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Great South Metals: Slitter Head Building Process

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Executive Summary

Great South Metals (GSM) operates two steel slitter machines, which take large coils of flat rolled steel and cut them into smaller strips for use in customers' applications. Setting up the working components of each machine, called the slitter head, is a precise and arduous task. This system relies on several manually performed calculations and acute attention to detail; and thus, is prone to human error. The management at GSM commissioned our team to simplify the slitter head assembly process by creating an automated computer program and make additional recommendations to improve their operations.

The program we created is a macro-based Microsoft Excel spreadsheet that accepts the customer's desired widths of cut and outputs a printable picklist of the required tooling and shim sizes for the job. This tool reduces the time required to calculate the required tooling by ten minutes or more. Additionally, the calculator is one hundred percent accurate in its calculations. This spreadsheet utilizes a graphical user interface for improved user experience, boosting adoption by GSM employees.

Though the calculator removes defects in determining the tooling required for a job, selecting and installing individual tooling components that are themselves unlabeled and stored on disorganized racks presents another opportunity for improvement. Based on the concept of Poka Yoke, our team designed custom 3D printed end caps for the existing racks that have clear labels and include features to help determine the size of components to reduce the likelihood of an operator selecting incorrect components. These end caps help ensure pieces are returned to their correct location and the user selects the correct size when building out a slitter head.

Recognizing that a cluttered and dirty workspace can hinder performance, our team utilized 5S methodology to recommend several improvements to GSM work centers. Old tooling components are stored near active ones, tooling components and hand tools are not well organized, there's lots of clutter around the work areas, and dirty shims and machines are difficult to work with. Cleanliness and organization standards should be implemented and sustained to improve efficiency.

Lastly, our team performed an ergonomic analysis on the 48-inch line and recommends changes to the current station layout. Relocating the shim storage rack and rotating the tooling rack to reduce bending and twisting movements for the operator. These changes can reduce the risk of repetitive motion injuries for operators and reduce fatigue, reducing the likelihood of mistakes in the head-building process.

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Chapter 1: Background and Overview

1.1 Introduction

Team MetalWorks worked with Great South Metals (GSM) to improve their slitter head assembly process. Through site visits and the utilization of various system evaluation methods, our team provided GSM with thorough system improvement ideas. As for the system itself, there are two steel slitters at GSM (a 60-inch and 48-inch machine) that make up part of the slitter head assembly process. The slitters precisely cut large rolls of steel into thinner strips as ordered by customers. The slitter heads, which do the actual cutting, are set up specifically for each order. Assembling the heads requires great attention to detail and is a very time-consuming process. The entire process, including important calculations, is done manually. The team's goal is to increase the efficiency and precision of the slitter head assembly process. Our team engaged in valuable conversations with GSM employees and gained a better understanding of the slitter head assembly process. We created multiple solutions through our site visits and provided suggestions for improvements during each step of the assembly process.

1.2 Overview

Each cut width requires a "male" knife configuration on one arbor and a "female" knife configuration on the other. The spacers on the female side are equal to the nominal dimension of the customer's required cut width. The spacers on the male arbor must account for the width of the cutting knives as well a small offset to ensure the blades do not contact each other. The size of that offset can vary depending on the gauge of the steel being cut. Currently, cut width calculations are done by the employees on pen and paper with a four-function calculator. Since GSM can make cuts of any width that will fit in the machine, the calculations involve fractions and small numbers that become tedious to compute in a fast-paced work environment. Due to the manual nature of the current process, there have been issues with the precision and consistency of the cuts. GSM also has concerns about the time this process takes and wants a quicker, more accurate process implemented.

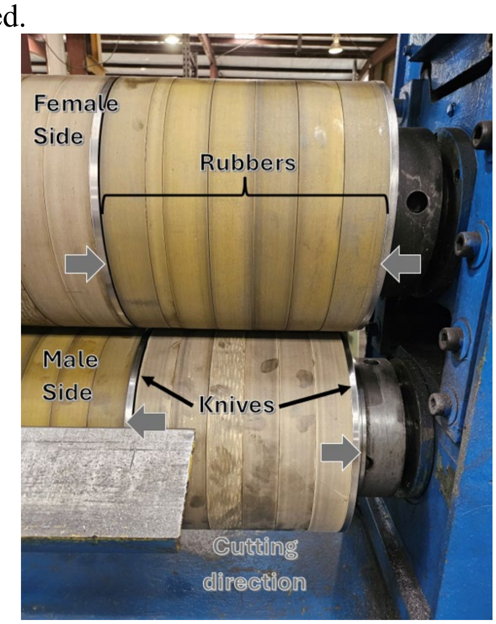


Figure 1: Annotated image of tooling installed on slitter head

1.3 Objective

The overall goal of our work with GSM is two-pronged. In an effort to simplify some of the calculation process, our team developed a simple computer-based calculator that will aid the head builders in completing calculations more efficiently and precisely. However, the head assembly process could also be improved through other measures such as a change in the job set up and the introduction of new equipment. With this in mind, our team explored other process improvement options and outlined their consequences. We had a variety of researched system improvement suggestions to present to GSM along with the requested advancements in their calculation process.

1.4 Justification

The current slitter head assembly process is completely manual and extremely tedious. Since the assembly of the heads requires a lot of fractional math, it can be difficult and is prone to more mistakes. Mistakes in calculations during the assembly process could result in inaccurate cuts and delays in the operation. These defects and delays cost the company time and money, so creating a system that takes out the factor of human error in the calculation process would be incredibly beneficial. In addition to the calculator, being able to streamline the overall assembly process through other system updates could reduce the time spent on each order and allow them to process more orders each day.

1.5 Project Background

GSM is an Acworth based steel processor specializing in flat rolled steel processing, typically fulfilling orders for rolls of steel strips that are cut to customer specifications. Customers can order steel in different widths and gauges, as well as specify tolerances that GSM needs to adhere to. GSM is over 40 years old but has only adapted computerization into their workflows in the last two years. As such, they are now looking for ways to optimize their processes with computers on the shop floor. The foremost process they want to optimize to optimize is slitter head assembly. Time-consuming calculations and human error resulting in reworks are the main things they want to counteract. In their project charter, GSM listed roadblocks to the project. Tedious mathematical calculations are inherent to the head building process. Compatibility with our proposed solutions with the existing systems and machinery, some of which are over half a century old, is another roadblock. Employee adoption of our solutions is an active concern as well. Last, and most important, they listed limited historical data on the assembly process as something that could inhibit progress. Our team is worked with little data, especially regarding defects in the assembly process, which are not recorded when they occur.

Among the list of expectations and goals set out by GSM in the project charter, there are a few key points that our team focused on: Analyzing the head building process and developing a tool to assist in in the selection of knives, reducing manual errors and time spent assembling heads, and cost-effectiveness and scalability of proposed solution.

1.6 Problem Statement

GSM is seeking a robust solution to the tedium and rework issues plaguing their slitter head building process. Our team's goal is to create a calculator to remove some of the human errors from this process, with the end goal of supplying GSM with a scalable head building method that is more efficient than their current procedure and exhibits high employee adoption.

Chapter 2: Literature Review

2.1 Computational Model for Decision-Making

This article looked at the assembly of something much smaller and simpler—a paper airplane. The increase was measured by defining a gain, a ratio between flight performances. A model was built that would monitor errors when the planes were developed and compare the gain of all the airplanes. The overall study showed the significance of a predictive generated model since it can perform well on processes with no "set solution".[1]

2.2 Scan-Based Hierarchical Heuristic Optimization Algorithm for PCB Assembly Process

The study looked at the mounting process for a beam head placement machine. It broke the process into three tiers. Some of the major points it talked about optimizing was combining similar tasks, such as nozzle pickups and head motion combinations. The paper focused on the importance of scheduling within a complex system with complicated constraints. The paper delved into the MIP formulated with its constraints and decision variables. Overall, the study decreased the need to frequently change the nozzle change while also increasing the number of pickups in the PCB assembly process.[2]

2.3 Cash, receivables and inventory management practices in small enterprises

The article looked at a measurable success criterion: financial performance. The three influences affecting financial performance that were studied were cash, receivables, and inventory management. The study found a correlation between financial performance and inventory management, albeit a weak one. However, it stated that a good functioning inventory management system in a small or medium sized company would reflect with higher financial performance.[3]

2.4 Degradation Mechanisms of Epoxy Molding Compound Subjected to High Temperature Long Term Aging

The study looked at the demand for high reliability electronic components. While the study looked at several different aspects, the pertinent information is the relationship between the high temperature aging with both the storage modulus and loss modulus. The epoxy showed degradation at high temperatures, accelerating in degradation after forty days of sustained use. The temperatures used were 100 and 150 degrees Celsius.[4]

2.5 Influences of shim stiffness on the vibration response of tool-shim system and the impact fracture resistance of cutting tool in intermittent cutting

The study looked specifically at the mechanical impact during an industrial cutting process. The shims tested were made of four materials: aluminum alloy, titanium alloy, steel, and cemented carbide. The study found that stiffness has a significant impact on fracture resistance of blade and tooling. Reducing the stiffness improved the tool's damage resistance.[5]

2.6 Inventory management and TQM practices for better firm performance: a systematic and bibliometric review

A comprehensive literature review that focused more on storefront inventory management. The study emphasized the importance of inventory management in a storefront setting, but it did not necessarily translate to a manufacturing setting. They noted a weak correlation between profit and inventory management but also acknowledged that there is a shortfall of data. They recommended future studies to expand.[6]

2.7 Investigation of chatter dynamics in face milling tool using different shim material by amplitude ratio method and ANOVA

The experiment is designed to see how five different shim materials affect high cutting speed for various processes (milling, drilling, boring). The experiment saw if the shim material is affected by external stimuli (chatter) and measured the Amplitude ratio—a metric to verify the steadiness of a task. The overall goal was to decrease the vibration and chatter in the process.[7]

2.8 Navigating a Robotic Future

This article explained how automation can be used to compensate for skilled labor. Despite the upfront cost, the ROI small confectionaries have seen since implementation has justified the cost. They are more reliable and consistent. Additionally, there is less training needed for the workers, making positions more accessible. They also pointed out that implementing new technology attracts a younger and more productive workforce.[8]

2.9 Robust Optimization for U—shaped assembly line worker assignment and balancing problem with uncertain task times

The study began by explaining how uncertainty in the assembly line can be addressed by robust optimization. The model made for the study focused on worst-case scenarios. The uncertainty that the model accounted for is from variable time to complete tasks in the assembly line. The line is treated as a mixed integer problem and aimed to minimize the total number of workstations required. The model was applied to a water meter producing company, but the model has been left open for adjustments so it can be applied to other production lines.[9]

2.10 The impact of information sharing and inventory management practices on firms' performance in supply chain practices

The study emphasized the importance of information sharing. Doing so leads to better inventory management which leads to better firm performance. This practice can streamline orders, reduce costs, improve customer service, and enhance the supply chain. Information sharing also influenced the roles of many parts of an organization, from corporate executives to material management and production selection.[10]

2.11 Wear Performance of Circular Shim against Cam in Engine Bench Test

This study looked at shim performance and reliability over a 1000-hour benchmark. Throughout the test, the study measured shim weight loss and deformation. These deformations manifested as pits and material spalling on the shims. Over time, this led to fatigue and inaccuracies within the shim. The study acknowledged that the weight loss of the shims was used as a convenient wear measurement technique and that sometimes more advanced/sophisticated metrics need to be used.[11]

2.12 Kloeckner Metals Corporation

This article about upgrading metal slitter equipment involved considering gauge capabilities, the need for new equipment, cost-effectiveness, benefits of automation, and safety advancements. These factors determined the long-term cost-effectiveness of such upgrades. Metal slitter equipment cuts sheet metal into narrower widths based on customer requirements. At Kloeckner Metals Corporation's facility in Tulsa, Oklahoma, metal slitter equipment's operational process and capabilities are highlighted. Factors influencing equipment upgrades included gauge capabilities, customer demands, efficiency, throughput, automation, and safety considerations. Upgrades were driven by market expansion opportunities, allowing companies like Great South Metals (GSM) to serve a wider range of customers and applications, improving product quality control and increasing business opportunities. Upgrading to meet specific gauge requirements leads to a higher ROI by improving efficiency, lowering costs, and opening new markets. Advances in technology have improved equipment efficiency and throughput, resulting in reduced labor hours and increased capacity. Greater automation, though beneficial, requires careful evaluation of cost-effectiveness and safety measures. In summary, insights from studying equipment upgrades focuses on the objectives of the GSM project, emphasizing automation, efficiency improvements, and safety considerations to enhance operations.[12]

