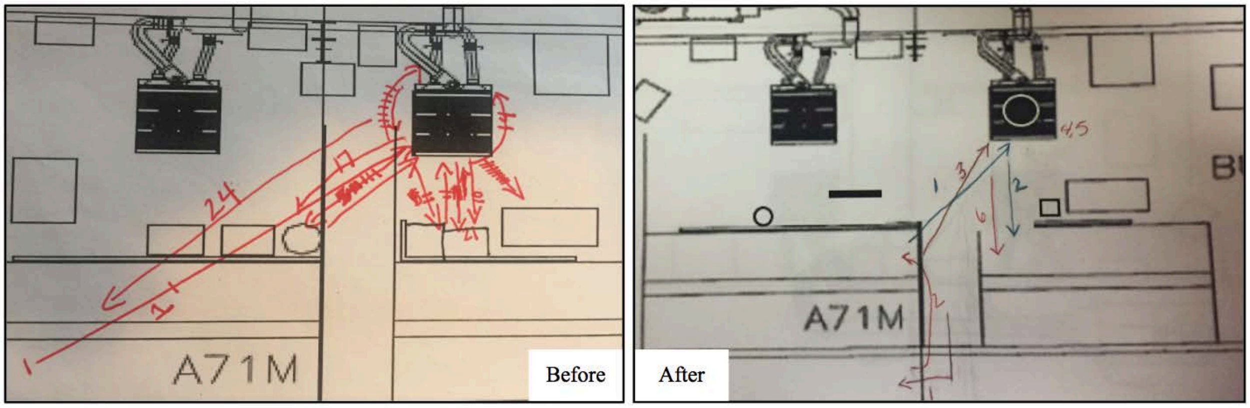


Figure 7: Spaghetti Diagrams

5.2.2 HMC6

The HMC6 is a high accuracy milling machine typically used to repeatedly machine similar parts. Due to the job shop nature of Primetals, many different parts and even versions of each part are put through, meaning there is a lack of standard procedure for setting each part on the machine. The process is laborious and can take up to 4 hours per part even with a highly skilled and experienced operator. The HMC6 is critical in the product flow at Primetals, so even small reductions in the overall setup time can have huge implications. Observations and the axiomatic design decomposition identified several potential areas of improvement. FR 1 is to minimize paperwork changeover time, FR 2 is to minimize tool changeover time, and FR 3 is to minimize part changeover time.

Our focus became the tool changeover time. Each time a new part is loaded into the machine, the correct tools for the operation must also be loaded in the machine. The HMC6 holds up to 180 tools at one time, and each part usually requires approximately 40 tools. Therefore, tools should ideally never have to be changed out of the machine except for calibration or wear. The problem is that the machine operator changes over tools in an unsystematic way, basing changes solely on what part is being machined next, and his experience working on these parts. This results in a machine that is full of tools, but possibly 5-10 tools that need to be added for each new part. In order to improve the tool changeover process at HMC6 we developed a linear programming model to optimize which tools are stored in the machine. We modeled the tool changeover process in order to minimize the number of changeovers and provide an exact changeover schedule for the machine operator at HMC6. The team followed the process of creating first the objective function, then decision variables, and finally constraints.

The objective function the team sought to minimize was the sum of all tool changeovers. To elaborate, every changeover process from part to part is accompanied by certain tools being removed and inserted from the machine, and the objective was to minimize the number of removals/insertions over roughly a month’s outlook of production.

The decision variables, assigned by the model, were defined in two parts: the first of which is the exact schedule for tools at HMC6. Based on the schedule defined part by part being manufactured, a “1” value represents that the tool will be in the machine while part X, for example, is being manufactured. A “0” value represents that the tool will not be in the machine during this phase. This set of decision variables provides the exact schedule for what tools will or will not be in the machine during the manufacturing of part X, and continuing on for part Y etc. The second set of decision variables are assigned to represent every time there is a changeover, whether it be a tool being removed or inserted.

These decision variables and the model are subject to several constraints to reflect key requirements of the problem. First, the number of tools that can be in the machine at once, reflected by the sum of “1” values in place for each part, cannot exceed 180, as this is the maximum capacity of the machine. Second, all decision variables in the changeover portion of the decision matrix must be greater than or equal to the two constraint matrices in the model. This is to maintain linearity while allowing the model to count the number of changeovers, whether they be insertions or removals. Also, each decision variable row in the schedule portion of the decision matrix must be greater than or equal to the corresponding tool card row in the model, in order to ensure that all tools necessary to manufacture a part are in the machine.

Following the construction of our model, the model is solved by selecting the “Solve” command in the OpenSolver dashboard in Microsoft Excel (2016) and uses the built-in CBC linear solver. The solver finds the global minima for the given data, which, along with the schedule provided by the model, can be interpreted as the optimal tool changeover schedule for HMC6.

An instruction sheet for using the model is included, and a screenshot can be found in Appendix C.

