Process Improvement Project
at Saint-Gobain Norton Abrasives

Submitted to the faculty of Worcester Polytechnic Institute

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Abstract

This project addresses late orders Saint-Gobain experiences with their superabrasive grinding wheels by implementing solutions aimed at reducing product lead time. We conducted 5S and implemented standard work documents for Saint-Gobain's siding operation and OD grinding stations. These solutions led to a reduction in process time and increased capacity, creating a foundation for future waste reduction and reducing the need for overtime labor.

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Leadership Statement

Shreeja Bhattacharjee, Nicol Garcia, Conrad Mera, Hong Chon Ng Fang, and Trung Tran Trong collectively worked on the project. All members contributed to performing time studies. In the later part of the project, the team was split into two smaller teams: one dedicated to producing the Standard Work deliverables and one dedicated to producing the 5S deliverables. Shreeja Bhattacharjee and Conrad Mera mainly contributed to the former, Nicol Garcia and Trung Tran Trong mainly contributed to the latter, and Hong Chon Ng Fang worked in both parts. Trung Tran Trong and Conrad Mera were the main editors for the project report.

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I. Introduction

Saint-Gobain

Saint-Gobain Abrasives (hereafter referred to as Saint-Gobain) is a leading manufacturer in grinding, polishing, and finishing solutions. Among these solutions, the Saint-Gobain Superabrasives plant in Worcester, formerly Norton Abrasives, specializes in superabrasive grinding wheels ("superabrasives"). These wheels are used in the electronics, gas, and medical industries for high precision and high performance manufacturing processes, particularly those involving the grinding of high-strength alloys. Superabrasives also provide enhanced durability and life cycles, suitable for high-productivity requirements.

Problem Statement

The superabrasives plant operates as a jobshop, with wheels being made to order with a high variety of specifications. The high variability in the wheel configurations translates to a complex manufacturing process and variable processing times. This complexity can lead to difficulties maintaining optimal operations, resulting in longer lead times, periods where stations are over capacity, and increased late orders, hurting Saint-Gobain's customer satisfaction and future growth prospects.

Project Goals & Objectives

The goal of this project was to reduce the lead times of Saint-Gobain's large resin superabrasives product line, which would increase order fulfilment and reduce overtime hours while improving customer satisfaction. We analyzed wheel production data to determine the areas for the most potential for improvement. With the key bottlenecks identified, we conducted several Gemba walks at the plant to understand the constraints these stations were facing. We determined that improvements could be made in workspace organization and workflow standardization in order to improve operator processing times, leading to a decrease in product lead time.

Project Deliverables

The project deliverables consisted of a value stream map; documented 5S improvements, both implemented and proposed; and operator process standard work documents incorporated into the workplace for two bottleneck operations.

Scope

We defined the scope to making improvements at the stations where there was most waste, which were the siding operation and the outer diameter (OD) grinding machine. Initially, we identified two main components that affect Saint-Gobain's superabrasives production line, which are order scheduling and floor-level operations. While the plant's make-to-order production scale would benefit from load-balancing, the order scheduling system was extensive and used throughout the entire plant, making implementation within our timeframe difficult. Regarding workflow, the plant has a number of limitations that make process improvement at a large scale difficult. We focused on high-impact solutions at a operation scale to increase potential for implementation within our timeframe.

Report Structure

The report covers the basics of the manufacturing process of superabrasive wheels and then outlines how we used a value stream map (VSM) to identify potential points of improvements in the plant, which is followed by our methodology of implementing 5S and standard work. Afterwards, we discuss the results obtained from the data we obtained, the conclusions drawn from our results, and further recommendations for the company.

II. Background and Methodology Overview

Manufacturing Process at Saint-Gobain

Grinding Wheels

Grinding wheels are made of naturally-occurring or synthetic abrasive minerals bonded together in a matrix to form a wheel ("Grinding Wheel," n.d.). They vary in size, shape, and material, depending on their intended use, as defined by the customer. Their use in the manufacturing industry includes, but is not limited to, sharpening tools, cutting metals, and preparing surfaces for painting or plating. These wheels provide an efficient way to shape and finish metals and other materials.

Superabrasive grinding wheels are a subset of grinding wheels characterized by higher grinding performance. These wheels utilize diamond or cubic boron nitride (CBN) as the grinding medium.

Materials used for grinding wheels

The main components of grinding wheels are abrasive grains, bonding material, fillers, and core material. The type of abrasive determines the effectiveness of the wheel in cutting various materials; diamond is used for non-ferrous material and CBN is used for ferrous material. The bonding material adheres the abrasive grains together, giving the wheel its durability. While some grinding wheels are entirely composed of abrasive or bond material, many of them follow the structure of two main components: a core with the abrasive material attached as an outer rim or side layer. There are other shapes of grinding wheels, but the superabrasives manufactured in the plant we focused on are typically in the form of 1A1 or 6A2 (Figure 1). The cores used for Saint-Gobain's superabrasives are primarily steel, aluminum, or resin-based.

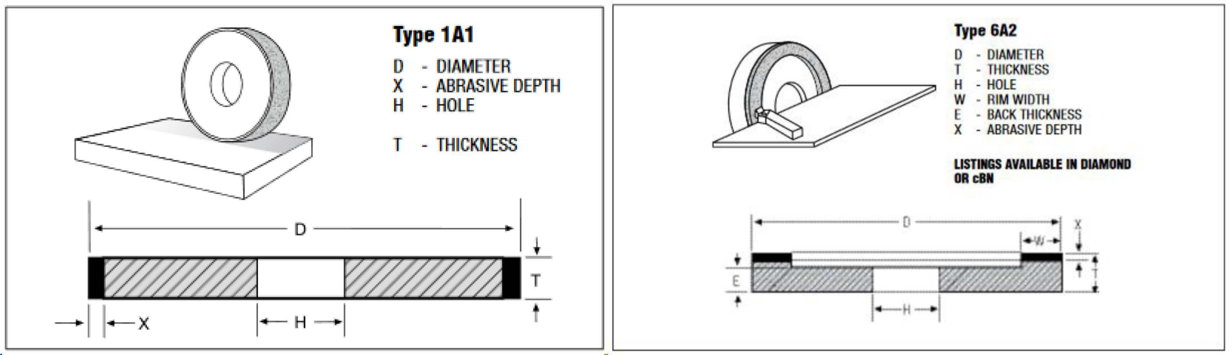

Figure 1. A typical grinding wheel with an outer abrasive rim (left) and with abrasives on the side (right) (Saint-Gobain, 2014).