2.13 Electronic Drives and Controls

EDC provided insights into common issues with slitting machines in the metals industry, emphasizing slow setup times and legacy control systems' challenges. Automated recipe management and retrofit options are highlighted to improve efficiency. GSM's implementation of automated systems could reduce setup time, enhance consistency, and boost production throughput. Legacy control systems pose reliability and downtime issues for GSM due to outdated equipment. Evaluating retrofit solutions can mitigate risks and enhance operational efficiency, though initial investment may deter smaller companies like GSM. Despite upfront costs, retrofitting offers long-term benefits such as increased productivity and reduced maintenance. Aligning with GSM's objectives, addressing slitting machine challenges through automation and retrofitting can improve efficiency and productivity.[13]

2.14 Fagor Arrasate

This article about Fagor Arrastate introduced automatic separators for slitting lines, focusing on productivity and reliability in steel processing. The system, aimed at reducing changeover times between coils, offered advantages such as improved Overall Equipment Effectiveness (OEE), reduced operator hours, enhanced safety, precise positioning, and minimized damage to slit edges. Although implementation may be unrealistic for smaller companies like GSM due to cost constraints, the technology promises increased productivity and minimized downtime. Fagor Arrasate's separators, installed in various slitting line brands worldwide, have successfully modernized and automated several lines, demonstrating effectiveness and versatility. However, GSM faces challenges with manual labor and organization in slitter head assembly, hindering efficiency. Implementing similar automation aligns with GSM's objectives of reducing errors and improving efficiency in the assembly process.[14]

Chapter 3: Problem Definition

3.1 Explored Solutions

To meet precise width requirements on work orders, GSM uses shims between the spacers that range from 2 thousandths of an inch to 5 hundredths. Currently, their shims are made of a flexible plastic, which can melt or tear due to heat. Under normal conditions, the shims do not melt, but when the rubbers get worn out, they stretch and generate more heat than the plastic can tolerate. GSM reported that they tried Teflon shims, but they were destroyed and covered the arbors with residue. Our literature review was unable to identify a more suitable material. With the price of replacement shims being around $2,000, it could be cheaper for GSM to simply replace their plastic shims than use a different material. Another consideration with shims is custom ordering widths, as there are some odd widths that use two shims together to reach a specified width for the spacers. Custom ordering would be more expensive but could save time on the assembly process by reducing fractional calculations for shimming.

A toolless setup, which would be ordering metal spacers to exactly fit order dimensions, would save GSM the most time on head assembly by simplifying the process down to very few components. However, this setup is very cost prohibitive; it would be at least half a million dollars according to GSM.

Another idea was to build a database of pick lists for commonly ordered sizes. The operator or production planner would use a set of components that was already calculated and set up for a previous order. This would improve consistency between orders, ensuring the same set of metals, rubbers, and shims are used for that cut every time. It would also eliminate the time needed to calculate the components required after the first time using it. One drawback is that after the project is completed, it is unlikely that anyone would maintain or grow the database.

Additionally, there is a lot of variation in ordered sizes and the thickness of sheet metal, so there are many possible combinations that would need to be stored and easily searched.
After exploring these different options, Team MetalWorks decided to create a PC-based calculator to determine the optimum component configuration for each cut in the work order. Given the width of cut, quantity of cuts, and coil thickness, the calculator will automatically output which size spacers and rubbers are required for the job. Also, it could keep track of which components have been used and provide alternative component lists if there are too few of a given size to complete an order. Tables 1 through 4 review the different solutions and breakdown the selection process and criteria via TOPSIS.

Tables 1-4: TOPSIS Breakdown

DATA MATRIX

	Effectiveness	Employee Adoption	Implementation	Price
Calculator	9	5	9	$1,400
Template Setup	3	3	3	$3,000
Toolless Setup	9	7	7	$500,000
Head Database	3	3	3	$1,400

CRITERIA WEIGHTS

	Effectiveness	Employee Adoption	Implementation	Price
Raw Weight	5	7.5	4.5	9.33
Weights	0.190	0.285	0.171	0.354

WEIGHTED DATA MATRIX

	Effectiveness	Employee Adoption	Implementation	Price
Calculator	0.1274	0.1485	0.1264	0.0010
Template Setup	0.0425	0.0891	0.0421	0.0021
Toolless Setup	0.1274	0.2079	0.0983	0.3543
Head Database	0.0425	0.0891	0.0421	0.0010

FINAL RANKING

	Closeness to Ideal
Calculator	0.864132
Template Setup	0.676263
Toolless Setup	0.306235
Head Database	0.676971

3.2 Calculator Requirements

1. User Interface
   a. The calculator shall be bilingual (English and Spanish)
   b. The calculator shall have a graphical user interface.

2. Calculator Outputs
   a. The output shall be printable.
   b. The output screen shall detect errors and alert the user.
   c. The output screen shall advise the operator to check blade-to-blade clearances during the head building process.
   d. The output shall contain a pick list of required blades and rubbers.
   e. The output shall contain the Date and Time that it was generated.
   f. The output shall contain the Work Order number it was generated for.
   g. The output shall not recommend blade or rubber sizes that are already used in the build.

3. Calculator Inputs
   a. Slitter head selection shall use a drop down or similar system to restrict user inputs where relevant.
   b. Cut size entry shall be a continuous variable.
   c. The calculator shall require a work order number.

3.3 Minimum Success Criteria

There are five main points that Great South Metals listed as their goals. One of the goals is a reduction of the time and human error when assembling the slitter head. Another goal is to increase the precision of the slitter head assembly process. This leads into one of their larger goals of having an automated method for selecting the knives and rubbers required for a specific work order. To be successful in this goal, our team will be working to create a simple and cost-effective calculator to introduce automation to GSM's processes. The fourth goal is to receive positive feedback from the employees indicating that the process has been made more efficient and easier to do. The final goal is that the proposed solution is easily implementable.

3.4 Verification Plan

Before implementing the calculator on the shop floor, we used the calculator ourselves to ensure that the program is accurately performing calculations. Once the initial prototype calculator is ready, we plan to implement and collect feedback from the slitter head building employees. This feedback will guide further edits to our calculator. Additionally, post implementation time studies will need to be conducted to measure the effectiveness of the system adjustments by comparing them to the time studies conducted at the beginning of the project.

3.6 Schedule

The project schedule, shown in the below Gantt chart, includes each design review date as well as the required tasks in between to reach completion.

Task name	Stard date	End date	Progress	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 8	WEEK 9	WEEK 10	WEEK 11	WEEK 12	WEEK 13	WEEK 14	WEEK 15	WEEK 16
Initial Design	1/10/2024	1/10/2024	100%																
Form Group	1/11/2024	1/11/2024	100%																
Select Project	1/11/2024	1/11/2024	100%																
Site Visits	1/17/2024	1/22/2024	100%																
IDR	1/25/2024	1/25/2024	100%																
Preliminary Design	1/25/2024	1/25/2024	100%																
Data Collection	1/25/2024	2/6/2024	100%																
Analyze Solutions	2/7/2024	2/17/2024	100%																
Define Scope	2/16/2024	2/20/2024	100%																
Literature Study	2/17/2024	2/20/2024	100%																
PDR	2/21/2024	2/21/2024	100%																
Intermediate Design	2/22/2024	2/22/2024	100%																
Calculator Data Gathering	2/22/2024	3/10/2024	100%																
Spring Break	3/13/2024	3/16/2024	100%																
Cost Analysis	3/26/2024	3/26/2024	100%																
5S/Poka Yoke	3/19/2024	3/27/2024	100%																
Work Order Time Study	3/24/2024	3/27/2024	100%																
IPR	3/24/2024	3/27/2024	100%																
Critical Design	3/28/2024	3/28/2024	100%																
Prototype Calculator Done	3/28/2024	4/1/2024	100%																
Print Endcaps	3/28/2024	4/9/2024	100%																
Evaluate Progress	4/6/2024	4/12/2024	100%																
CDR	4/17/2024	4/17/2024	100%																
Final Design	4/19/2024	4/19/2024	100%																
Calculator Completion	4/19/2024	4/26/2024	100%																
Revised Endcaps	4/19/2024	4/19/2024	100%																
5S Complete	4/19/2024	4/19/2024	100%																
Cost-Savings Analysis	4/21/2024	4/23/2024	100%																
Finalize Shop Layout	4/21/2024	4/23/2024	100%																
Senior Design Expo	4/29/2024	4/29/2024	100%																
Make Video	4/30/2024	5/1/2024	100%																
Submit Final Report	5/1/2024	5/1/2024	100%																

Figure 2: Full 16-week project schedule

3.7 Budget

Based on the average salary for similar engineering positions, we expect that the hourly cost of our work would be $45. Initially, labor hours were projected to 450 hours, which, at the given rate, would cost GSM $20,250. The team ended the project with 421 recorded hours, meaning that we were able to write up our margin to 14%.

Contingency, as seen in the full cost analysis table below, was calculated as 10% of the total projected cost. Other costs include Microsoft 365, 2 laser printers for printing calculator output on the shop floor, a MATLAB subscription, and labeled 3D printed caps. The cost for endcaps was based on a quote from a custom 3D printing company. The total cost breakdown is shown in Table 6.

		Labor			Materials		Fixed				BALANCE
		Planned Hours	Actual Hours	$/HR	UNITS	$/UNITS	Travel	Equipment	BUDGETED	ACTUAL	UNDER/OVER
Project Tasks	**Assigned To:**								$27,611.00	$23,755.77	$ 3,855.23
Project Management	Evan Swierski	50.0	48.0	$45.00				$50.00	2,300.00	2,210.00	90.00
Project Coordination/5S	Raven Morin	50.0	51.0	$45.00				$50.00	2,300.00	2,345.00	(45.00)
Programming	Nabhan Karim	50.0	60.0	$45.00				$1,030.00	3,280.00	3,730.00	(450.00)
CAD	Patrick Kelsey	50.0	42.0	$45.00				$50.00	2,300.00	1,940.00	360.00
Research/Shop Layout	Michael Williams	50.0	40.0	$45.00				$50.00	2,300.00	1,850.00	450.00
Combined Effort	All	200.0	180.0	$45.00			$1,278.0		10,278.00	9,378.00	900.00
Laser Printers					2.0	$175.00			350.00	350.00	-
(132) Printed Endcaps					1.0	$1,952.77			1,952.77	1,952.77	-
Contingency									2,550.00	-	2,550.00
									-	-	-
SUBTOTAL		450.0	421.0	$18,945.00		$2,129.77	1,278.00		27,610.77	23,755.77	3,855.00

Table 5: Final Budget updated to reflect labor costs as of 4/15.

Equipment cost refers to the cost of buying Microsoft Excel for all members and MATLAB Standard for Nabhan. Travel Cost was calculated based on the distance from GSM to Kennesaw State's Marietta Campus.

Real-world engineering consultants would charge a fee for their services in addition to billing the customer for their services. The team chose a 10% fee, which brings the total projected revenue of the project to $30,372 (Table 7).

Table 6: Projected and actual revenue with an added 10% fee, with revenue before and after markup.

	Projected	Actual
Revenue:	$27,611	$23,756
10% Margin	$2,761.10	$2,375.58
Total	$30,372	$26,131

3.8 Available Resources

The team's primary resource was access to Great South Metals' employees and facility. The machine operators have decades of combined experience that MetalWorks can leverage to develop new tools and processes. During the project, team members will be onsite observing plant activity and gathering data on the head building and exchange processes.
The head builder calculator and any new processes will utilize existing IT and mechanical infrastructure at the plant wherever possible; an objective of the project is to minimize additional capital expenditures.

Chapter 4: Tooling Selection Calculator

Calculations are currently done by hand for each order placed with GSM. When meeting with GSM's plant foreman, he indicated that one of the major bottlenecks during the head assembly process was calculation stage. He also pointed out that each head builder had their own method of completing the calculations prior to head building. GSM's management indicated they were interested in a calculator that would standardize the process, reduce errors during the process, expedite the building process, and have a low implementation cost.

4.1 Initial Observations

We began by talking to the individual head builders to hear their thoughts on the current process. We were mainly concerned with their calculation process and anything they would prefer to see in an automated process. Currently, a head builder will write each unique cut on an order down. They will then create a T-table for the female and male cuts. They continuously subtract available metal and shim sizes until they reach a remainder of length that is less than 0.005 inches.

Their main concern with the process was the complexity when dealing with fractional remainders. Keeping the fractional amounts straight can become tedious and, as their shifts continue, they are more likely to make a mistake. They also indicated that dealing with the fractional remainders could be a reason that other employees are unwilling to train to be head builders. We saw confirmation that heads built towards the end of a shift were more likely to have a measured inaccuracy. Since an inaccuracy cannot be measured until the head is installed, these mistakes were not caught until the slitting process began. The time it takes for the mistake to be corrected depends on both the mistake's location and the severity of the miscalculation on the head.