3.3 Solution Analysis

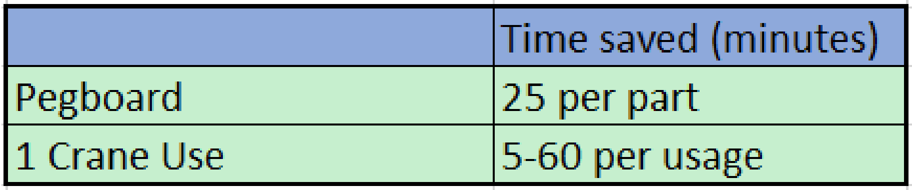
The team tracked the time saved at each area after implementation of the respective solutions. At A71M, the team quantified the reduced number of steps taken, and the reduced crane usage. We also examined the improved ergonomics and quantified the reduction in cost. At HMC6, the team tracked the current state of how many tools are changed each time and compared to the optimized number. Improvements made by the model were quantified by the reduction in number of tool changes. The results of this analysis are shown in section 6.0 Results.

Chapter 4: Results

Here are the results of the implementation of lean and linear programming, and our financial analysis.

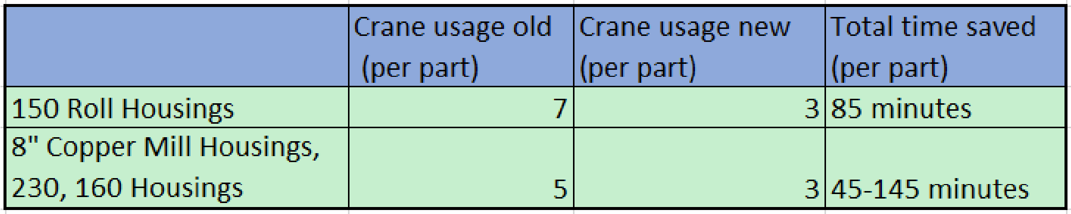
4.1 Lean Implementation at A71M

Implementation of 5S at A71M yielded a large reduction in the time required to prepare and clean parts. The time savings calculations are shown in the two tables below (Table 2 & 3). In addition to saving time the team improved the ergonomics of the area. This will indirectly save them time and money, as a more comfortable operator will take less days off due to physical ailments.



	Time saved (minutes)
Pegboard	25 per part
1 Crane Use	5-60 per usage

Table 3: Time Savings Results (A71M)



	Crane usage old (per part)	Crane usage new (per part)	Total time saved (per part)
150 Roll Housings	7	3	85 minutes
8" Copper Mill Housings, 230, 160 Housings	5	3	45-145 minutes

Table 2: Time Savings Results (HMC6)

4.2 Linear Programming at HMC6

The success of our linear model was quantified by the decreases in tool changeovers. In order to measure our model's success, the machine operator at HMC6 recorded the number of tool changeovers needed over the course of several part changeovers. These results were then compared with the number of changeovers which the model states were needed.

Observations showed that over the course of 4 part changeovers the HMC6 operator had to perform 48 tool changeovers. The model produced tool scheduling that could completely eliminate the tool changeover phase of the process over the life of 4 part changeovers, after an initial optimized setup. Estimating that this first phase took 16 changeovers, an above average measure, we would have saved 32 changeovers over the cycle of 4 changeovers, or about 8 per part. A time-study showed that each tool change takes 2-4 minutes, meaning over the period that the 4 parts were machined, 64-128 minutes could be saved, or an average of 16-32 minutes per part.

4.3 Financial Analysis

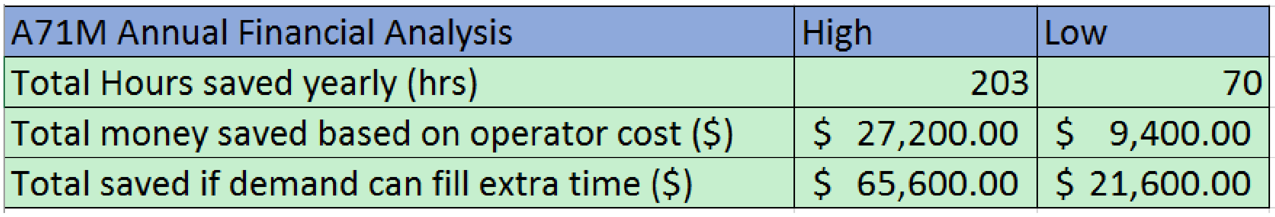
The goal of a process improvement project in an industrial setting aims to make processes more efficient in order to generate greater profits, whether it be in the form of adding revenue or cutting costs. In the case of this MQP, we focused on decreasing setup and process times in order to cut the costs associated with longer throughput time and increase revenue potential due to greater production capacity as a result of saved time.

4.3.1 A71M

The team was able to calculate a financial analysis based on how much time was saved a year and the cost and price of each of the four main parts assembled at A71M and the demand for each piece for 2018. The team took two different approaches to the financial analysis. First, was looking strictly at the number of hours saved per year. Second, we made calculations based on the assumption that demand could fill the saved hours, making Primetals additional profit. Even if those saved hours are not able to be filled with prepping additional parts, the A71M operator is often asked to help out in other areas and would not be idle during this saved time.

Summarized in Table 4 are the quantities for money saved through the team's implementations at A71M.