Manufacturing Process

The typical manufacturing process of superabrasive grinding wheels consists of mixing, molding, firing, and finish machining of the product. During the mixing process, the ingredients used to make the wheels, abrasives, bond materials, and additives, are mixed according to a designated formula. The blend of ingredients is designed to be free-flowing and distribute grain evenly throughout the structure of the grinding wheel to assure uniform cutting and minimal vibration ("Manufacturing Process of Grinding Wheels," n.d.).

Eventually, the wheels are moved to the finishing area, where arbor holes are reamed or hubs are cemented to sides and the wheel circumference is made concentric with the center. Additionally, corrections to the wheel's thickness and contouring are done; large wheels might be balanced to reduce the vibrations that occur when the wheel is spun ("Grinding Wheel," n.d.). The wheels are then marked and prepared for shipping. The typical and simplified process for specific types of wheels are described in Figure 2. In this figure, the "children" works in process (WIP) are subcomponents that are manufactured individually and later come together to form the top-level WIP which is designated the "parent".

Figure 2. The flow of operations at Saint-Gobain for manufacturing large resin superabrasive grinding wheels.

Finishing Process

This project focuses specifically on the finishing process at Saint-Gobain, particularly the siding and OD grinding processes at the siding operation machine and OD grinding machine machine, respectively. These processes are summarized in Figure 3.

Figure 3. A value stream map for the three main stations in finishing, with times derived from 22 months' worth of production data.

The siding operation grinds the flat side of the wheel. The siding process specifically removes excess material from the two flat faces of the wheel. This step follows cementing in the manufacturing process and has a mean cycle time of 55 minutes per production order but varies highly with different wheel configurations (see Appendix A). There are two shifts operating the siding operation totaling 20 hours per day, with an additional shift added when demand is high or if there is an accident on the work floor involving the operators. During 2017 and 2018, approximately 550 large resin orders went through the siding operation, making this machine essential. This significance resulted the station becoming a key bottleneck.

The OD grinding machine grinds excess material from the outer circumference of wheels to meet diameter specifications and to open the face of the abrasive material, detailed in Appendix B. This step typically follows boring the inner diameter of the wheel. The mean cycle time is 50 minutes and varies with abrasive hardness. There are two shifts that operate the OD grinding machine, totaling 16 hours per day. During 2017 and 2018, 350 large resin orders were processed on this machine.

Project Goal

The goal of this project was to reduce the lead times of Saint-Gobain's large resin superabrasives product line, which would increase order fulfilment and reduce overtime hours while improving customer satisfaction. The timeframe and methodology used is summarized in Figure 4.

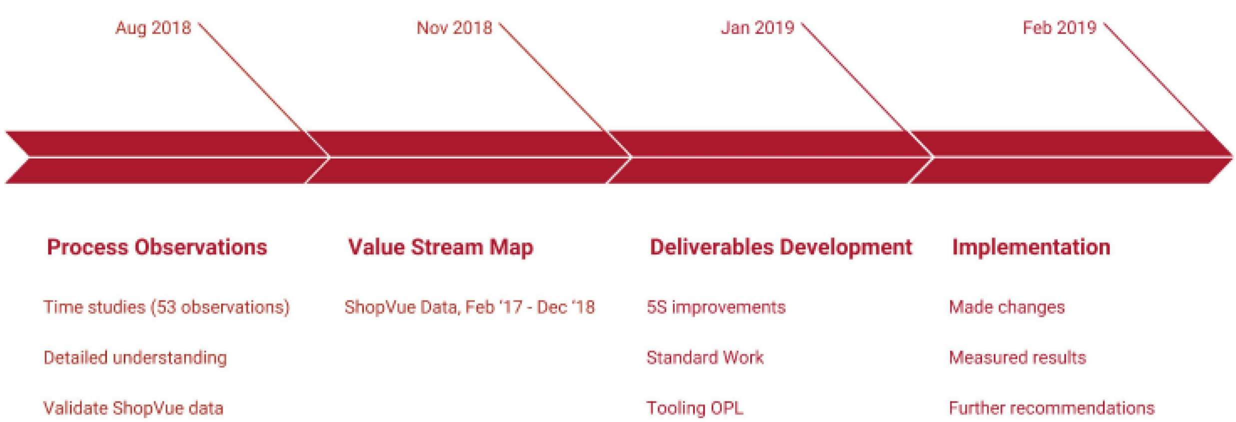

Figure 4. Timeline of the methodology used in this project.

III. Value Stream Mapping

Introduction to Value Stream Mapping

Value stream mapping is a form of process mapping that illustrates cycle times, queue times, and other relevant data in order to assist in visualization of the process as well as highlight value-added and non-value-added times (What is Value Stream Mapping (VSM)?, n.d.). VSM's may aid in identifying delays, excess inventory, and other areas for improvement. The value in utilizing a VSM then comes from being able to focus efforts where improvement is most needed.

Value stream mapping begins by defining the scope and selecting a process family to map. Mapping the flow and structure of operations to obtain a process map to which information may be added, allowing effort to be focused on where improvement is most needed (Pearson, 2018).