4.2 Time Study

A requirement we set for the calculator was to expedite the calculation time while remaining accurate. In order to measure this, we collected the time needed to complete calculations on both the 48-inch and 60-inch slitter. Thirty measurements for each head were collected. We then found the average amount of time it takes on an individual cut. On the 48-inch, the average time found per cut was 72.47 seconds. On the 60-inch, the average time found per cut was 69.37 seconds. Since each order has a minimum of two cuts and could have up to ten cuts, calculations for an entire order can range anywhere from two to ten minutes, regardless of the machine.

4.3 Calculation Logic

The automated calculator is designed to minimize the total number of metals and shims required for each cut on both the female and male side. The cut size provided on an order form is the measurement for the female side. An order form also includes the gauge of the steel coil that will be used. The gauges used to find the offset on the male side. Gauges between 0.0100 and 0.0199 inches have an offset of 0.481 inches; gauges between 0.0200 and 0.0299 inches have an offset of 0.482 inches; gauges between 0.0300 and 0.0399 inches have an offset of 0.483 inches;

gauges between 0.0400 and 0.0499 inches have an offset of 0.484 inches; and gauges between 0.0500 and 0.0599 inches have an offset of 0.485 inches. The male side measurement is found by subtracting the offset value from the ordered cut size. Notably: the male side's value will always be less than the female side's value.

Each side will have a unique number of metals and shims needed for the calculated cut side. The process to find the quantity of pieces required is the same regardless of being a female or male side. With the cut size, we subtract the largest metal size that won't result in a negative value (i.e. a 6-inch spacer cannot be used on a cut size of 4 inches). This process starts with the largest spacer size that could be used and then decreases the sizes as necessary until within the acceptable tolerance range (0.005 inches). Once completed for one side, the process repeats for the other side.

To go through a calculation, let's have a hypothetical order for a 11.463 inch cut on 0.0274-inch gauge. The offset for the male side will be 0.482 inches, meaning that the female side will need to be 11.463 inches and the male side will need to be 10.981 inches. Next, focusing on the female side, the largest available spacer that can be used is 6-inches. Subtracting that from the female side, 5.463 inches remain. Since 6-inches is too large for this remainder, the next size that can be used is 4-inches. Subtracting that leaves 1.463 inches. The next spacer that can be used is the 1-inch, leaving 0.463 inches. The next largest spacer that can be used is 0.250 inches, leaving a remainder of 0.213 inches. Then a 0.125-inch spacer is used followed by a .0625-inch spacer. The remaining 0.0255 inches need to be made up by the available shims. The same process is used, starting with the largest usable shim, 0.02 inches in this case, and subtracting that from the remainder. The remaining 0.0055 inches can be accounted for with a 0.005-inch shim. This leaves 0.0005-inches as the remaining cut, which is well within the 0.005-inch tolerance. For the female side, that gives a final metal count of one 6-inch spacer, one 4-inch spacer, one 1-inch spacer, one 0.250-inch spacer, one 0.125-inch spacer, one 0.0625-inch spacer, one 0.02-inch shim, and one 0.005-inch shim.

This process has to be repeated for the male side again. Following the same process, we start with 10.981-inches and get remainders of 4.981-inches, 0.981-inches, 0.231-inches, 0.106-inches, 0.0435-inches, 0.0035-inches, and finally 0.0005-inches. The corresponding spacers and shims are one 6-inch spacer, one 4-inch spacer, one 0.75-inch spacer, one 0.125-inch spacer, one 0.0625-inch spacer, one 0.04-inch shim, and one 0.003-inch shim. Once again, the remaining 0.0005 inches is within the allowed tolerance. Table 5 shows the process.

Table 7: Sample T-Table

Female	**Male**
11.463	**10.981**
-6 (5.463)	-6 (4.981)
-4 (1.463)	-4 (0.981)
-1 (0.463)	-0.75 (0.231)
-0.25 (0.213)	-0.125 (0.106)
-0.125 (0.088)	-0.0625 (0.0435)
-0.0625 (0.0255)	-0.04 (0.0035)
-0.02 (0.0055)	-0.003 (0.0005)
-0.005 (0.0005)	
Remainder: 0.0005	Remainder: 0.0005

4.4 MATLAB Prototype:

The first calculator developed was in MATLAB to optimize calculations done in arrays. The program requires two inputs from the user. The first prompt asks for the length of the cut in inches. This input is stored as the variable "femaleCutSize." The second prompt requests for the offset amount, also in inches. The program subtracts the "offset" value from the "femaleCutSize" variable and stores that value as the variable "maleCutSize." The program then creates three arrays. The first array contains every spacer and shim variant, a total of 21 elements. This array is stored as the variable "metalSizes." The other two arrays each have lengths of 21, corresponding to each spacer and shim size. Every element in each of these arrays has a value of 0 and are named "femaleMetalCount" and "maleMetalCount."

With all the variables initialized, the program begins an iterative process similar to the manual process. Using a while loop, the program begins with the first element in both "femaleMetalCount" and "metalSizes." One is added to the first element in "femaleMetalCount." This is then multiplied by the first element in "metalSize." Finally, this value is subtracted from "femaleCutSize" and stored as the variable "cutnew." "cutnew" is then logically evaluated. If "cutnew" is less than zero, this means that the most recently added spacer is too big for "femaleCutSize." The index is increased by one so the process can repeat for the next spacer or shim. If "cutnew" is greater than or equal to zero, then "femaleCutSize" is assigned the same value as "cutnew." The index is not increased in this case because there is a possibility another spacer or shim of the same size can be used. The process repeats until "cutnew" is a negative value before increasing the index. This process is shown in Table 6.

Once the loop completes its cycle, the array "femaleMetalCount" has been filled out with at least one in every single element. Since the loop never subtracted the extra piece that was added to each element, a for-loop iterates through every single element in "femaleMetalCount" and subtracts one. This gives an accurate array with the total number of each spacer and shim needed for the female side.

The program repeats this process for the variable "maleCutSize" using the "maleMetalCount" array. Once this process is completed, there are two arrays with the number of metals and shims needed for both the female and male side. The program exports these two arrays to a notepad file so it can then be printed and taken to the floor. Table 7 shows the propagation of the script for the female side of one cut.

Table 8: MATLAB Process

User Input: femaleCutSize = 11.463 offset = 0.482
Derived Input: maleCutSize = 10.981
Program Initiated Variables: metalSizes = [6, 4, 3, 2, 1, 0.75, 0.625, 0.5, 0.25, 0.125, 0.0625, 0.05, 0.04, 0.03, 0.02, 0.015, 0.01, 0.005, 0.004, 0.003, 0.002] femaleMetalCount = [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0] maleMetalCount = [0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]
Loop Logic (False): Index = 1 While Index < length(metalSizes): (1 < 21) femaleMetalCount(Index) = femaleMetalCount(Index) + 1: ([1, 0, 0, ..., 0]) cutNew = femaleCutSize – metalSize(Index): (11.463 - 6 = 5.463) if cutNew < 0: (5.463 ~< 0) Index = Index + 1 (False)
Loop Logic (True): While Index < length(metalSizes): (1 < 21) femaleMetalCount(Index) = femaleMetalCount(Index) + 1 : ([2, 0, 0, ..., 0]) cutNew = femaleCutSize – metalSize(Index) (5.463 - 6 = -1.463) if cutNew < 0: (-1.463 < 0) Index = Index + 1: (True: 2 = 1 + 1)

Table 9: Propagation of Female Metal Count Loop—MATLAB backend

Female Metal Count	Spacer/Shim Size	Cut New
[0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	-	11.463
[1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	6	5.463
[2, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	6	-0.537
[2, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	4	1.463
[2, 2, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	4	-2.537
[2, 2, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	3	-1.537
[2, 2, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	2	-0.537
[2, 2, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	1	0.537
[2, 2, 1, 1, 2, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	1	-0.537
[2, 2, 1, 1, 2, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	0.75	-0.287
[2, 2, 1, 1, 2, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	0.5	-0.037
[2, 2, 1, 1, 2, 1, 2, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	0.5	0.213
[2, 2, 1, 1, 2, 1, 2, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	0.25	-0.037
[2, 2, 1, 1, 2, 1, 2, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	0.125	0.088
[2, 2, 1, 1, 2, 1, 2, 1, 2, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	0.125	-0.037
[2, 2, 1, 1, 2, 1, 2, 1, 2, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	0.0625	0.0255
[2, 2, 1, 1, 2, 1, 2, 1, 2, 2, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0]	0.0625	-0.037
[2, 2, 1, 1, 2, 1, 2, 1, 2, 2, 1, 0, 0, 0, 0, 0, 0, 0, 0, 0]	0.05	-0.0245
[2, 2, 1, 1, 2, 1, 2, 1, 2, 2, 1, 1, 0, 0, 0, 0, 0, 0, 0, 0]	0.04	-0.0145
[2, 2, 1, 1, 2, 1, 2, 1, 2, 2, 1, 1, 1, 0, 0, 0, 0, 0, 0, 0]	0.03	-0.0045
[2, 2, 1, 1, 2, 1, 2, 1, 2, 2, 1, 1, 1, 1, 0, 0, 0, 0, 0, 0]	0.02	0.0055
[2, 2, 1, 1, 2, 1, 2, 1, 2, 2, 1, 1, 1, 2, 0, 0, 0, 0, 0, 0]	0.02	-0.0145
[2, 2, 1, 1, 2, 1, 2, 1, 2, 2, 1, 1, 1, 2, 1, 0, 0, 0, 0, 0]	0.015	-0.0095
[2, 2, 1, 1, 2, 1, 2, 1, 2, 2, 1, 1, 1, 2, 1, 1, 0, 0, 0, 0]	0.01	-0.0045
[2, 2, 1, 1, 2, 1, 2, 1, 2, 2, 1, 1, 1, 2, 1, 1, 1, 0, 0, 0]	0.005	0.0005
[2, 2, 1, 1, 2, 1, 2, 1, 2, 2, 1, 1, 1, 2, 1, 1, 2, 0, 0, 0]	0.005	-0.0045
[2, 2, 1, 1, 2, 1, 2, 1, 2, 2, 1, 1, 1, 2, 1, 1, 2, 1, 0, 0]	0.004	-0.0035
[2, 2, 1, 1, 2, 1, 2, 1, 2, 2, 1, 1, 1, 2, 1, 1, 2, 1, 1, 0]	0.003	-0.0025
[2, 2, 1, 1, 2, 1, 2, 1, 2, 2, 1, 1, 1, 2, 1, 1, 2, 1, 1, 1]	0.002	-0.0015
Minus one from each index	**Recommend Spacers/Shims**	
[1, 1, 0, 0, 1, 0, 1, 0, 1, 1, 0, 0, 0, 1, 0, 0, 1, 0, 0, 0]	[6, 4, 1, 0.25, 0.125, 0.0625, 0.002, 0.005]	

4.5 MATLAB Analysis:

After completing the program, the program was analyzed for accuracy. Several cuts were calculated by hand with the spacer and shim sizes written down. The same cuts were then run through the calculator. The output from the calculator was compared to the hand calculations for accuracy. We verified that the calculator's inputs matched the hand calculations, meaning the algorithm was designed correctly.

We also conducted a time study to see if there was a change in the amount of time needed to complete a cut's calculation. Thirty cuts from each slitter were timed. On the 48-inch slitter, the average time needed per cut was 6.2 seconds (a decrease of 66.27 seconds). On the 60-inch slitter, the average time needed per cut was 6.43 seconds (a decrease of 62.95 seconds).

There are three major problems with the MATLAB program. The first issue is that it requires a MATLAB license to run the program. The price of a license is not worth program. The second problem is from the usability of MATLAB. The interface with MATLAB is not intuitive and would not be friendly for floor employees to use. The last issue is the printable table. It is only able to save one cut at a time, making it cumbersome to print multiple cuts at the same time.