Improving the ergonomics of the area will indirectly save them time and money, as a more comfortable operator will obtain less Musculoskeletal Disorders (MSD). Further, with improved ergonomics operators will have less MSD's which can save Primetals money on medical bills, payments or days off due to MSD's over time. A single MSD can cost between $30,000 - 40,000 in direct costs, and $24,500 - 43,700 in indirect costs (NCCI Holdings Inc).

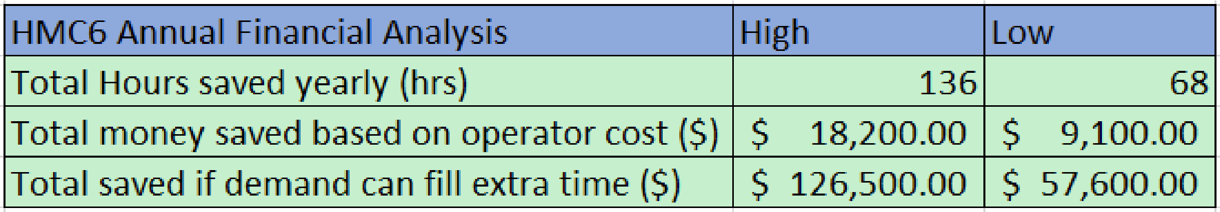


A71M Annual Financial Analysis	High	Low
Total Hours saved yearly (hrs)	203	70
Total money saved based on operator cost ($)	$ 27,200.00	$ 9,400.00
Total saved if demand can fill extra time ($)	$ 65,600.00	$ 21,600.00

Table 4: Financial Analysis Results (A71M)

4.3.2 HMC6

Utilizing the same metrics used for A71M, the linear programming model could save Primetals 65-135 hours of labor over the course of a year. Assuming that this extra time can be used for further production and demand is in place, the total revenue added could be from $57-126,000. Strictly from an operator wage standpoint, $9-18,000 can be saved in a year. The quantities for money saved through the team's implementations at HMC6 can be shown in Table 5.



HMC6 Annual Financial Analysis	High	Low
Total Hours saved yearly (hrs)	136	68
Total money saved based on operator cost ($)	$ 18,200.00	$ 9,100.00
Total saved if demand can fill extra time ($)	$ 126,500.00	$ 57,600.00

Table 5: Financial Analysis Results (HMC6)

Chapter 5: Discussion

Through proper implementation and maintenance, we are confident the changes we have made will benefit Primetals Technologies from an operational, financial, and cultural standpoint. That being said, this project did not come without challenges along the way.

5.1 Impact

The impact of our project will be financially advantageous. In the short term, the team has made changes and recommendations that will improve operations at HMC6 and A71M. The team predicted these changes will have long term financial benefits as well. That being said, this MQP made a greater impact than simply dollars and minutes saved. At A71M, the implementation of 5S techniques was beneficial to the culture of the manufacturing facility as a whole. Further, the final pillar of 5S, Sustain, is what will ultimately determine the impact of our project on the A71M area. If rigorous 5S is implemented and sustained this aspect of the project can be extremely beneficial for Primetals. The 5S work done in the A71M area can be similarly implemented around Primetals in other areas as well.

A culture built on organization and the aspiration to be as lean as possible can yield great results if embodied by all. Further, the implementation of a linear programming model to improve tool changeover time is a first step in the direction of using advanced analytics and modeling to improve work processes. Finally, the continuous pursuit of improvement, as this MQP embodied, can have a compounding effect. On a macro scale, the recommendations and changes we have made at Primetals are small. That being said, the changes we have made may allow for the budgeting of more time and capital to go towards process improvement, and potentially greater savings and returns. This cycle can continuously happen with diligent and lean-driven project work.

The applications of the linear program and lean can be utilized across many other workstations within the facility. This means that the implications of our work, both financially and operationally, can continuously expand at the discretion of Primetals, potentially increasing the value added by this MQP tremendously.

5.2 Challenges

We faced several challenges over the course of this MQP. First, the nature of the production environment interfered with our MQP at times. For example, seeing a tool changeover first-hand could not be done at any time. Primetals maintains a production schedule, and unless we were on sight for the scheduled change, time could not be made to fully re-enact a tool changeover simulation.

Second, while we initially found that operators were open-minded, certain levels of apprehension came with some changes. Operators were against change in regard to their workspace organization and process flow at times. Further, implementation of certain practices required operator initiative, which was not always taken fully.

Finally, working on two areas simultaneously had impacted the depth of our research, because the team had to split up in subgroups and operate separately. The team had made a significant effort in collaboration and communication but could have achieved better results.

Chapter 6: Recommendations

Following completion of our MQP, we have several recommendations for continued improvement past the timeline of our project. Our recommendations seek to reduce waste and increase efficiency at Primetals.

6.1 Standard Work

The teams first recommendation is for Primetals to utilize standard work. Standard work is the act of documenting the best practice of a certain action and enforcing this method to be utilized. Standard work “ensures execution of standardized processes” and “ensures performance-tracking data...for problem solving and corrective action” (Mann 2009). In the case of Primetals, standard work would ensure that consistent practices are being documented and used by all employees, across all shifts. This allows for a calculated approach to problem-solving, as there are consistent actions being taken that can be measured without the possibility of extraneous errors, such as differing operator methodology. Standard work also ensures ease of turnover not only between shifts, but also following the departure of long-time employees.