Rationale

In order to quantitatively identify the key bottlenecks in Saint-Gobain's manufacturing process for large resin superabrasive wheels, we decided to create a value stream map of the overall process. Employees at the plant find that the siding operation is the main bottleneck, and we aimed to verify this with the data they provided us. Analyzing the production data and creating a value stream map allowed us to evaluate the performance of each station in the context of the whole manufacturing process. Due to the long lead times and low volume nature of large resin superabrasive grinding wheels at Saint-Gobain, we concluded it would be infeasible to get enough data for statistically significant conclusions by conducting time studies. As such, we determined to use production data as the base for our analysis.

Methodology

Process Familiarization

Even with the Gemba walks and past projects to reference, the information presented to us was difficult to conceptualize and appropriately filter without extensive study of the process on site, as we were unfamiliar with what the operations entailed. In order to familiarize ourselves with the overall process, we referenced the previous MQP's VSM while conducting Gemba walks and taking further observations. This aided us in understanding which stations were relevant to which types of wheels, which was important to note because the manufacturing process of Saint-Gobain's wheels varies depending on their specifications. With this knowledge, we were able to assess the previous MQP's VSM and identify parts of their mapped process that we deemed irrelevant due to the low volume of wheels that would require those operations. Understanding stations and operations relevant to large resin superabrasive grinding wheels and how they were represented in the production data allowed us to appropriately filter the data and create our VSM.

Data Validation

Engineers at Saint-Gobain provided us with production data that detailed the recorded timings of each order as they went through each step in the manufacturing process. As orders progress through stations, the operators scan the production order twice: once at the beginning to log when they begin working on the wheel and once at the end when their operation is completed. For each operation, a number of statistics are derived from these two recorded data points, such as queue time, cycle time, how late the order is, etc. The data provided to us spanned February 2017 through December 2018 and consisted of records for 277 orders.

To ensure that we would get credible results, we decided to evaluate the quality of the production data, namely by learning about the manner in which the data was recorded. We learnt from discussion with employees and observations of operators that there exists a small degree of error in the production logs. Occasionally, operators may correct a forgotten starting scan by scanning the order as it finishes, which produces a total time of zero. Similarly, there were some entries with comparatively long cycle times. Overall, these inaccuracies made up a minority of the records, and engineers at Saint-Gobain estimated that the production data was roughly 80% accurate. We attempted to evaluate this claim by conducting time studies at the siding operation and the OD grinding machine, but due to time constraints, much of our recorded data is biased towards shorter values.

Data Processing

With the consideration of both the relevant processes to our scope and the nature of the inaccurate data points, we were able to appropriately assess the data. Using SQL Server Management Studio, we filtered out records with cycle time values of NULL or 0, as well as disregarded any records where the operation finished on a different day than it started. Seeing as the cycle time statistic was calculated by the difference between the finish and start time for the operation, orders that were started one day and finished the next would have inflated cycle times due to the time spent idle overnight. The queries performed and the resulting times are detailed in Appendices C and D, respectively. Figure 5 is the completed VSM with times included.

Figure 5. Completed VSM with cycle and queue times

The VSM indicates that some of the longest cycle and queue times belong to the mixing, molding, and apply to assembly processes. Upon inquiring about improvements for these processes, however, we realized that implementing process improvements would likely be infeasible for this project. As such, we focused on the finishing processes (i.e., siding, boring, and facing), prioritizing the siding operation and then the facing operation, as they respectively had the first and second longest combined cycle and queue times.

IV. Process Improvement

We worked on implementing standard work and 5S processes in the siding and OD grind machines following the identification of the finishing process as our main area of focus through the development and analysis of the Value Stream Map. In the following sections, we go more in depth on our process for implementation of the standard work and 5S methodologies, in that order.

Standard Work

Introduction to Standard Work

Standard work is a detailed definition of the current best practices for performing an activity or process, which is efficiently organized and easily repeatable by anyone in the workplace (Millard, 2016). Standard work aims to allow operators to work efficiently without wasteful motions, set standards for and allow visibility of areas of improvements, reduce variability between operators, highlight variation inherent in the process, and aid in other improvement activities.

The main components needed to create adequate standard work documentation are takt time and identifying a well defined work sequence (Millard, 2016). Takt time is used to determine the rate at which the company should be producing a certain product to satisfy customer demand. Takt time is determined by using data that is collected through time studies or provided by the company for a certain work cell. Takt time is then used as the maximum time threshold it should take an operator to complete the observed operation (Abreu et al., 2016).

Once takt time is determined, a well defined work sequence must be established. Determining the current work sequence is achieved through observations made during time spent on the floor and interviewing operators and supervisors of the area of interest. Once the current work sequence is identified, steps in the process that show the most variability are identified and standardized. The work sequence identified must reduce variability between operators and must be easy to reproduce by anyone in the company (Abreu et al., 2016).

Once all of these components are determined, the final step is creating a standard work document. A standard work document contains detailed instructions on preferred actions, useful graphics to aid the workers, the prescribed order sequence of the process in question, and appropriate times for each of the steps in the operation to be completed. The document should convey this information effectively.

Implementation of enhanced standard work documents in the siding and OD grinding operations at Saint-Gobain should further improve productivity at the plant. ThyssenKrupp, one of the largest global technology groups in the world, implemented standard work at one of its main plants in Campo Limpo, Brazil. The implementation of standard work in their facility led to 40% reduction in WIP, 1500 fewer meters per day of operator movement, 9% improved productivity, improved operator satisfaction, and improved safety conditions (Guerra et al., 2009).

As demonstrated by ThyssenKrupp's efforts, having a standard work document makes the process more organized and makes improvement opportunities more apparent for the company. Benefits of standard work include increased productivity, elimination of all types of waste (particularly the waste of motion), and facilitating the implementation of further improvements by easily integrating them into the actions of all employees.