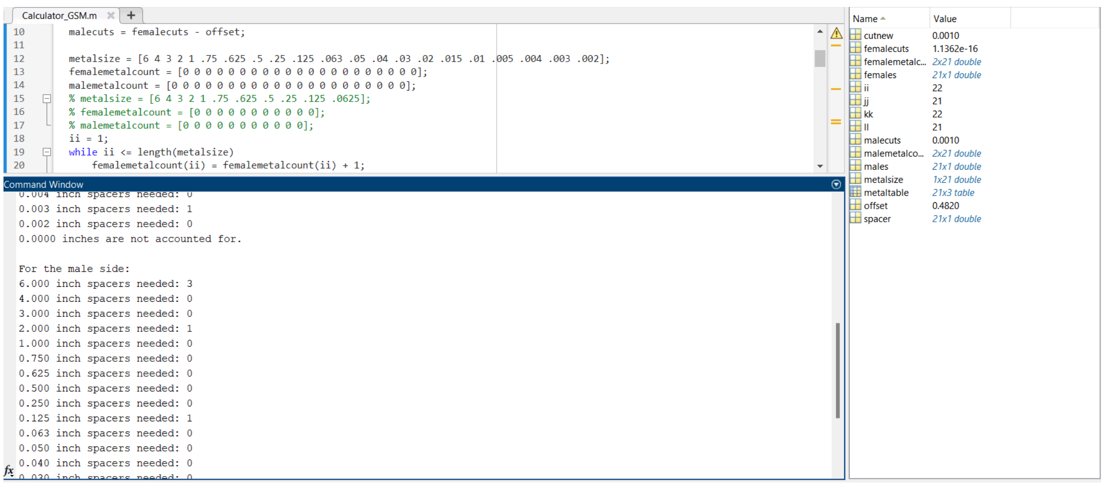
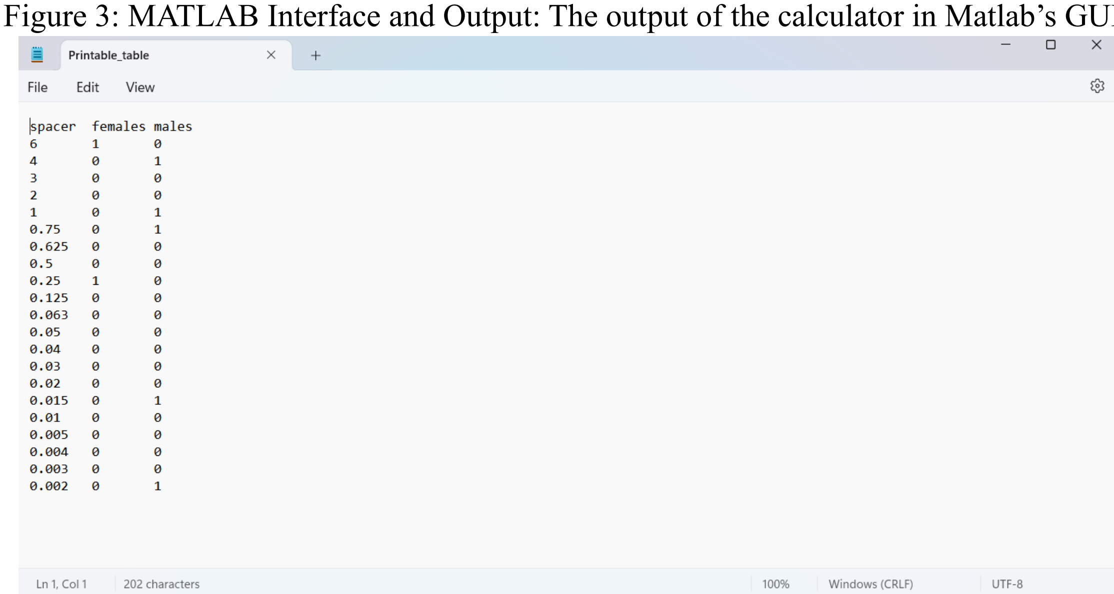


Figure 3: MATLAB Interface and Output: The output of the calculator in Matlab's GUI.



spacer	females	males
6	1	0
4	0	1
3	0	0
2	0	0
1	0	1
0.75	0	1
0.625	0	0
0.5	0	0
0.25	1	0
0.125	0	0
0.063	0	0
0.05	0	0
0.04	0	0
0.03	0	0
0.02	0	0
0.015	0	1
0.01	0	0
0.005	0	0
0.004	0	0
0.003	0	0
0.002	0	1

Figure 4: Printable table on Notepad: A text file of the completed calculations, capable of being printed for use on the shop floor.

4.6 Excel Logic:

The next iteration of the calculator was designed in Excel. Since the logic from MATLAB was proven to work, the Excel worksheet was designed to follow similar logic. The inputs are the same as the MATLAB program, a cut's size and the offset amount. However, the iterative process needed to be designed differently for Excel. Once the cut size and offset are inputted, the program automatically finds the male cut size to start the calculation process.

The worksheet has a hidden row dedicated to calculations—storing the remaining portion of the cut. The spacer and shim count row is floor function that takes the remaining cut size and divides it by its associated value. The floor function ensures that whatever value is found is rounded down to the next whole number. This number is multiplied by the associated spacer or shim value and represents how many inches need to be taken away from the remaining cut length. That length is kept hidden and updated for every spacer and shim, leaving two tables to read at the end: one displaying the female spacer and shim count; the other displaying the male spacer and shim count. Table 8 shows the process for one side of a female cut.

Table 10: Excel Logic

Remaining Size	**Metal**	**Floor Divide**	**New Remaining**
X	**Y**	**Floor(X/Y)**	**X – (Floor(X/Y) * Y)**
11.463	**6**	Floor (11.463/6) = 1	11.463 - (6*1) =5.463
5.463	**4**	Floor (5.463/4) = 1	5.463 - (4*1) =1.463
1.463	3	Floor (1.463/3) = 0	1.463 - (3*0) =1.463
1.463	2	Floor (1.463/2) = 0	1.463 - (2*0) =1.463
1.463	**1**	Floor (1.463/1) = 1	1.463 - (1*1) =0.463
0.463	0.75	Floor (0.463/0.75) = 0	0.463 - (0.75*0) =0.463
0.463	0.5	Floor (0.463/0.5) = 0	0.463 - (0.5*0) =0.463
0.463	**0.25**	Floor (0.463/0.25) = 1	0.463 - (0.25*1) =0.213
0.213	**0.125**	Floor (0.213/0.125) = 1	0.213 - (0.125*1) =0.088
0.088	**0.0625**	Floor (0.088/0.0625) = 1	0.088 - (0.0625*1) =0.0255
0.0255	0.05	Floor (0.0255/0.05) = 0	0.0255 - (0.05*0) =0.0255
0.0255	0.04	Floor (0.0255/0.04) = 0	0.0255 - (0.04*0) =0.0255
0.0255	0.03	Floor (0.0255/0.03) = 0	0.0255 - (0.03*0) =0.0255
0.0255	**0.02**	Floor (0.0255/0.02) = 1	0.0255 - (0.02*1) =0.0055
0.0055	0.015	Floor (0.0055/0.015) = 0	0.0055 - (0.015*0) =0.0055
0.0055	0.01	Floor (0.0055/0.01) = 0	0.0055 - (0.01*0) =0.0055
0.0055	**0.005**	Floor (0.0055/0.005) = 1	0.0055 - (0.005*1) =0.0005
0.0005	0.001	Floor (0.0005/0.004) = 0	0.0005 - (0.004*0) =0.0005
0.0005	0.003	Floor (0.0005/0.003) = 0	0.0005 - (0.003*0) =0.0005
0.0005	0.002	Floor (0.0005/0.002) = 0	0.0005 - (0.002*0) =0.0005

4.7 Excel Analysis:

The biggest advantage of the Excel spreadsheet is its ease of use. Unlike the original MATLAB program, Excel allows easier to follow prompts and more intuitive use. The program is also color coded for users to associate shim colors with the measurements. Being built in Excel also allows for the users to directly print out the calculations rather than exporting them individually to a notepad file. The spreadsheet that is going through implementation right now can hold six unique cut sizes and can be adjusted to hold more. Figure 5 shows the first iteration of the calculator in Excel.

Work Order Number:	XXXXX
Date Generated:	4/16/2024

Cut 1

Input	
Cut Size	11.463
Gage	0.482
Derived Input	
Male Cut	10.981

	Female Metal Count											Female Shim Count									
inch	6	4	3	2	1	0.75	0.625	0.5	0.25	0.125	0.063	0.05	0.04	0.03	0.02	0.015	0.01	0.005	0.004	0.003	0.002
QTY	1	1	0	0	1	0	0	0	1	1	1	0	0	0	1	0	0	1	0	0	0

	Male Metal Count											Male Shim Count									
inch	6	4	3	2	1	0.75	0.625	0.5	0.25	0.125	0.063	0.05	0.04	0.03	0.02	0.015	0.01	0.005	0.004	0.003	0.002
QTY	1	1	0	0	0	1	0	0	0	1	1	0	1	0	0	0	0	0	0	1	0

Work Order Number:	XXXXX
Date Generated:	4/16/2024

Cut 2

Input	
Cut Size	15.248

Figure 5: Excel spreadsheet showing calculations for one cut of 11.463 inches

The algorithm to carry out the calculations has been locked and hidden on the spreadsheet. This was done to ensure the calculator's logic is not disrupted after implementation. This also ensures that the only parts that are updated are the user inputs.

After feedback from the headbuilders, the calculator was adjusted to better suit their needs. The worksheet running the calculator was hidden and a landing page was created. The landing page has two buttons, one to reset values in the calculator and the other to bring up a Graphical User Interface (GUI). The GUI has fields for the following (Figure 6):

a. Order Number: The assigned order number with the Work Order.
b. Customer Name: The customer who ordered the coils.
c. Coil Gauge: The thickness (in inches) of the steel being slit (supports values between 0.01 and 0.059999).
d. "Number" Cut: The unique width of each coil ordered (in inches). Corresponds to the female size. The calculator is only able to accept six unique widths at once.
e. Quantity: The frequency of the associated unique cut. A quantity of "3" indicates the customer ordered three coils of the corresponding width.

f. Blade Type: Select whether the slitter will use thin blades or thick blades. This will affect the offset for the male side.

The output is saved to the sheet used to launch the GUI, is color coded for the shims, and easy to print (Figure 7).