6.2 Improved Layout

Another recommendation we made is to consistently seek to improve workstation layout. Well-designed layouts minimize unnecessary waste such as material or employee movement and can increase the safety of the employees. We recognize that certain infrastructure would be costly to rearrange and recommend that the focus for such corrective actions be directed towards small changes that can reap small benefits, and less on major layout changes. We gather through our observations that the flow of jobs and information between the A71M and HMC6 areas and the surrounding areas should be looked at and coordinated more efficiently.

6.3 Expanded 5S

Within A71M there are three major cabinets with several drawers that are filled with unorganized tools and equipment. The A71M operator has started foaming and organizing these drawers (shown in Figure 8), we suggest that he continues to clean out and equip drawers with foam board and give a home and address to the tools in his area. This would allow for the operators at A71M to access tools easier and more importantly much faster.

Figure 8: Continued foam boards in cabinets; job kit queue system

The next recommendation for A71M is to implement a queue system for the kitted parts that the worker receives for all of his jobs. As shown in Figure 8, when job kits are delivered to A71M they are in cardboard boxes and are placed on a shelf, they tend to pile up and become unorganized. Implementing a queue system located on the top shelf of the operator's desk which would have labels for what number in the queue a job is would make these parts easier and faster to find. Another important part of the queue system is that other workers who do not normally work in this area can easily find these necessary parts. Implementing this system would save time on every single job and would be ergonomically much better for all operators.

6.4 Part Fixturing

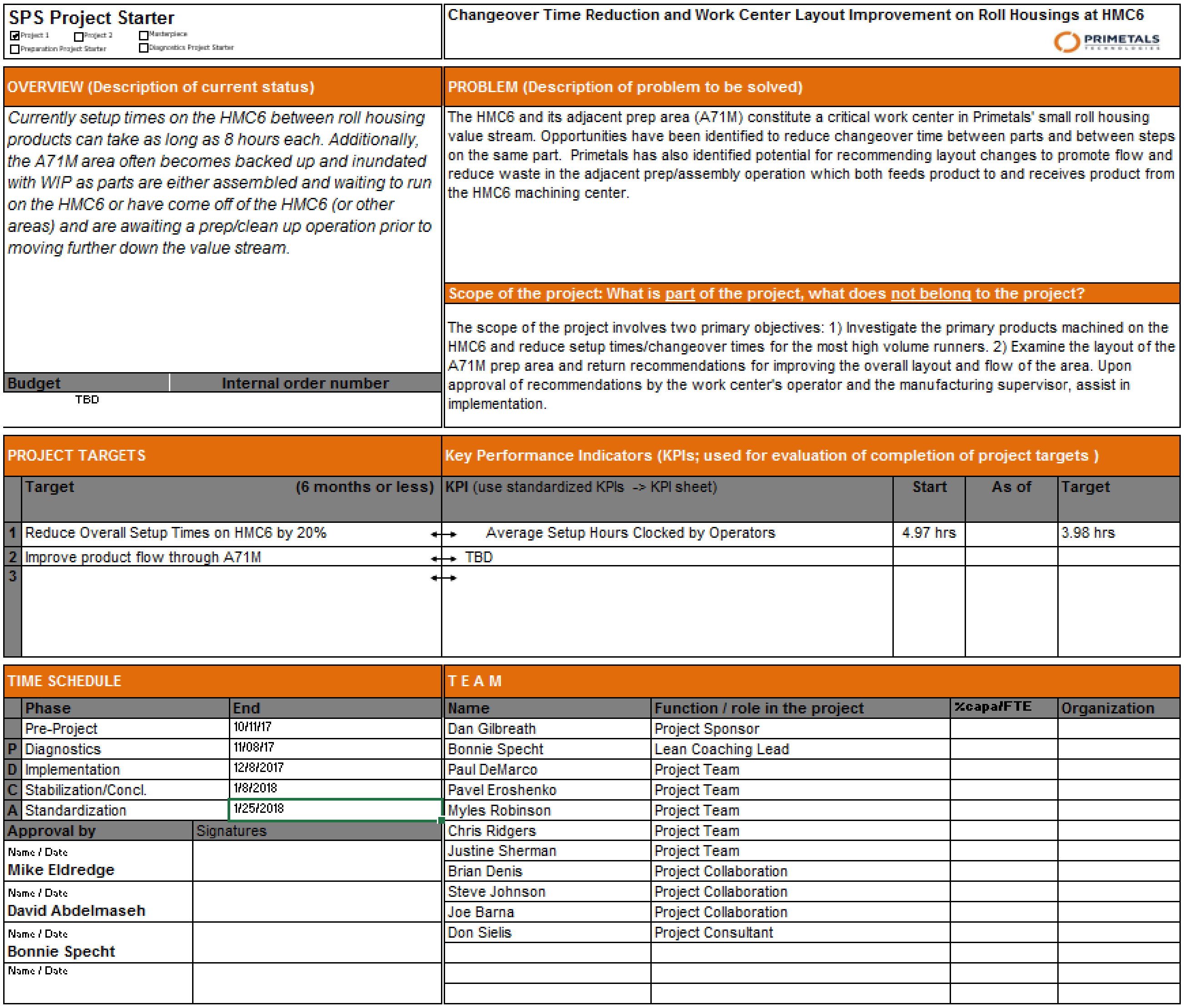
Our final recommendation is to create more part fixtures. In specific, we recommend creating part fixtures for the most frequently manufactured parts at HMC6. Parts manufactured at HMC6 without pre-designed part fixtures add an estimated 1-2 hours of labor in the setup process (HMC6 Machine Operator, Personal Communication, November 2016). Creating a part fixture would require investments in design and creation, but any capital invested in a part fixture would be repaid in time due to time savings and the potential for increased production/revenue.