Rationale

Due to limited job-specific documentation, training new operators and standardizing operations has historically been difficult at Saint-Gobain. Most of the knowledge on how to operate the machines at Saint-Gobain is effective but tribal; it has been passed down by word of mouth from operator to operator throughout the years as iterative knowledge without written SOPs. To formalize this information, Saint-Gobain started developing work instructions for their work stations but have not done so for the siding operation and OD grinding machine yet. In an effort to mitigate errors and standardize operations in the finishing operations at Saint-Gobain, we believe that developing standard work documents for their work stations is important. Having standard work documents will reduce lead time in their manufacturing process, reduce the time it takes to train operators, and assist managers in identifying potential areas of improvements.

Methodology

We researched standard work formats online (Figures 5 and 6) and those currently used in Saint-Gobain. Of the formats we found online, most focused on graphical representations of different aspects of the process. Keeping that in mind, our solution is mainly based on the standard work document Saint-Gobain has for another area of the plant.

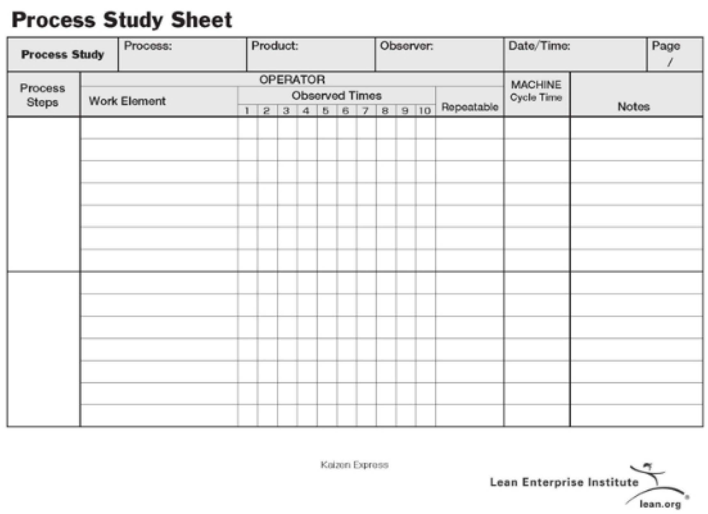

Figure 6. Example of Standard Work (Lean Enterprise Institute, 2012)

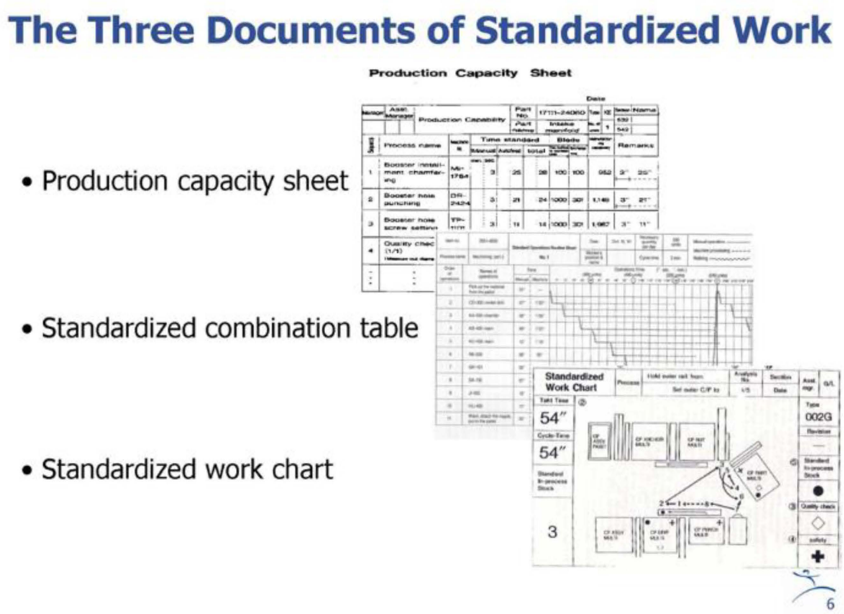

Figure 7. Different Types of Standard Work (Lean Enterprise Institute, 2019)

To construct our standard work for the siding operation and the OD grinding machine, we conducted time studies (see Appendix A) and observations at the machines. In total, we had 53 time studies, taken during November and December 2018, at different times of the day. Through our observations over the course of several weeks, we constructed process maps for both machines (see Appendices A and B) and translated them to linear steps to fit the standard work format. Each step included a standard time the operator should take to perform the step. These times were based on observations as well as operator and supervisor input. Conducting detailed observations and documenting the process contributed to our understanding of the processes, which was necessary to construct an impactful standard work document.

Operator Feedback

Getting feedback from the operators was crucial to developing standard work documents, as they helped us better understand every step of the process within their work cell. For this part, we created a separate document with the process steps observed and printed it to show to operators and get their feedback. During our interview with the operators, we asked them to verify the order of the steps as well as identify any variable steps to ensure the accuracy of our observations. Later, we asked them about any regulations and safety steps set in place to get a better understanding of any safety concerns and address them in our document. Finally, we asked them about the approximate amount of time each process step should take and noted them down (see Appendix E) .

During these discussions with operators, they voiced difficulty in keeping track of which tooling configurations corresponded to different wheel specifications. This difficulty necessitated the operators to find and consult previous, more experienced operators in order to ascertain the correct tooling to use. This was a clear source of waste in motion, so we consulted management regarding possible solutions, and we agreed upon creating tooling reference charts—or OPLs (One Point Lessons)—to describe which wheel specifications necessitate which tooling configurations.

Writing the Standard Work Document

Once we finished the interviews with the operators, we started to make the standard work document for the siding operation. In order to keep a standard format, we used the standard work for another operation provided by Saint-Gobain as the template. We included the process steps identified, the type of operation, the time estimate for each operation, visual references, and safety measures and regulation checks (see Appendices F, G, and H).

Regarding the tooling OPL for the siding operation, we gathered all operators with experience and consolidated their knowledge into a simplified chart (see Appendix H). We intended to create an equivalent OPL for the OD grinding machine's tooling; however, we were unfortunately constrained by time and found that the OD grinding machine's tooling requirements would entail more complex means. As such, we have provided Saint-Gobain with a skeleton OPL document (see Appendix J) and recommend that they further pursue this matter with their operators and engineers.