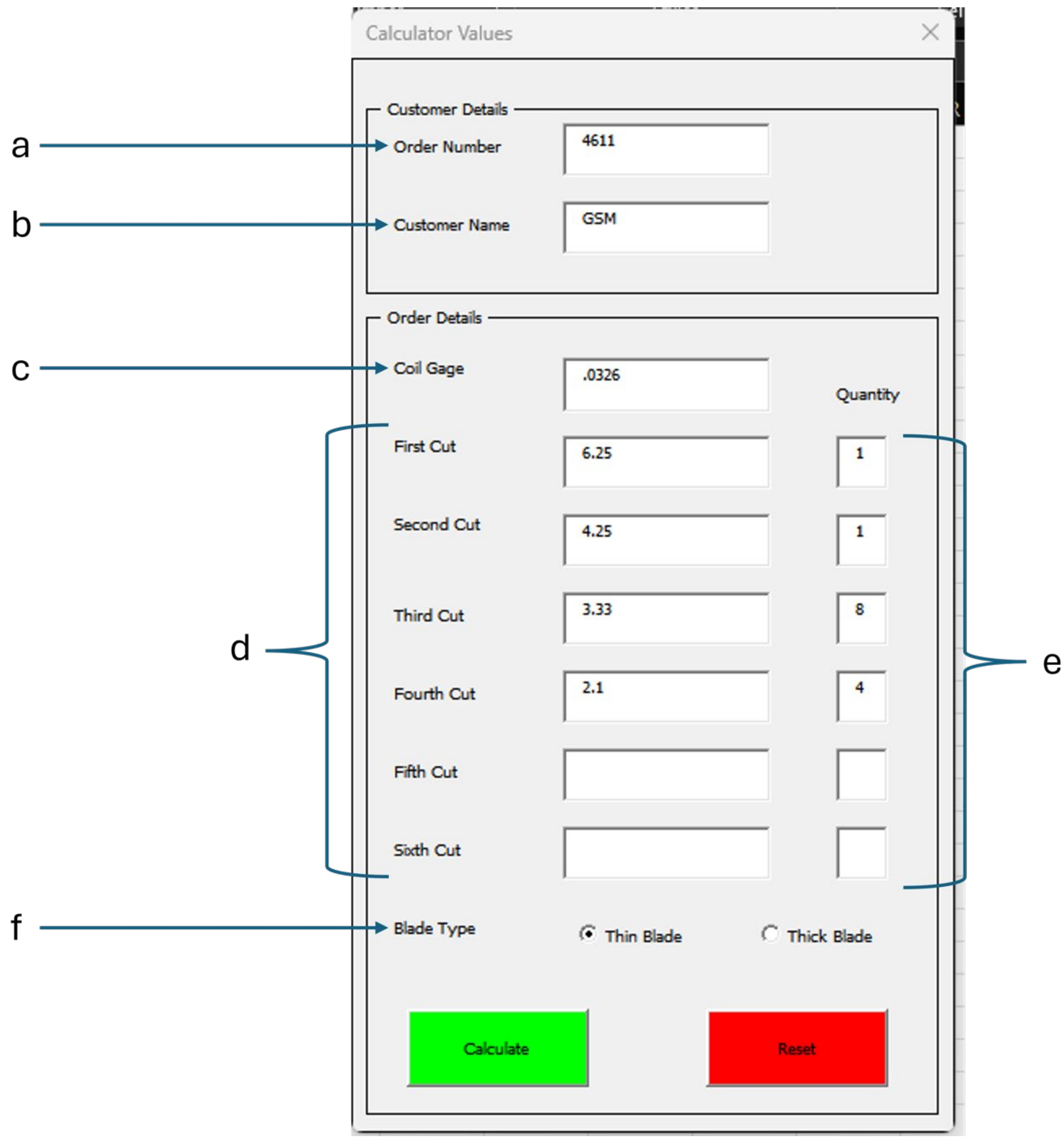


Figure 6: Calculator GUI

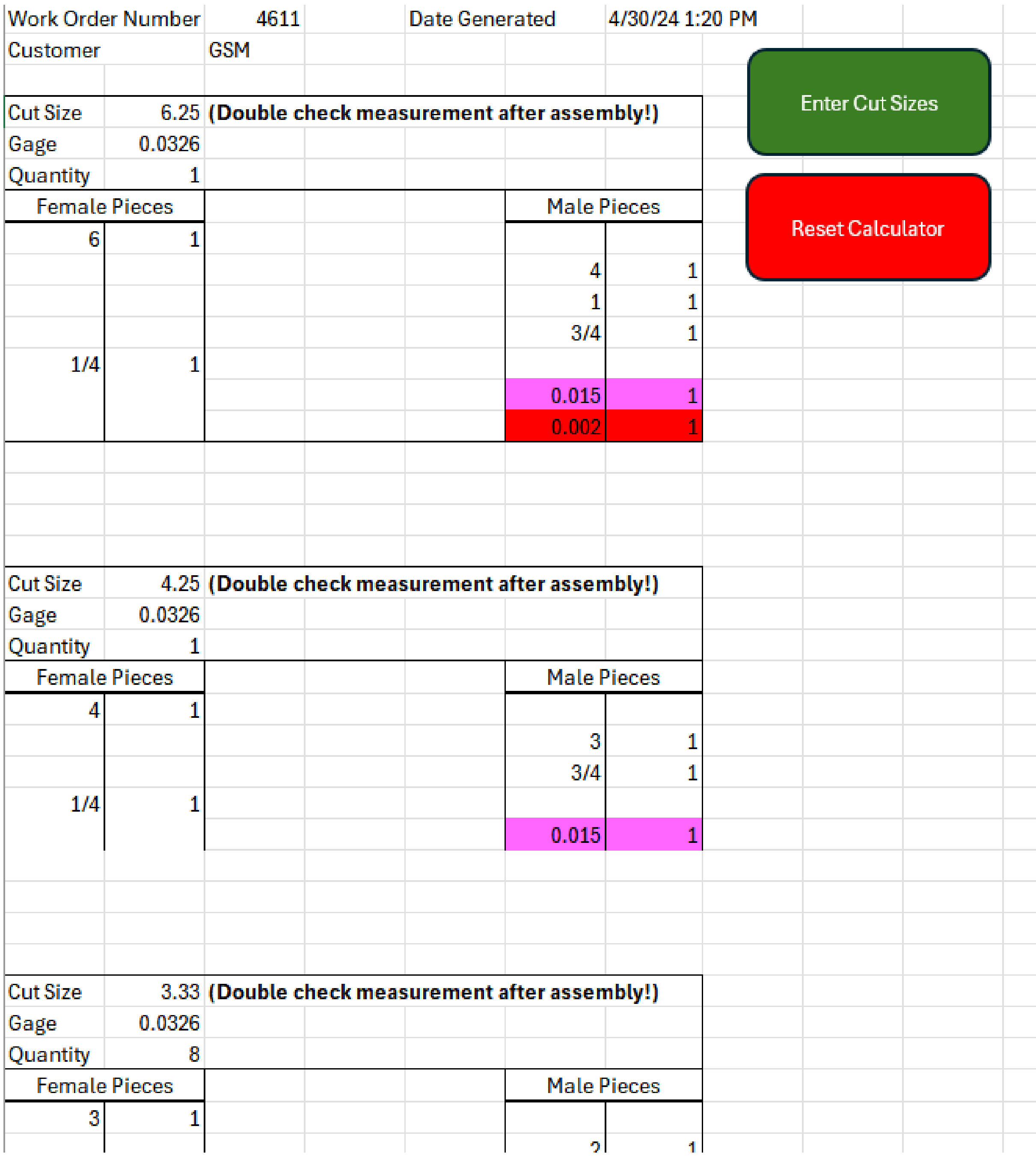


Figure 7: Printable Output Page

The program would benefit from an associated inventory system. Currently, there is nothing stopping the output from reporting multiple spacers that are not in stock. By studying the most frequently used spacers, additional ones can be ordered and used.

4.8 Validation:

When comparing the current iteration of the calculator to the original design requirements, we see that requirements 2 and 3 have nearly been fulfilled in the Excel spreadsheet. The calculator will need to undergo a more formal translation, which will be done by speaking with the employees that will use it in general (Requirement 2). The outputs initially specified have changed since the project progressed. Of note, the output is printable, detects errors for non-numerical inputs, has space for the work order, and has an automatic updating date (Requirement 3).

While designing the spreadsheet, Requirement 1 began to expand beyond the focus of the team. Having no member stay behind to constantly keep the inventory updated will lead to an obsolete inventory system. GSM currently does not maintain inventory of their spacers and shims.

The calculator is currently going through testing and the team will have feedback on its effectiveness

Chapter 5: Continuous Improvement Efforts

During our visits to the GSM plant, many opportunities for process improvements were identified. Some examples include improvements to the layout and identification of different tooling, reducing the number of tooling components needed to reduce opportunities for defects, and changing work center layouts to improve material flow and ergonomics. To expand the impact of our project on Great South Metals' operation, we are implementing process improvements wherever possible and recommending specific changes that are larger in scope.

5.1 Poka Yoke: Reducing Errors with Improved Labeling

While learning about the head-building process, one area we found for improvement was finding specific tooling sizes when building up the heads and returning pieces when breaking it down. Tooling for each slitter head is stored on a rack constructed of upright steel panels with 1.25" square or 1.675" round tube pegs welded to them. At the 48" slitter head-building station, tooling sizes are currently marked using wax pencil inscriptions on the back of the rack; while on the 60" line, labels from a common ¼" label maker are used. These labels are difficult to read when they are exposed and effectively impossible once more than a few pieces are placed onto the rack. Additionally, it can be difficult to tell which spacers are which as they are not marked. In fact, a metal spacer was found to be on an incorrect rack during one of our team's onsite visits.

To remedy this, we designed endcaps, shown in Figures 10 and 11, to be installed on the end of each peg on the rack to indicate which size belongs there. Besides being clearly marked with the dimension of that component, the endcaps for fractional sizes include a notch the width of the tool so the operator can double check that it belongs there and that they selected the expected size. The endcaps are designed to fit flush with the tube sidewalls to avoid damage or accidental removal from the tube, demonstrated in Figure 10.

To fabricate these endcaps, we decided to utilize selective laser sintering (SLS) 3D printing. We considered injection molded plastic, but the cost is prohibitively high. An injection molding tool intended for production parts costs $12,000 on average, and we would need eighteen tools to make endcaps for the various sizes of tooling [15]. This would bring the cost to $216,000 before any parts are produced. Negating the cost of materials, the cost per part is $3,000 each if we produced four of each size. For comparison, Protolabs can produce the parts for $14.35 per part. These selective laser-sintered parts are quite robust to withstand the harsh industrial environment they will be used in. A prototype endcap was installed on a rack and hit with a hammer several times to test durability. It did not break. However, some of the retaining tabs broke off of another example when installed. The prototypes were printed out of Nylon 12, which is strong but brittle. For improved durability, we recommend printing the finished parts from Nylon 11 which is more ductile and impact resistant. A quote was solicited from Protolabs Inc. for sixty-four square end caps and seventy-two round endcaps. The estimated price was $1,952.77 including shipping fees and taxes.
The improved labeling will reduce the likelihood of hanging a piece tooling on the wrong rack and therefore reduce mistakes in the head-building process. Clearer labeling also speeds up the head-building process, as components are easier to find.

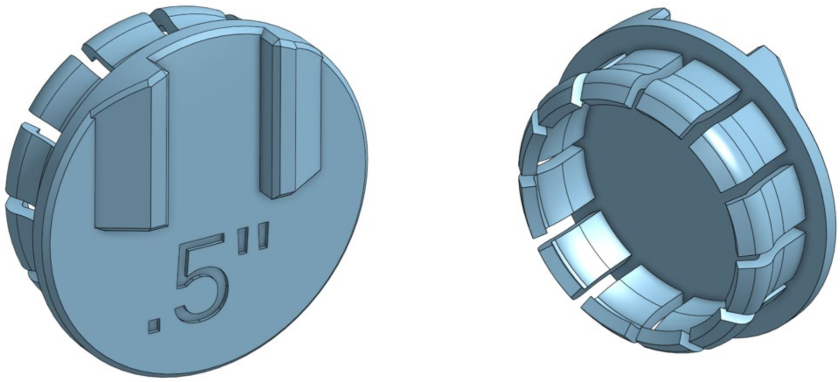


Figure 8: Front and rear of an endcap used on the 60” slitter line.

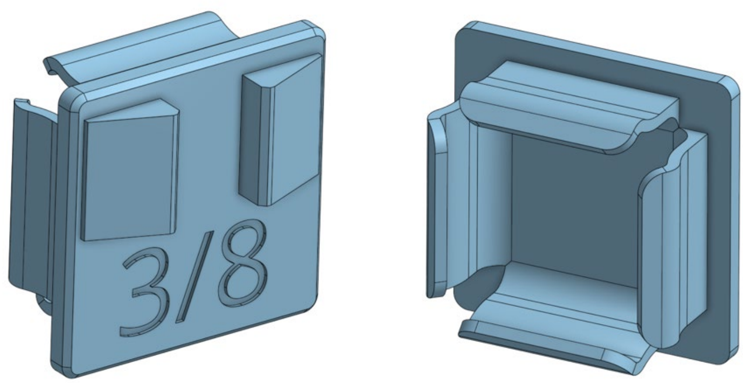


Figure 9: Front and rear of an endcap used on the 48” slitter line or shim storage racks.

Figure 10: An endcap installed at the 60” slitter head-building station.

5.2 Analyzing the System with 5S

The 5S methodology is an approach to workplace organization that focuses on five key components: sort, set in order, shine, standardize, and sustain. Figure 11 gives a brief description of what each part of 5S entails. Using the idea of 5S, we can perform an analysis on the slitter head assembly workspace through a more critical lens.

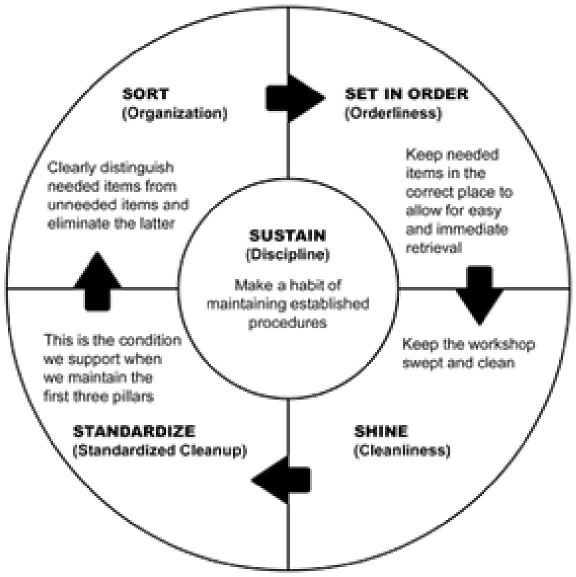


Figure 11: 5S diagram summarizing each step [16].

1. Sort
   During our visits at GSM, we noticed an abundance of equipment in the slitter head assembly workspaces. Some of this equipment is actively being used but not stored in an ideal location, while some of it is old and worn-out equipment that has not been discarded yet. Sorting through the equipment would clear out any items that are not currently being used and create room for the equipment that is being used to be stored more effectively. Figure 12 provides an example of equipment with an unclear purpose. Sorting through these rubbers would give GSM a better idea of how much usable tooling they have while also freeing up another large worktable that could be used more effectively for other tasks.

Figure 12: Unsorted equipment table at the 60” slitter.

In addition to sorting through the tooling equipment, it would be beneficial to sort through all the miscellaneous items that have accumulated in the workspaces—such as trash and storage spaces not being utilized. Determining what storage areas are available to be used would help with the next 5S step: setting in order.

The sorting process would also be an ideal time to inventory the equipment being used. Recording an accurate inventory helps to determine if each workstation has the equipment it needs to function optimally as well as if any equipment should be replaced. The lead times for the slitter head tooling, such as rubbers and metals, is over a year, so being able to plan orders more accurately could prevent process delays.

2. Set in Order
   Once the workspace has been thoroughly sorted, the remaining items can be set in order. Organizing the tooling equipment helps to ensure that errors are not made due to a misplaced piece of equipment. The tooling racks do have some labels that indicate what item should be hung on that peg, but they are difficult to read, hidden under the hanging equipment, or inconsistently placed. Figure 13 shows an example of the current rack labeling system. Developing a clear and consistent labeling system would be beneficial while setting items in order. Section 5.1 details one way in which these racks could be labeled more clearly and therefore facilitate the implementation of this 5S component.