Chapter 7: Conclusion

Our team worked with Primetals to achieve reduced part preparation and tool changeover times. The solutions implemented at A71M and HMC6 were able to reduce setup times by roughly 115-215 hours per year. In addition to these improvements, the team implemented 5S applications which aid in cultivating a culture of lean practices. Further, the team implemented a linear programming model with potential applications far beyond the scope of this MQP. Despite any setbacks that occurred, the team satisfied the goals of this project and created improvements which will reap benefits for Primetals far beyond the completion of this project. This Primetals MQP project utilized knowledge from both majors associated with the team, industrial engineering and management engineering. The industrial engineers used time studies, lean manufacturing, and linear programming in order to identify and solve problems. The management engineer has a concentration in mechanical engineering, which helped the team better understand and analyze the parts worked on during this MQP. Throughout the completion of this MQP the team has gained real world experience with process improvement in a manufacturing setting. The team recognizes that you have to take an active role in keeping your education current, in order to mirror all the changes that are occurring in the world of engineering every day.

Appendices

Appendix A: Project Charter



SPS Project Starter

☑ Project 1 ☐ Project 2 ☐ Masterpiece
☐ Preparation Project Starter ☐ Diagnostics Project Starter

Changeover Time Reduction and Work Center Layout Improvement on Roll Housings at HMC6

OVERVIEW (Description of current status)

Currently setup times on the HMC6 between roll housing products can take as long as 8 hours each. Additionally, the A71M area often becomes backed up and inundated with WIP as parts are either assembled and waiting to run on the HMC6 or have come off of the HMC6 (or other areas) and are awaiting a prep/clean up operation prior to moving further down the value stream.

Budget	Internal order number
TBD	

PROBLEM (Description of problem to be solved)

The HMC6 and its adjacent prep area (A71M) constitute a critical work center in Primetals' small roll housing value stream. Opportunities have been identified to reduce changeover time between parts and between steps on the same part. Primetals has also identified potential for recommending layout changes to promote flow and reduce waste in the adjacent prep/assembly operation which both feeds product to and receives product from the HMC6 machining center.

Scope of the project: What is part of the project, what does not belong to the project?

The scope of the project involves two primary objectives: 1) Investigate the primary products machined on the HMC6 and reduce setup times/changeover times for the most high volume runners. 2) Examine the layout of the A71M prep area and return recommendations for improving the overall layout and flow of the area. Upon approval of recommendations by the work center's operator and the manufacturing supervisor, assist in implementation.

PROJECT TARGETS | **Key Performance Indicators (KPIs; used for evaluation of completion of project targets)**

	Target (6 months or less)		KPI (use standardized KPIs -> KPI sheet)	Start	As of	Target
1	Reduce Overall Setup Times on HMC6 by 20%	↔	Average Setup Hours Clocked by Operators	4.97 hrs		3.98 hrs
2	Improve product flow through A71M	↔	TBD			
3		↔				

TIME SCHEDULE

	Phase	End
	Pre-Project	10/11/17
P	Diagnostics	11/08/17
D	Implementation	12/8/2017
C	Stabilization/Concl.	1/8/2018
A	Standardization	1/25/2018

Approval by	Signatures
Name / Date **Mike Eldredge**	
Name / Date **David Abdelmaseh**	
Name / Date **Bonnie Specht**	
Name / Date	