Implementation and results

The standard work and OPL documents were printed, laminated, and given a dedicated location in the workplace for both the stations. Operator feedback was positive, and the document was adopted into the workflow. To measure the impact, we conducted additional time studies of the operators following the standard work document and compared it to the initial time studies. For more conceptual feedback, we had a newly hired operator use the standard work and acquired feedback. The final deliverables can be found in Appendices F through J.

5S

Introduction to 5S

5S is a methodology used to organize workspaces, typically with the following steps: Sort, Set in Order, Shine, Standardize, and Sustain. A workspace with 5S implementation should be free of clutter, utilize visual control, and reduce waste in operator motion. The 5S method is described as follows by the American Society of Quality (n.d.).

Sort describes the step of removing unnecessary items. Typically a red tag area is set up for items to be reviewed for removal. Sorting decreases the waste of finding the right item for the task, eliminates physical obstacles, and increases available space.

Set in Order describes the step of organizing items in optimal and logical places. This step further reduces the waste of motion by placing necessary items nearby and reduces the waste of time used finding the correct item. Additionally, with each item having a fixed location, operators can more easily identify clutter and misplaced items.

Shine describes the step of maintaining a clean workspace. A clean workspace should enhance safety, visual control, and familiarity. The space and items within the space should be routinely inspected and cleaned.

Standardize ensures frequent application of the previous steps, typically with standard schedules and processes implemented. Frequent review of the workspace, reference to visual standards, and audits constitute the Standardize step.

Sustain is the final step of 5S with the goal of ensuring that the previous steps are accomplished throughout the workplace. This step establishes and maintains a culture of 5S, typically through training sessions, kaizen events, and further audits.

A review of the 5S implementation in the siding operation and OD grinding machine areas can potentially increase productivity and reduce lead times. Case studies such as Veres et al.'s have shown positive correlations between 5S audit scores and productivity in manufacturing environments. Additionally, Patel and Thakkar show that the awareness and sustaining of 5S increase employee morale by enabling a better working environment (2014). We expect that performing a 5S review in the siding operation and OD grinding machine areas will produce similarly positive results.

Rationale

While Saint-Gobain has implemented 5S throughout its plants, some areas have more extensive implementation than others. In particular, in the previous state of the workspace, the siding operation had many potential areas for 5S review. During our inspection of the area, we identified several unused items and items that would benefit from further organization. The OD grinding machine had fewer unused items, but operators commented that many of the tools used could be organized further. In both areas, 5S review could reduce the time taken to find the correct tools, clear up the workspace, and lead to a reduction in lead time.

Due to procedural limitations, we were only able to implement solutions for Sort and Set in Order, and our solutions for Shine, Standardize, and Sustain were submitted at the proposal level.

Methodology

Sort

We set up a red tag area within the siding operation workspace and interviewed one of the operators about the usage frequency of their tools. We compiled that list and classified each item's use frequency as every wheel, daily, weekly, monthly, or never (see Appendix J). We ran this list by the operators' supervisor and proceeded to place unused items in the red tag area for review. Figure 8 shows some of the effects of sorting in the area. The list of items removed can be found in Appendix K.

Figure 8. Storage cabinet before (left) and after (right) red tagging the siding operation machine

We interviewed two OD grinding machine operators and found that there were minimal items to remove. Thus, we moved forward with implementing Set in Order solutions for the siding operation and OD grinding machine workspace.

Set in Order

The team created and implemented organizational solutions for the siding operation and the OD grinding machine areas. We discussed ideas with the operators and their supervisor and proposed a number of options. The team then moved forward with implementing some of these solutions to decrease clutter and set determined locations for each item. The concepts for these areas and improvements came from a combination of passive observation, operator interviews, and supervisor consultations.

Continuing from the list of use frequency by item, we considered the organization of the items most often used in the siding operation first. These items included blocking plates, stationery, a mallet, and other items that were already found on the workbench. We produced solutions outlined in Appendix L and worked with the area supervisor to implement them into the workspace.

We suggested that the blocking plates be organized by thickness in sets of three and placed on racks (Figure 9). In the previous state of the workspace, the operator would spend time shuffling through a pile of plates to find the appropriate set for the current wheel. To decrease the time required to find the correct plates, we suggested having specific slots and colors for each set. Both the rack and the plates themselves would have corresponding colors to enhance visual control and decrease wasted motion.

Figure 9. Proposed blocking plates organization.

To further organize the workbench areas, we suggested relocating several key items. Stationery items in the siding operation area could be located in a deskside tray, while currently they are strewn across the desk. The mallet, which is used to set the blocking plates in place during the siding operation, would be located on a pinboard by the workbench, as close as possible to the interaction area. Gloves and wipes for both the siding operation and the OD grinding machine would also be removed from the desktop to the desk underside, which still allows easy access but reduces clutter at the work area.

The OD grinding machine workbench was already mostly organized, but we found that there could be an improvement in the location of the operators' most common tools. These were tools such as the wrenches needed to place the grinding wheel into the machine. The current solution places these tools in a drawer under the workbench. Our solution suggests locating the tools on a pinboard attached to the workbench (Figure 10). The tools would be more accessible, and the operator would not have to open a drawer to find them.