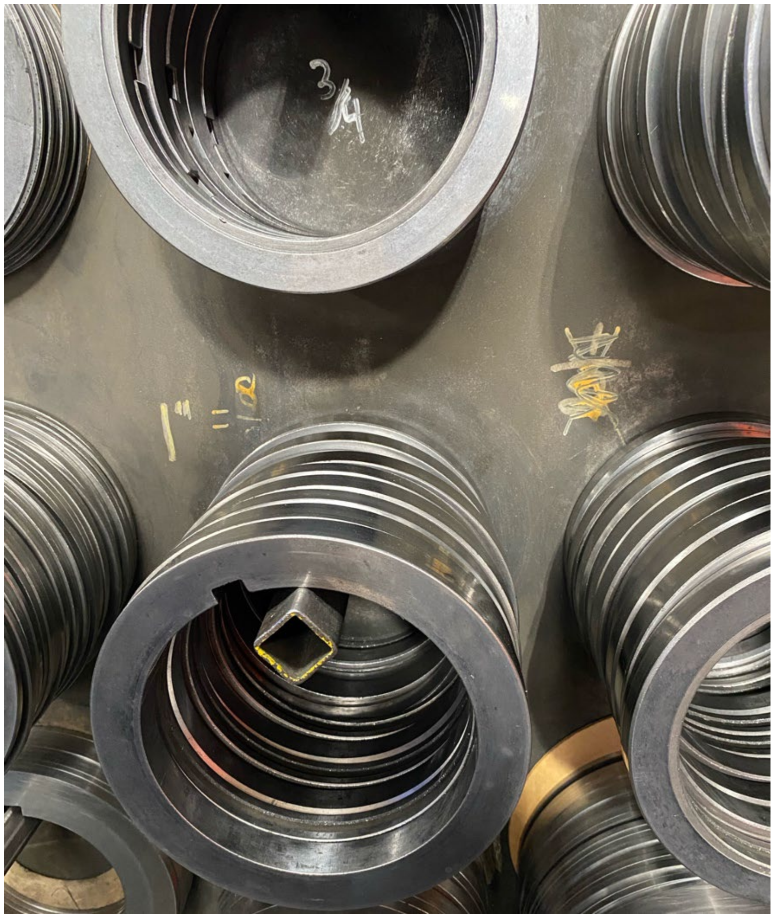


Figure 13: Current tooling labels on a rack at the 48” slitter.

Labeling is only one part of making sure that items make it back to their designated storage location. Another important part of setting things in order is making sure that items have a consistent place to be stored and that storage is being used. Storing the equipment in its designated location not only helps keep the workspace more organized, but also helps make sure that errors are not made due to grabbing the wrong item. At GSM, accuracy and precision during the head building process directly impacts the quality of their work, so the equipment must be stored in a way that encourages accuracy. One item that is commonly misplaced or poorly organized is a shim. Shims are stored differently at the 48” and 60” slitters, but both organization methods are either flawed or unused. More specifically though, the 60” slitter has a lot of room for improvement. Shims are currently being stored in three different places; only one of which has a clear organizational method that is intended to be used. The three different shim storage areas are pictured in the following three figures. In Figure 14, the shims are hung on a wooden rod with no particular order or grouping. In Figure 15, the shims are stored in wooden buckets that contain multiple shims sizes. These buckets often end up housing shims that belong elsewhere as well as trash. In Figure 16, the shims are stored on one of the larger tooling racks with no order or grouping.

Figure 14: Wooden rod shim storage at the 60” slitter.

Figure 15: Wooden basket shim Storage at the 60” slitter.


Figure 16: Rack hanging shim storage at the 60” slitter.

The inconsistent storing of the shims makes it hard to properly set the shims in order. As seen in Figure 15, there are bins in this workspace that are supposed to be used for shim storage, but they are not being used as the primary storage anymore. This suggests that a new primary shim storage area may need to be created, or the bin storage simply needs to be revitalized. Without a consistent storage location, the shims are being misplaced and misused and therefore causing errors during the head assembly process. One of the possible solutions to this issue is to build a new hanging rack for the shims that is color coded. This would establish a centralized home for all the shims at each slitter with color coordinated peg end caps that provide a visual verification that shims are being stored in the correct place.

In addition to these more creative solutions, simply emphasizing the importance of returning all equipment to its designated area is critical to the success of head assembly. Returning items back to their storage location not only keeps the workspace tidier, but it also provides a safer place for the tooling to be stored that promotes equipment longevity.

3. Shine
   There is currently a lot of trash in the workstations, specifically the 60-inch slitter as seen in Figure 17. Removing the trash and practicing regular cleaning habits would create a space that allows the employee to focus on the task at hand without clutter. The 48-inch slitter workspace typically has less trash but is very cluttered. The space is smaller than the 60-inch workstation, so keeping this area clean is even more important. The more cluttered nature of the 48-inch workstation does warrant an investigation into the layout of this area. The details of this investigation can be found in Chapter 6.

Figure 17: 60” slitter tooling storage rack.

   Additionally, the slitter heads are often covered in chips and grease from the assembly process. These heads must be cleaned frequently to ensure that the head and the tooling remain in prime condition. The buildup of grease on the equipment could result in defects if not cleaned properly. Figure 18 shows an example of an uncleaned slitter head that not only has grease build up, but also miscellaneous items laying in the workstation that should be put away.

Figure 18: Grease build-up on a 48” slitter head.

The shims are another item that needs a regular cleaning process. The color of shims is important when building the heads because they are often referenced to by their color and not their specific width. This becomes an issue when the shims have not been cleaned because it can be difficult to determine the color of the equipment or distinguish shims of different sizes from each other. For example, Figure 19 shows that the red and tan shims at the 48” slitter appear to be the same color due to the buildup on the equipment. Additionally, the red shims no longer appear to be red. This can be incredibly problematic when selecting tooling for the head assembly as well as when someone is trying to return equipment to its designated location.

Figure 19: 48” slitter red and tan shims.

4. Standardize
   To keep the workspaces in acceptable condition, there needs to be a standard tidying process implemented at the end of each shift. Also, the current head assembly process is not standardized, with each head builder using their own method throughout the process. Standardizing the process would lower the barrier to entry for new employees to be head builders.

5. Sustain
   One of the most difficult aspects of the 5S methodology to implement is the sustaining of the previously discussed topics. For these practices to be sustained, they must be easily adoptable and feasible for the employees. Through our site visits, we connected with the employees, which gave us insight into how they function. In general, employees have responded well to the idea of creating a more centralized and consistent storage system for tooling. One of the employees has even offered to help build new racking systems that would support the ideas presented in the sorting and setting in order phases of our analysis. We are confident that with the simple changes we have suggested and implemented, a better head building system can be sustained.

Chapter 6: Enhancing Ergonomics and Safety

Efficiency and precision in the slitter head assembly process are not solely reliant on technological advancements but also on the ergonomics of the workspace and the workflow. Ergonomics plays a crucial role in ensuring that GSM head builders can perform tasks comfortably without unnecessary movement, strain, or risk of injury. This chapter explores how the ergonomics of the slitter head building process can be improved to enhance both efficiency and the well-being of the employees involved at Great South Metals (GSM).

6.1 Current Ergonomic Challenges

Before delving into potential solutions, it is essential to identify the existing ergonomic challenges within the slitter head building process. Common challenges observed included awkward postures, repetitive motions with wasted movement, and inadequate workspace layout. Those challenges contributed to discomfort, fatigue, and an increased risk of musculoskeletal injuries among workers. Awkward postures can lead to strain and potential injuries, as workers may need to bend, twist, or reach uncomfortably to access tools or equipment. Repetitive motions, such as lifting heavy components or performing repetitive tasks, can also contribute to fatigue and overuse injuries. Additionally, an inadequate workspace layout can result in inefficiencies, clutter, and safety hazards. Poorly designed tools and equipment can further exacerbate these challenges, making tasks cumbersome and increasing the likelihood of errors or accidents. Figure 20 shows the current 48-inch head building workspace. With the current layout, builders must make repetitive 180-degree rotations to bring tooling from the rack to the slitter head.

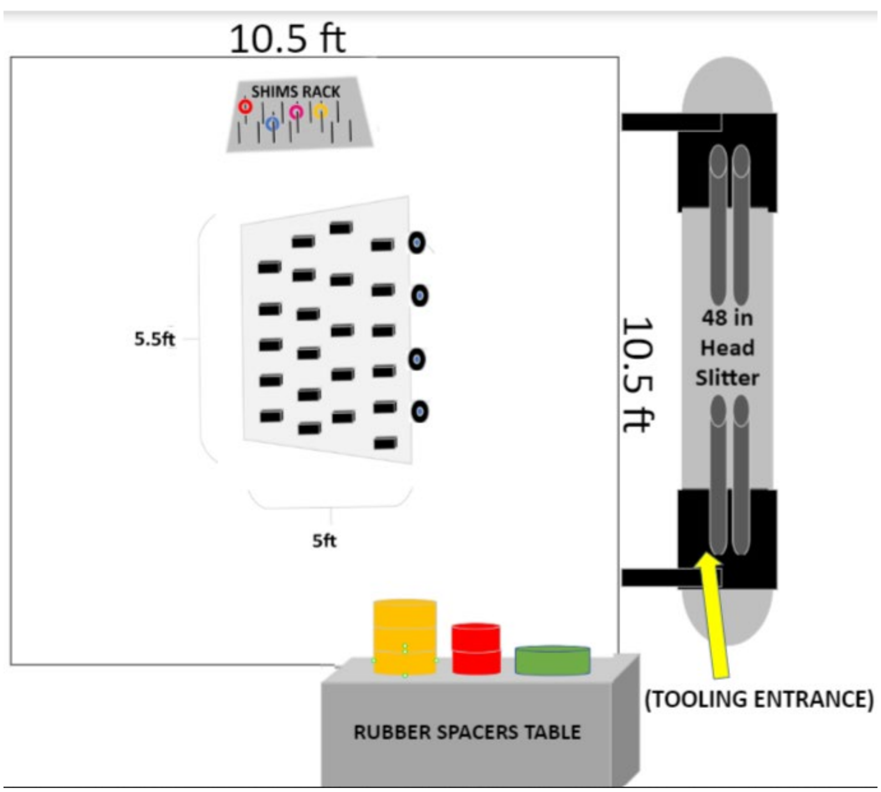


Figure 20: Current workspace layout of the 48” slitter line.

6.2 Proposed Ergonomic Solutions

To address these challenges and create a more ergonomically sound work environment, several solutions have been considered. A workspace redesign plays a vital role in optimizing a workstation layout and facilitating a smooth workflow. A redesign recommendation would involve rearranging the workstation by moving both the shim rack along with the tooling rack and optimizing tool placement. Moving along, GSM would also benefit from the addition of two cushioned floormats along the work area. This would not only reduce foot discomfort for the head builder from constant standing, but also potentially reduce the risk of accidents by reducing floor slickness from the grease. The last recommendation for GSM would be for them to provide training and education on proper ergonomic principles such as lifting techniques for heavy objects as well as posture and workspace organization. Empowering workers to recognize and address incorrect lifting habits, including not bending your knees and using your back instead of your legs, leads to a safer and more productive workplace.

6.3 Ergonomic Workspace Redesign

After identifying the need to improve ergonomics in the slitter head building process, a recommendation was devised to pivot both the tooling rack to make it parallel with the head building station along with potentially adding wheels to a new shim rack to provide it some mobility within the workspace. This change aimed to eliminate the need for workers to make excessive and repetitive 180-degree turns when accessing tools and components on the rack to transfer them to the male and female coils. By rotating both tooling racks, workers will limit the amount of 180-degree turns they have to make and only need to make one turn most of the time—significantly reducing the strain and fatigue associated with repetitive turning motions. The workspace dimensions were carefully measured to ensure that the tooling rack could be rotated. Figure 21 illustrates the recommended redesign.