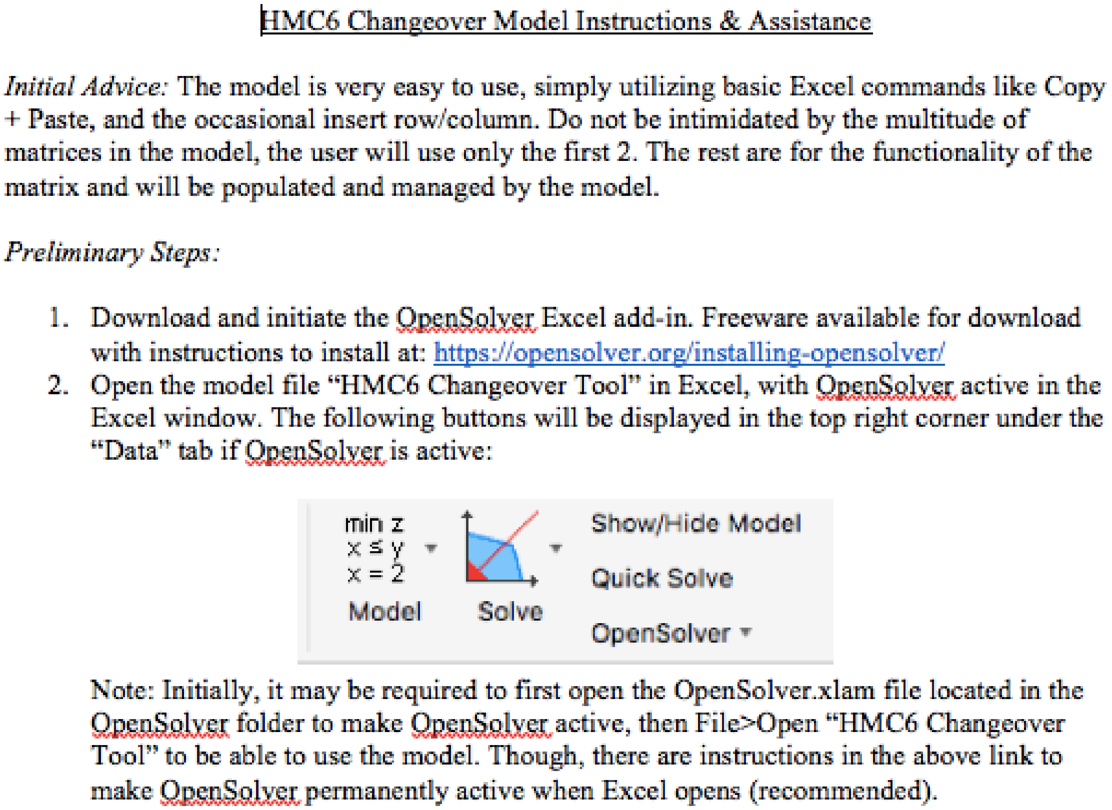
T E A M

Name	Function / role in the project	%capa/FTE	Organization
Dan Gilbreath	Project Sponsor		
Bonnie Specht	Lean Coaching Lead		
Paul DeMarco	Project Team		
Pavel Eroshenko	Project Team		
Myles Robinson	Project Team		
Chris Ridgers	Project Team		
Justine Sherman	Project Team		
Brian Denis	Project Collaboration		
Steve Johnson	Project Collaboration		
Joe Barna	Project Collaboration		
Don Sielis	Project Consultant		

Appendix B: LP Model

	Tool #	0	1	2	3	5	6	7	8	9	10	11	12
	Part Number	FRAME TOO	DR25.0MM	BB26.0MM	M6.0(ROUGH	R38.0MM(ALLIED	F06.809-CI-11.425-12.1	.58MM=07.488-BRING-INSRT-SN	DR30.0MM	DR31.7MM	DR11.8MM	R0.272(CAR	DR17.5MM(CAR
8 in CU Mill	10297919	1			1							1	
230 RH	10075535	1	1		1		1	1	1	1	1	1	1
160 RH	10316655	1	1	1	1				1	1	1	1	1
150 RH Op1	10553631	1				1						1	
150 RH Op2	10553631	1											
150 RH Op3	10553631	1			1							1	
Pinch RH Assem Op20	10631488	1										1	
Pinch RH Assem Op15	10631488	1									1		
Pinch RH Assem Op10	10631488	1			1							1	
Roller Holder Mach. Assem Op15A	10631299	1											
Roller Holder Mach Assem Op15B	10631285	1											
Retainer, 400mm Bearing Op30	10547958	1		1									
Housing, 320 Rotary Shear Op15	10334041	1											
Machining Assembly Gearbox	10416785	1			1								
		HMC6 Tool Schedule Matrix											
Part Schedule:	Housing, 320 Rotary Shear Op15	1	1	0	1	0	1	1	1	1	1	1	1
	??? 10658373	1	1	0	1	0	1	1	1	1	1	1	1
	8 in CU Mill	1	1	0	1	0	1	1	1	1	1	1	1
	8 in CU Mill	1	1	0	1	0	1	1	1	1	1	1	1
	8 in CU Mill	1	1	0	1	0	1	1	1	1	1	1	1
	8 in CU Mill	1	1	0	1	0	1	1	1	1	1	1	1
	8 in CU Mill	1	1	0	1	0	1	1	1	1	1	1	1
	??? 10658374	1	1	0	1	0	1	1	1	1	1	1	1
	10548074 ??	1	1	0	1	0	1	1	1	1	1	1	1
	Retainer, 400mm Bearing Op30	1	1	0	1	0	1	1	1	1	1	1	1
	10548074 ??	1	1	0	1	0	1	1	1	1	1	1	1
	Retainer, 400mm Bearing Op30	1	1	0	1	0	1	1	1	1	1	1	1
	Roller Holder Mach Assem Op15B	1	1	0	1	0	1	1	1	1	1	1	1
	Roller Holder Mach. Assem Op15A	1	1	0	1	0	1	1	1	1	1	1	1
	Roller Holder Mach Assem Op15B	1	1	0	1	0	1	1	1	1	1	1	1
	Roller Holder Mach. Assem Op15A	1	1	0	1	0	1	1	1	1	1	1	1
	Roller Holder Mach Assem Op15B	1	1	0	1	0	1	1	1	1	1	1	1
	Roller Holder Mach. Assem Op15A	1	1	0	1	0	1	1	1	1	1	1	1
	Pinch RH Assem Op10	1	1	0	1	0	1	1	1	1	1	1	1
	Pinch RH Assem Op10	1	1	0	1	0	1	1	1	1	1	1	1
Changeover Confirmation Matrix:	Transition 1	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 2	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 3	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 4	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 5	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 6	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 7	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 8	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 9	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 10	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 11	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 12	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 13	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 14	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 15	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 16	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 17	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 18	0	0	0	0	0	0	0	0	0	0	0	0
	Transition 19	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL CHANGEOVERS:	0												