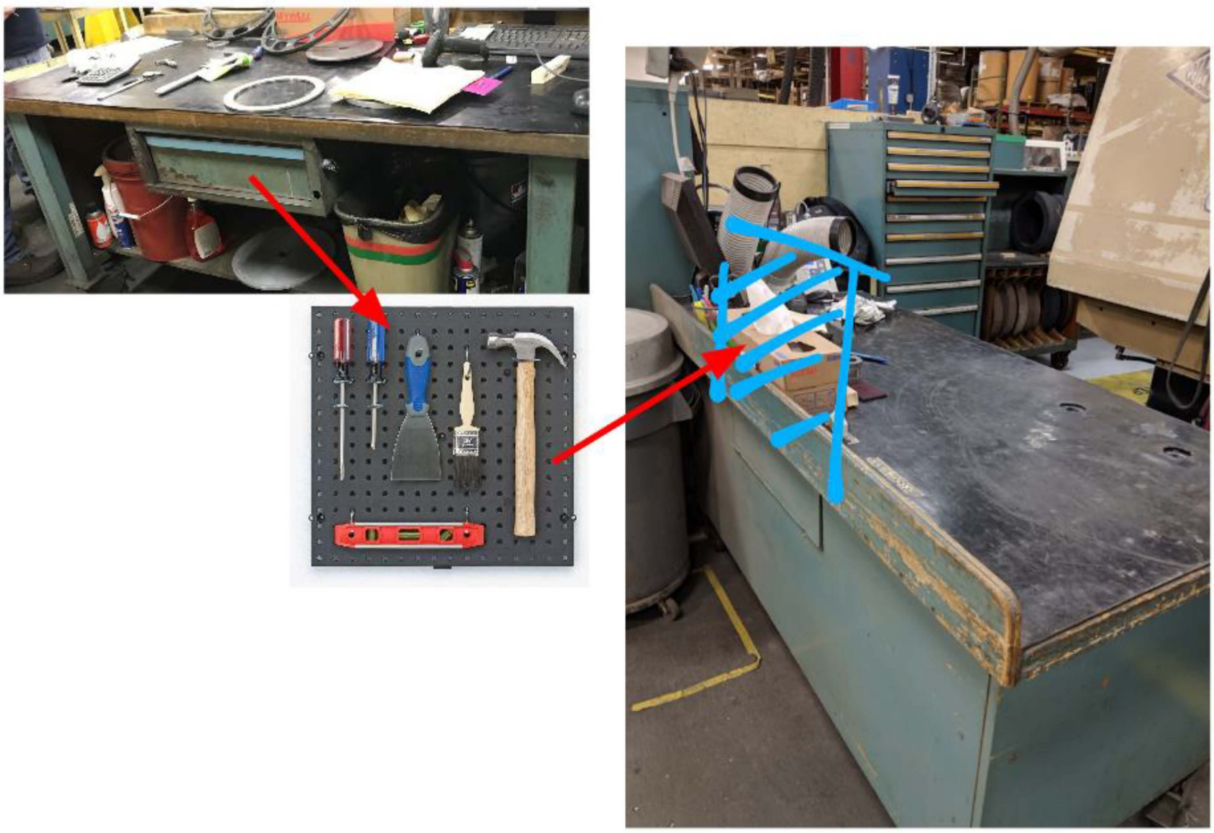

Figure 10. Proposed relocation of commonly used tools in the OD grinding machine area.

The bushings, which are used for every order on the OD grinding machine, would require a more thorough organizational solution. Figure 11 shows the current state of the bushings shelf, in which each bushing has a dedicated slot. Approximately a third of the bushings are sorted by diameter, while the remaining are not sorted in a particular order. A reference sheet on the shelf matches slots with bushings, but this is also not sorted in a particular order, and the mixed units of measurement used on these sheets add additional confusion. One of the operators stated that he typically requires five to ten minutes to find the correct bushing for each order, with the effort sometimes taking as long as half an hour. Our solution to reduce the searching time is to sort and color code the bushings by diameter and more consistently label the reference sheets to reflect each bushing. For example, each bushing would be labeled with diameters in both millimeters and inches to aid in searching. This would provide additional visual control and encourage operators to return bushings to their correct slots.

Figure 11. Bushings shelf - note insufficient capacity and reference sheet on the side.

The major implementation was the creation of the "Order being worked on" area. To prevent the slow creep of clutter on the desk, the free area of the desk is now taped off to establish defined borders between an active area and a storage area (Figure 12). This addition helps operators perform a quick and intuitive visual check on workbench clutter.

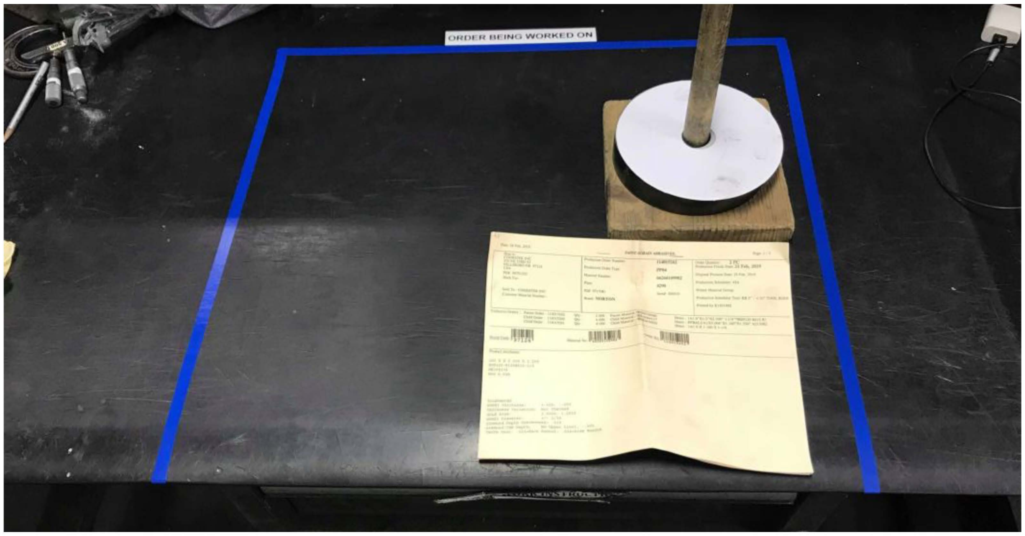

Figure 12. Implemented dedicated work area labeled "Order being worked on".