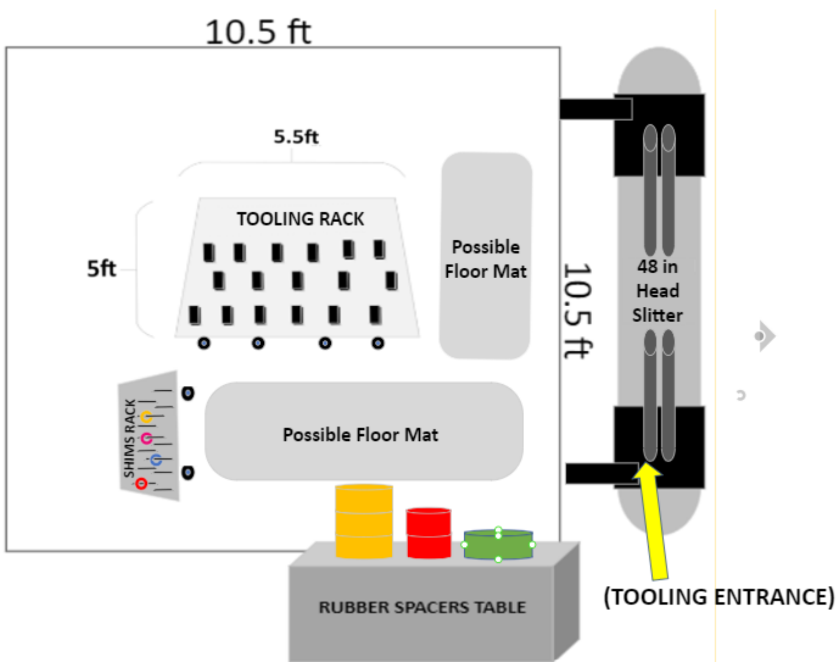


Figure 21: Recommended Workspace Layout of the 48" Slitter Line.

6.4 Potential Benefits of Workspace Redesign

The implementation of the recommended workspace redesign would enhance the head building process. First, it would reduce fatigue and strain as head builders will no longer have to make multiple unnecessary turns to access tools and components. This would lead to increased comfort and productivity as workers could focus on the assembly process without unnecessary physical exertion. Furthermore, a new workspace layout enhances efficiency by streamlining the workflow and reducing the time required to retrieve necessary items from the tooling rack. These potential recommended changes promote worker safety and well-being. Enhanced ergonomics can also contribute to improved accuracy and consistency in the assembly process. Improving the ergonomics of the slitter head building process is essential for promoting worker safety, comfort, and efficiency at GSM. Additionally, improvements to the head building process overall would enhance productivity, reduce the risk of injuries, and demonstrate a commitment to employee welfare. Prioritizing ergonomics and safety not only benefits the workforce, but also contributes to operational success and sustainability. By creating a healthier, more ergonomic work environment, GSM can optimize its operations and create a culture of safety and well-being for its employees.

Chapter 7: Results and Discussions

7.1 Tooling Calculator:

The current iteration of the calculator meets most of the original design requirements. The user interface has a graphical user interface (1a). Any errors with the inputs are detected and reported to the user (2b). Additionally, there are multiple alerts for the head builder to manually verify the head during assembly (2c). Every single order has a generation time stamp, an associated work order, and the customer's name (2e, 2f, and 3b). Finally, the field for "Cut Size" allows the user to input any positive numerical value (3a),

Due to time constraints, the calculator was not translated into Spanish (1a). We will provide instructions on how to add the Spanish output to GSM. Additionally, since there are inventory control capabilities, requirement 2g was not met. There are warnings provided to the head builders to verify that the recommended output is feasible and practical. Finally, the calculator does not have any recommendations when picking blades and rubbers (2d). Blades must be picked prior to head building since the male side offside is directly affected by this. Rubber selection is done one to one with the spacers and shims, with one-sixteenth of an inch being left as a gap between a rubber and blade.

When presented to the head builders, the calculator was positively received. They requested a few new usability functions after verifying the output was the same as their manual calculations. Those features have been added to the latest version of the calculator. The calculator also received a positive reception from the president and foreman. They appreciated the program's speed and the option to print out an easy-to-read table to take to the head building station. An instruction manual for the calculator can be found in Appendix D.

7.2 Tooling Rack Endcaps:

Even with more accurate calculations, operators can still make mistakes by selecting incorrect components when building out the slitter head for each work order. The racks the tooling is stored on are either unlabeled or, in some cases, not labeled at all. The tooling components themselves are also unmarked. This makes it difficult for operators to consistently return components to the correct location or positively identify what size they are selecting. Using the concept of Poka Yoke, we designed labeled endcaps for the tooling storage racks that designate what size belongs at a given location. These endcaps also incorporate a gauge that immediately indicates whether the metal spacer or rubber is the correct size. The endcaps are 3D printed from Nylon 11 for durability and low cost, making them an economical and sustainable solution. The CAD models and a vendor quote were provided to GSM, they have tentative plans to buy them and install them on both production lines.

7.3 5S Analysis:

After spending a significant amount of time observing the slitter head building workspaces, it was clear that they would benefit from implementing 5S concepts. Sorting through the equipment to determine the used and unused equipment would help to clear out a lot of the clutter. This would also help them determine how much equipment they have to work with and if they need to replace any of the tooling. The setting in order phase will likely yield the most benefits for these workspaces as there is a general lack of centralized and consistent organizational methods for some of the tooling. We determined that one of the main areas of concern from this perspective was the storage of the shims at the 60" slitter. We recommended that they build a new storage rack for these shims that use the Poka Yoke end caps and color coding to provide multiple forms of verification that a shim is placed on its correct peg. For shine, we have recommended that they begin to clean shims and slitter heads regularly as those two pieces of equipment seem to build up the most grime that could cause errors in the process. Finally, to support standardization and sustaining the benefits of 5S, we created a 5S maintenance checklist that provides simple reminders for the sort, set in order, and shine phases. The checklist is in Appendix E.

7.4 Recommended 48" Slitter Workspace Redesign:

The challenges identified in the slitter head building process included awkward postures, repetitive motions, and inadequate workspace layout, leading to discomfort, fatigue, and increased risk of injuries among workers. To address these issues, a recommendation was made to pivot the tooling rack to align it parallel with the head building station and potentially add wheels to a new shims rack for mobility. This change aimed to reduce the need for excessive 180-degree turns by workers when accessing tools and components, thus minimizing strain and fatigue. Careful measurements were taken to ensure the feasibility of rotating the tooling rack within the workspace. Improving ergonomics in the slitter head building process at GSM will not only enhance worker safety and well-being but also foster accuracy and consistency in assembly. This prioritization of ergonomics benefits employees by reducing the risk of injuries, promoting comfort, enhancing overall productivity, and demonstrating a commitment to employee welfare. By creating a healthier work environment, GSM can optimize operations and cultivate a culture of safety and well-being.

7.5 Economic Analysis

Since we were not provided with labor or shop time factors, our comparison of costs and savings are based on an estimated labor rate of $35. Using this rate, we were able to calculate an approximate amount of money that GSM would save upon implementation of our calculator and other suggestions. We observed that a typical shutdown due to a head building mistake would take around 30 minutes, meaning that every employee pulled away from their task to fix an error would cost GSM $17.50. If our suggestions can prevent one error per week, then GSM can expect a savings of $875 annually for a single employee. From what we observed, it is usually two to three shop workers losing time to an error.

Labor hours are not the only area affected by these errors. Our suggestions will also reduce scrap material by ensuring that more cuts are performed correctly on the first attempt, as a correction to the setup of the arbors usually means that shop workers will need to stop to trim the excess steel. Additionally, any time a slitter is shut down, GSM loses time that could be spent cutting additional rolls to width.

The second angle we performed economic analysis from was cut calculation times. Initially, we performed a time study to get an average time needed to calculate a single cut with the manual method: a T-table and a calculator. Next, we repeated this to get the average time for our excel calculator to calculate a single cut. Our team found that the calculator reduced times by 68%. If

GSM employees were to average 12 cut calculations per day, the calculator would save over 40 hours annually, resulting in a savings of $1,457 using the previously mentioned labor rate estimate. This result could however be impacted by the workflow in the shop; head building times tend to be shorter than the time it takes to cut a single coil, so the time gained from the calculator expediating the process may be spent idle unless the head builder is given additional tasks for after their work is completed.

Chapter 8: Conclusions

Team MetalWorks worked hard to create a well-rounded package of process improvement suggestions for Great South Metals and their slitter head assembly process. Although we were mainly asked to create an automated way to perform the slitter head assembly calculations, we saw the opportunity to explore other avenues of improvement and took it. Ultimately, the calculator could only do so much to improve the process, since many errors stemmed from the workspace itself. Poor organizational methods and workspace layouts were contributing to building errors and decreased employee satisfaction. This gave our team the opportunity to apply our Industrial Engineering mindsets to the system and break it down using the tools we learned during our time at Kennesaw State University. Through site visits, literature reviews, hands-on learning, and several Industrial Engineering analyses, we have created a set of final recommendations.

Final Recommendations:

- Encourage adoption and use of the Calculator in daily head building operations.
- Implementation of the recommended workspace redesign for the 48-inch slitter.
- Procure and install the tooling rack endcaps to reduce mistakes caused by selecting incorrect tooling components while building out each slitter head.
- Implement the use of the 5S Maintenance Checklist to improve the organization and cleanliness of the slitter head workspaces and sustain the benefits of the 5S analysis

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Appendix A: Acknowledgements

We, the Metal Works team from Kennesaw State University, would like to extend our sincerest appreciation and gratitude to the entire team at Great South Metals for your invaluable support and collaboration throughout our senior project, "Slitter Head Building Process." Your sponsorship, guidance, and encouragement have been instrumental in the success of our endeavor. We would like to specifically acknowledge: Gary E. Roberts, President of Great South Metals, for his vision and commitment to innovation in the steel processing industry. Kathleen Cox, Director of Business Process, for her leadership and expertise in this niche industry, and Chuck Brooks, Plant Manager, for his invaluable insights and support in navigating the project's operational aspects. Furthermore, we extend our gratitude to every member of the Great South Metals team for their cooperation and assistance throughout our project journey. Your dedication and professionalism have significantly contributed to the achievement of our objectives. Additionally, we express our heartfelt thanks to Dr. Adeel Khalid, our esteemed professor, for his unwavering support, mentorship, and provision of essential resources that have enabled us to execute our project with precision and excellence. His guidance has been instrumental in shaping our project's direction and ensuring its success. We also wish to extend our appreciation to Dr. Lois Jordan for her personal insights and guidance, which have been invaluable in steering our project in the right direction. Lastly, we would like to thank Dr. Parisa Pooyan for her help in our economic analysis. As a team, we are immensely proud of the progress we have made, and the outcomes achieved in the development of the Slitter Head Building Process. Your continuous support and encouragement have motivated us to strive for excellence and deliver results of the highest caliber.

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Appendix C: Reflections

Evan Swierski	I found that this project forced me to direct more energy towards my academic progress than anything else I have done in my time at KSU. I learned so much from my team this semester. I also learned some surprising things about the steel cutting industry, such as GSM operating on equipment over half a century old. I thought GSM was a pleasure to work with but felt that if they had been able to provide more data from their shop floor that I could have delivered better recommendations.
Nabhan Karim	This was certainly an eye-opening experience for me. It was my first time experiencing a factory setting. Getting to try the things we learned in the classroom was rewarding. Applying my research skills to this problem helped put into perspective how to apply broad solutions to extremely unique problems. This project also really pushed my coding and Excel skills. I learned about many different toolboxes that both MATLAB and Python provide. I also learned basic VBA to provide a smoother Excel interface. Learning how to make macros is a skillset I think will be extremely helpful in the future. I was extremely happy with how our group worked together as well. We all had work styles that complimented each other and would ensure that all of our work was done to the best of our ability. We were also really good about our communication with one another and open about any concerns or criticisms we had. In the end, this was an extremely rewarding experience to cap off my college journey. I hope GSM is able to use our recommendations for the assembly process and hope to stay in touch with the personnel there.
Raven Morin	At the conclusion of this project, I can confidently say that this was one of the most challenging but rewarding projects I have worked on in my academic career. This project encouraged me to learn so much about not only industrial engineering concepts, but also working in an unfamiliar industry. GSM was truly a pleasure to work with. They were very welcoming of us and took the time to answer all of our questions throughout the course of this project. I was thankful to be able to connect with a majority of the employees at GSM as this helped us to really understand what we needed to deliver to them at the end of the semester. Although it was difficult to determine a direction to go in with our work at the beginning due to the lack of baseline data, I think that our group was able to recover well and create a well-rounded set of strong process improvement suggestions. Finally, when I reflect on this project, I think about how well our group worked together. Everyone in the group was dedicated to the work and made sure to pull their weigh. Each of us had a very different perspective to share and that really helped us to look at our work from a multitude of perspectives.