Appendix C: Instruction Sheet to use Linear Programming Model



HMC6 Changeover Model Instructions & Assistance

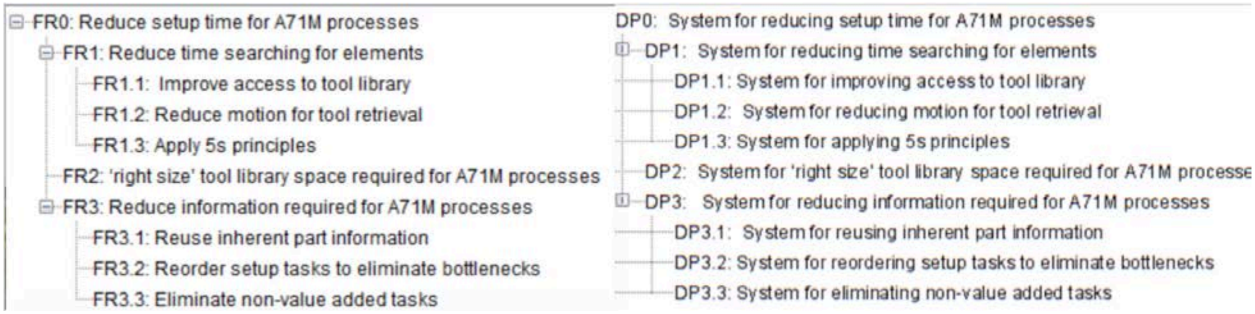
Initial Advice: The model is very easy to use, simply utilizing basic Excel commands like Copy + Paste, and the occasional insert row/column. Do not be intimidated by the multitude of matrices in the model, the user will use only the first 2. The rest are for the functionality of the matrix and will be populated and managed by the model.

Preliminary Steps:

1. Download and initiate the OpenSolver Excel add-in. Freeware available for download with instructions to install at: https://opensolver.org/installing-opensolver/
2. Open the model file "HMC6 Changeover Tool" in Excel, with OpenSolver active in the Excel window. The following buttons will be displayed in the top right corner under the "Data" tab if OpenSolver is active:

Note: Initially, it may be required to first open the OpenSolver.xlam file located in the OpenSolver folder to make OpenSolver active, then File>Open "HMC6 Changeover Tool" to be able to use the model. Though, there are instructions in the above link to make OpenSolver permanently active when Excel opens (recommended).