Shine, Standardize, and Sustain

We developed proposals in the last three S's (Shine, Standardize, Sustain) that Saint-Gobain could implement when time allowed. These proposals were presented in detail to Saint-Gobain in a presentation format along with the Sort and Set in Order implementations.

We proposed that implementing Shine in the workspace would require making the action of cleaning less inconvenient to the operators. Cleaning tools, such as rags and brooms, should be kept near the common entry point to encourage cleaning after a shift. Further encouragement to keep the workspace, machinery, and tools clean would be provided through daily cleaning checklists outlined as part of the Standardize step.

As part of the Standardize step, we propose several standards to assist the organization of the workspace. Currently, the siding operation has visual standards set up for the workbench. This document is located at the side of the machine. However, it would potentially be useful to also have visual standards for the machine area and the overall workspace. Additionally, having a checklist for items that the operator would need to clean on a regular basis should encourage the maintenance of the work area as a regular routine.

Lastly, to ensure the maintained success of the four previous steps, we developed proposals for the Sustain step. Since we began the process of 5S with red tagging and because useless items tend to accumulate over time without the operators noticing, we proposed that there should be a dedicated red tag area at all times on the plant floor. A dedicated red tag area actually used to be a part of the workfloor at Saint-Gobain in the past, so the implementation of this recommendation should not be too difficult. This area would be accessible by all operators and would serve as a key part of 5S audits. We also recommend starting semiannual 5S presentations to encourage ideas to be shared across the workfloor. The sharing of ideas and bridging of practices across areas would also tie back to standardizing since operators could understand how different areas operate and facilitate coordination of visual standards.

Additionally, Saint-Gobain established a dedicated 5S team and updated their audit procedures towards the end of this project's timeline. We expect the addition of this team and the updating of the procedures to help with the future 5S improvements. Our complete proposal can be found in Appendices M and N.

V. Results

Comparing previous state time studies (n=53) to the new current state time studies (n=3), the siding operation time was reduced by 37% and the OD grinding operation time was reduced by 60%. These times do not consider the time the machine takes to work on the wheel as this time varies much depending on the wheel configuration. There may be other factors in the time reduction in addition to the standardization of the process, such as awareness of the time studies and general variation in the cycle times.

In addition to quantitative results, feedback from operators also provided positive qualitative results. Their feedback supports our results as they agreed with the order of the steps and approximate times assigned to each step for the standard work documentation. Operators also appreciated the additional 5S implementation in their workspace.

VI. Conclusion

During the course of this project, we found that Saint-Gobain can benefit from improvements targeted towards organizational and informational improvements at the operator level finishing area. By identifying stations with comparatively longer cycle times, we found that the siding operation and OD grinding machine were bottlenecks in the manufacturing process. From assessing the workspace, we found that operators in the finishing area can be more productive following a 5S review and an implementation of standard documents. Improvements in workspace organization and information accessibility can lead to a higher ratio of value-added to non-value-added time. Focusing improvements on the bottleneck of the finishing area, we were able to target improvements towards where they could provide the most impact.

Employees at Saint-Gobain showed familiarity with the improvements we proposed, and this showed the potential of bringing their skills and experience into the consideration of process improvement. Operators and supervisors responded positively to a more rigorous implementation for standard work and OPL and the 5S review. These procedures further encouraged them to provide their suggestions. There are a number of pending proposals from our project that were developed from those suggestions that could be implemented in the future.

VII. Further Recommendations

Following the positive feedback we received from the standard work documents, we recommend following similar procedures to further review standard work and OPL documents throughout the plant. In addition to reducing variation and potentially further reducing lead time, these procedures also provide additional access to the operators' skills and experience. Continuing review of standard work and OPL documents can potentially further increase employee satisfaction at the plant.

With the recent formation of a 5S committee, Saint-Gobain can also potentially exceed current 5S standards at other locations in the plant. It may be helpful to review 5S audit procedures and ensure that continuous improvement continues to be encouraged throughout Saint-Gobain. This will allow 5S culture to strengthen and potentially identify and reduce more waste in the future.

Further conducting time studies will also help with future process improvement projects, as future project teams will be able to have a stronger understanding of the current state to which they would compare a future state.

VIII. Reflections

Engineering design in our project constituted process analysis and improvement and the consideration of human factors in the system. We established clear objectives and evaluation criteria in which our project was framed. Our methodology was directly connected to our objectives, which were the constituents of our overall goal. This process involved several decisions that had to consider the constraints of the system.

Much of the decisions in terms of what would be implemented were constrained to economic and safety limitations. To increase the probability of implementation, we took into consideration of how much of the process uptime we would be taking. We avoided solutions that would require much machine downtime, which would affect Saint-Gobain's productivity. Additionally, we scheduled our subproject timelines based around response times. With such volume through their communications, we did not expect immediate responses on requests such as those for datasets and documents. We therefore planned much of our subprojects ahead of time to account for response times.

During this project, our group was able to gain first-hand experience of working in a manufacturing environment and the constraints of the facility. We learnt about the importance of including operators in the process of making process improvements. Getting feedback from operators was important in this process because it allowed a higher level of ownership over the changes, which made implementation easier. The most valuable learning experience that we felt we learnt outside coursework was interacting with the various stakeholders in the system. Putting that skill into practice led to valuable professional development. While much of the knowledge we used during the project we learnt in classes, applying this material solidified our understanding of the tools we used. Additionally, working on this project allowed us to learn about standard work and OPL, which we had not formally encountered previously.

We developed a collaborative environment by using collaborative online tools where we could all access our resources and data. Everyone had access to literature sources, drafts, communication, raw data, and processed information. Our frequent meetings allowed us to stay on track and rapidly produce solutions. In these meetings we were able to precisely keep track of tasks and ensure that progress was made at a steady pace.