Patrick Kelsey	I think the biggest challenge we faced was the lack of baseline data regarding GSM’s operations. It’s difficult to measure improvement if you don’t know where you started. We made up for that with the wide breadth of topics we covered and qualitative analyses we performed.
Michael Williams	This project was extremely niche and for me that was the biggest obstacle for improving this process for GSM along with their minimal baseline data. I consider myself incredibly fortunate to have chosen Industrial Engineering as my major and to have selected Kennesaw State University as my academic home for this journey. The professors at KSU have been nothing short of exceptional—supportive, knowledgeable, and genuinely invested in our learning. Their guidance has been invaluable in shaping my understanding of Industrial Engineering. My time at KSU has been transformative, equipping me with essential skills like time management, critical thinking, and decision-making. Through projects like this one, I've had the chance to apply theoretical knowledge to real-world scenarios, solidifying my grasp of process improvement—the cornerstone of business success. As I look ahead to my career as an Industrial Engineer, I'm grateful for the practical experiences gained during my time at KSU. I owe a debt of gratitude to the professors who have nurtured my growth and helped me become the engineer I am today. Moreover, I'm thankful for my incredible group members. Despite joining the team later in the semester, I was welcomed warmly, quickly feeling like an integral part of the group. Together, we've navigated challenges, celebrated successes, and grown into a cohesive unit. I leave this semester not as an outsider, but as part of a unified team, ready to take on whatever challenges come our way.

Appendix D: Tooling Selection Calculator User Manual

Tooling Selection Calculator User Manual:

Introduction:

The purpose of the excel sheet and calculator is to assist with picking the tooling needed for slitter head assembly. The tooling selector does not have access to current levels of inventory for spacers and shims. Adjustments may have to be made for spacers with lower inventory.

Directions:

1. Initialize the calculator by clicking “Reset Calculator” (Figure 1).
2. Bring up the calculator by clicking “Enter Cut Sizes” (Figure 2).
3. Fill out the Calculator Interface fields with the appropriate information (Figure 3). Any “Cut Size” left blank will be hidden on the final output:
    a. Order Number: The assigned order number with the Work Order.
    b. Customer Name: The customer who ordered the coils.
    c. Coil Gauge: The thickness (in inches) of the steel being slit (supports values between 0.01 and 0.059999).
    d. “Number” Cut: The unique width of each coil ordered (in inches). Corresponds to the female size. The calculator is only able to accept six unique widths at once.
    e. Quantity: The frequency of the associated unique cut. A quantity of “3” indicates the customer ordered three coils of the corresponding width.
    f. Blade Type: Select whether the slitter will use thin blades or thick blades. This will affect the offset for the male side.
4. Once all the appropriate fields are filled out, click the “Calculate” button (Figure 3).
5. The output is saved to the “Output” worksheet (Figure 4). You may now exit the Calculator Interface.
6. Set the print area and print the suggested tooling for the order.
7. After printing, clear the calculator by clicking “Reset Calculator.”

Conclusion:

The calculator is meant to assist with tooling selection. Headbuilders must verify that the selection is practical while building the head. Always verify the assembled head meets the specifications of the order.

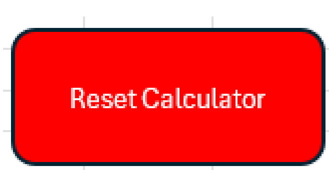


Figure 1

Figure 2

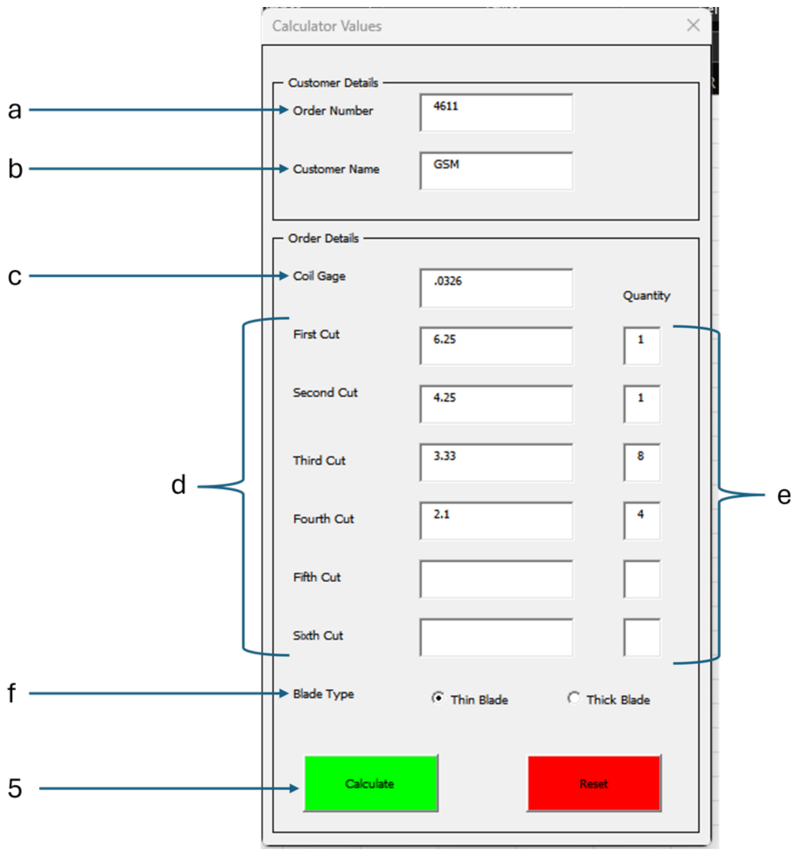


Figure 3

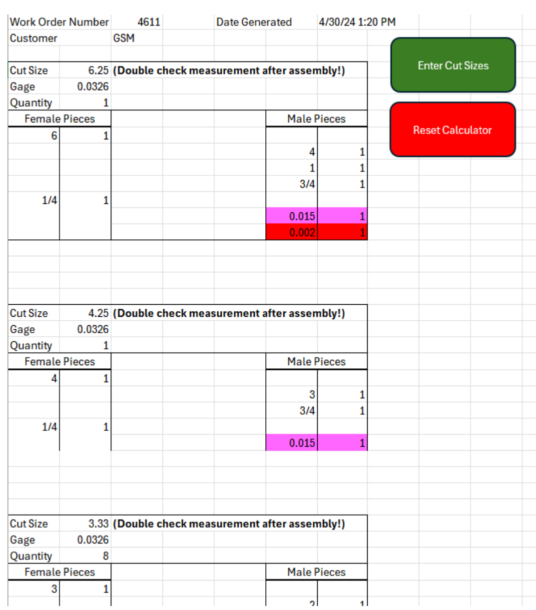


Figure 4

Appendix E: 5S Maintenance Checklist

5S Maintenance Checklist

Use this checklist to implement 5S practices into your regular work routine.

Sort

- ☐ Sort between used and unused rubbers
- ☐ Sort used and unused metals
- ☐ Sort used and unused shims
- ☐ Sort trash items from items that just need to be put away

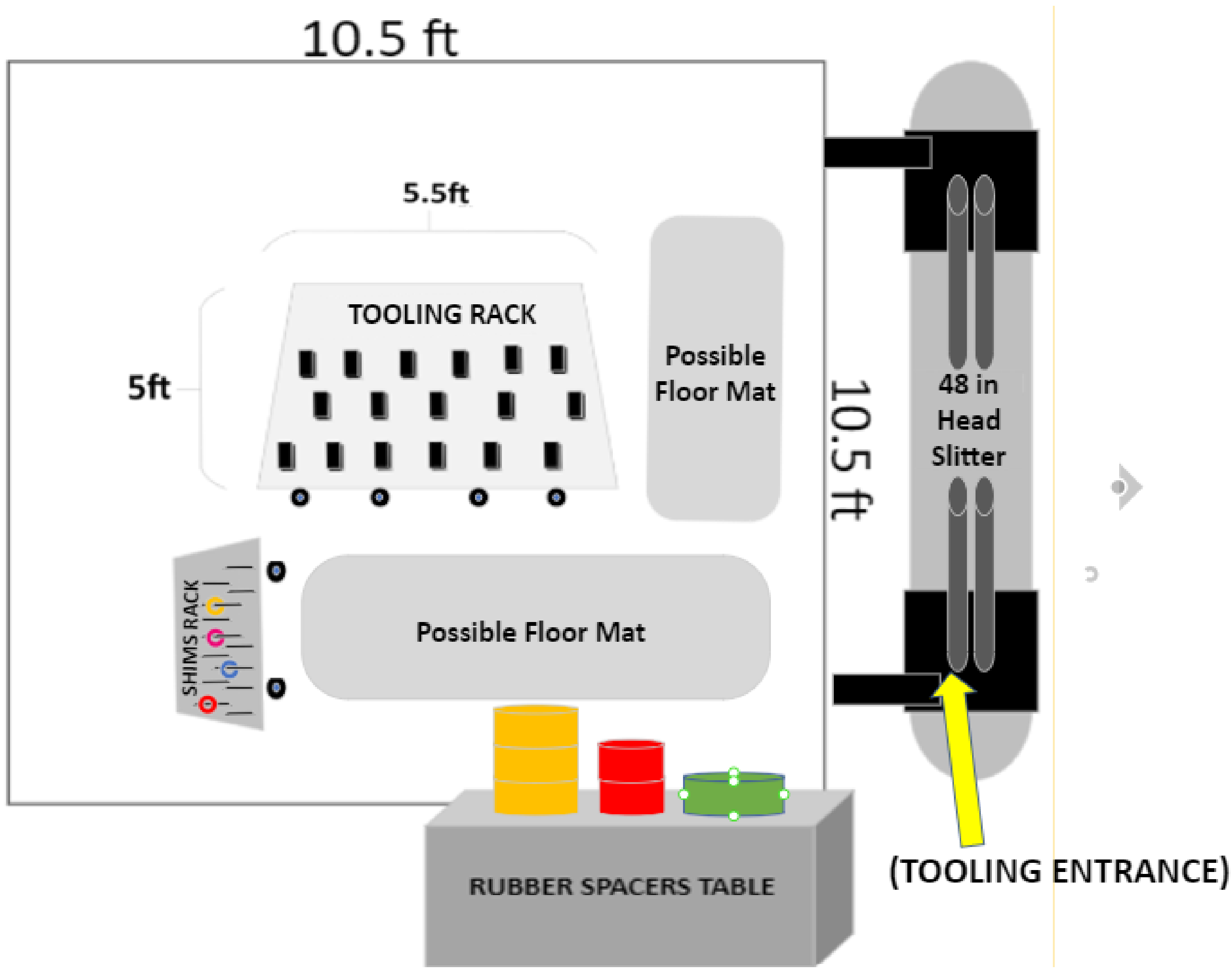
Set in Order

- ☐ Return shims to labeled color coded pegs
- ☐ Return rubbers to labeled pegs
- ☐ Return metals to labeled pegs
- ☐ Throw away grease rags that cannot be used again
- ☐ Return grease rages that can be used again to their storage location
- ☐ Do a workspace walkthrough at the end of each shift to double check that all items have been returned to their designated storage location

Shine

- ☐ Clean shims weekly
- ☐ Clean grease from the slitter head after breaking it down
- ☐ Sweep workspace at the end of each shift
- ☐ Throw away all trash immediately (do not let it build up in the workspace)

Appendix F: Recommended Workspace Layout



Appendix G: Team Member Responsibilities

Evan Swierski	As the project manager, Evan tracked labor and material cost for the project and constructed a cost analysis. He also managed the group's schedule and handled economic analysis. He wrote sections 1.5, 3.6, 3.7, 7.5, and part of 3.1. He also met with Dr. Parisa Pooyan for advice on economic analysis.
Nabhan Karim	Nabhan started the project by focusing on researching different solutions and methodologies other experts have used to address similar issues. He used this research to help write Chapter 2 and develop the TOPSIS in Chapter 3. After the first two reports, Nabhan shifted his focus to developing and testing various forms of the tooling calculator. He wrote Chapter 4 and the associated Instruction Manual in Appendix D.
Raven Morin	Raven served as the liaison between Team MetalWorks and GSM. She scheduled the team site visits as well as updated GSM on the progress of the project. Raven was also responsible for planning task assignments within the group and assisting the project manager with the organization of work. Raven was a main contributor to chapter 1 as well as section 5.2 in chapter 5. She was responsible for all 5S analysis and the creation of the 5S maintenance checklist. She also wrote section 7.3 and the conclusion paragraph in Chapter 8. Lastly, Raven recorded content for the YouTube video and created the final video product.
Patrick Kelsey	Patrick was the process engineer in this project. He spent extensive time at the worksite learning and participating in the steel slitting process at Great South Metals and used this experience to advise other team members on their assignments. Patrick conceived, designed, and fabricated the tooling rack endcaps and defined requirements for the Calculator. Patrick wrote

	Sections 5.1 and 7.2 as well as the Executive Summary.
Michael Williams	As the Field Researcher Michael was very active in the market research portion of the project. He has communicated with and learned from other companies in the industry, which has given our team valuable insight into how others go about this process. Michael analyzed and devised a complete rework of GSM's current 48-inch workspace redesign and the literature review. Michael also came up with the idea of bringing tangible tooling from GSM to help showcase the endcaps, which was essential to the senior expo presentation. Michael created Figures 22 & 23 and wrote Chapter 2 and Chapter 6, along with Section 7.4, Acknowledgments Appendix and helped with the References and editing the final report