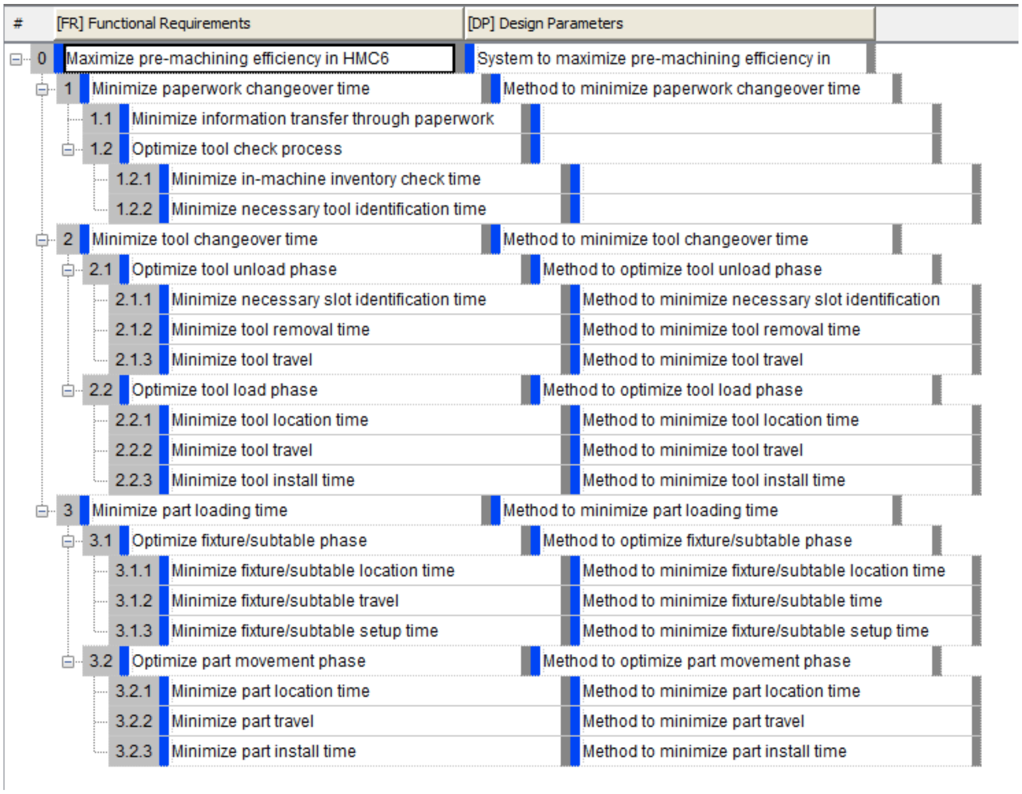
Appendix D: A71M Axiomatic Design



- FR0: Reduce setup time for A71M processes
  - FR1: Reduce time searching for elements
    - FR1.1: Improve access to tool library
    - FR1.2: Reduce motion for tool retrieval
    - FR1.3: Apply 5s principles
  - FR2: 'right size' tool library space required for A71M processes
  - FR3: Reduce information required for A71M processes
    - FR3.1: Reuse inherent part information
    - FR3.2: Reorder setup tasks to eliminate bottlenecks
    - FR3.3: Eliminate non-value added tasks

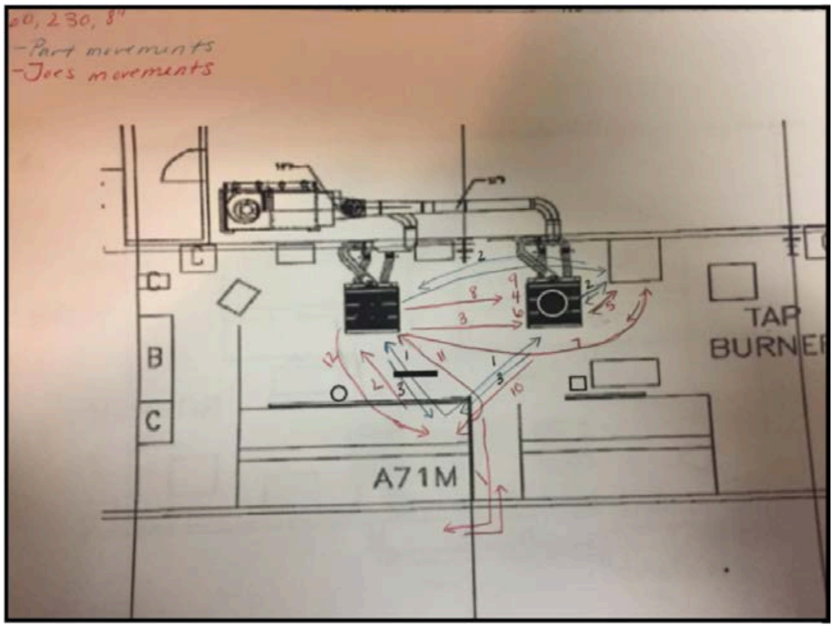
- DP0: System for reducing setup time for A71M processes
  - DP1: System for reducing time searching for elements
    - DP1.1: System for improving access to tool library
    - DP1.2: System for reducing motion for tool retrieval
    - DP1.3: System for applying 5s principles
  - DP2: System for 'right size' tool library space required for A71M processe
  - DP3: System for reducing information required for A71M processes
    - DP3.1: System for reusing inherent part information
    - DP3.2: System for reordering setup tasks to eliminate bottlenecks
    - DP3.3: System for eliminating non-value added tasks

Appendix E: HMC6 Axiomatic Design



#	[FR] Functional Requirements	[DP] Design Parameters
0	Maximize pre-machining efficiency in HMC6	System to maximize pre-machining efficiency in
1	Minimize paperwork changeover time	Method to minimize paperwork changeover time
1.1	Minimize information transfer through paperwork	
1.2	Optimize tool check process	
1.2.1	Minimize in-machine inventory check time	
1.2.2	Minimize necessary tool identification time	
2	Minimize tool changeover time	Method to minimize tool changeover time
2.1	Optimize tool unload phase	Method to optimize tool unload phase
2.1.1	Minimize necessary slot identification time	Method to minimize necessary slot identification
2.1.2	Minimize tool removal time	Method to minimize tool removal time
2.1.3	Minimize tool travel	Method to minimize tool travel
2.2	Optimize tool load phase	Method to optimize tool load phase
2.2.1	Minimize tool location time	Method to minimize tool location time
2.2.2	Minimize tool travel	Method to minimize tool travel
2.2.3	Minimize tool install time	Method to minimize tool install time
3	Minimize part loading time	Method to minimize part loading time
3.1	Optimize fixture/subtable phase	Method to optimize fixture/subtable phase
3.1.1	Minimize fixture/subtable location time	Method to minimize fixture/subtable location time
3.1.2	Minimize fixture/subtable travel	Method to minimize fixture/subtable time
3.1.3	Minimize fixture/subtable setup time	Method to minimize fixture/subtable setup time
3.2	Optimize part movement phase	Method to optimize part movement phase
3.2.1	Minimize part location time	Method to minimize part location time
3.2.2	Minimize part travel	Method to minimize part travel
3.2.3	Minimize part install time	Method to minimize part install time

Appendix F: Spaghetti Diagram



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