By splitting up the project into smaller subprojects, we could individually focus more on our tasks. While our smaller teams worked effectively and out of each other's ways, we continued to ensure that everyone was aware of the overall progress. When a team required additional help, we were able to coordinate resources accordingly to complete the task.

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X. Appendices

Appendix A: Siding Operation Siding Process

Appendix B: OD Grinding Machine Facing Process

Appendix C: Queries Used for VSM Timings

--Get stats for orders at Weigh Diamond, grouped by operation

```
SELECT Operation, COUNT(Operation) AS Count,
AVG(EstimatedExecutionTimehours) AS AvgEstEx,
AVG(CycleDiffHours) AS AvgDiff, AVG(ActualCycleTimeHours) AS
AvgCycle,
STDEV(ActualCycleTimeHours) AS StdvCycle, AVG(QueueTimeDays)*24
AS AvgQueue, STDEV(QueueTimeDays)*24 AS StdvQueue, Avg(QtyDue)
AS AvgQty
FROM dbo.WorkCenter$
WHERE WorkCenter = 200
AND ActualCycleTimeHours IS NOT NULL
AND ActualCycleTimeHours < 16
AND ActualCycleTimeHours > 0
AND CONVERT(Varchar,FirstActivityTime,1) =
CONVERT(Varchar,LastActivityTime,1)
GROUP BY Operation
ORDER BY Count DESC
```

--Get stats for orders at Mix Diamond, grouped by operation

```
SELECT Operation, COUNT(Operation) AS Count,
AVG(EstimatedExecutionTimehours) AS AvgEstEx,
AVG(CycleDiffHours) AS AvgDiff, AVG(ActualCycleTimeHours) AS
AvgCycle,
STDEV(ActualCycleTimeHours) AS StdvCycle, AVG(QueueTimeDays)*24
AS AvgQueue, STDEV(QueueTimeDays)*24 AS StdvQueue, Avg(QtyDue)
AS AvgQty
FROM dbo.WorkCenter$
WHERE WorkCenter = 120
AND ActualCycleTimeHours IS NOT NULL
AND ActualCycleTimeHours < 16
```

```
AND ActualCycleTimeHours > 0
AND CONVERT(Varchar,FirstActivityTime,1) =
CONVERT(Varchar,LastActivityTime,1)
GROUP BY Operation
ORDER BY Count DESC
```

--Get stats for orders at Mold/Press Diamond, grouped by operation

```
SELECT Operation, COUNT(Operation) AS Count,
AVG(EstimatedExecutionTimehours) AS AvgEstEx,
AVG(CycleDiffHours) AS AvgDiff, AVG(ActualCycleTimeHours) AS
AvgCycle,
STDEV(ActualCycleTimeHours) AS StdvCycle, AVG(QueueTimeDays)*24
AS AvgQueue, STDEV(QueueTimeDays)*24 AS StdvQueue, Avg(QtyDue)
AS AvgQty
FROM dbo.WorkCenter$
WHERE WorkCenter = 133
AND ActualCycleTimeHours IS NOT NULL
AND ActualCycleTimeHours < 20
AND ActualCycleTimeHours > 0
AND CONVERT(Varchar,FirstActivityTime,1) =
CONVERT(Varchar,LastActivityTime,1)
GROUP BY Operation
ORDER BY Count DESC
```

--Get stats for orders at Bake, grouped by operation

```
SELECT Operation, COUNT(Operation) AS Count,
AVG(EstimatedExecutionTimehours) AS AvgEstEx,
AVG(CycleDiffHours) AS AvgDiff, AVG(ActualCycleTimeHours) AS
AvgCycle,
STDEV(ActualCycleTimeHours) AS StdvCycle, AVG(QueueTimeDays)*24
AS AvgQueue, STDEV(QueueTimeDays)*24 AS StdvQueue, Avg(QtyDue)
AS AvgQty
```

```
FROM dbo.WorkCenter$
WHERE WorkCenter = 145
AND ActualCycleTimeHours IS NOT NULL
AND ActualCycleTimeHours < 20
AND ActualCycleTimeHours > 0
AND CONVERT(Varchar,FirstActivityTime,1) =
CONVERT(Varchar,LastActivityTime,1)
GROUP BY Operation
ORDER BY Count DESC
```

--Get stats for orders at Apply to Assembly, grouped by operation

```
SELECT Operation, COUNT(Operation) AS Count,
AVG(EstimatedExecutionTimehours) AS AvgEstEx,
AVG(CycleDiffHours) AS AvgDiff, AVG(ActualCycleTimeHours) AS
AvgCycle,
STDEV(ActualCycleTimeHours) AS StdvCycle, AVG(QueueTimeDays)*24
AS AvgQueue, STDEV(QueueTimeDays)*24 AS StdvQueue, Avg(QtyDue)
AS AvgQty
FROM dbo.WorkCenter$
WHERE WorkCenter = 162
AND ActualCycleTimeHours IS NOT NULL
AND ActualCycleTimeHours < 20
AND ActualCycleTimeHours > 0
AND CONVERT(Varchar,FirstActivityTime,1) =
CONVERT(Varchar,LastActivityTime,1)
GROUP BY Operation
ORDER BY Count DESC
```

--Get stats for orders on siding operation, grouped by operation

```
SELECT Operation, COUNT(Operation) AS Count,
AVG(EstimatedExecutionTimehours) AS AvgEstEx,
AVG(CycleDiffHours) AS AvgDiff, AVG(ActualCycleTimeHours) AS
```

```
AvgCycle,
STDEV(ActualCycleTimeHours) AS StdvCycle, AVG(QueueTimeDays)*24
AS AvgQueue, STDEV(QueueTimeDays)*24 AS StdvQueue, Avg(QtyDue)
AS AvgQty
FROM dbo.WorkCenter$
WHERE WorkCenter = 155
AND ActualCycleTimeHours IS NOT NULL
AND ActualCycleTimeHours < 20
AND ActualCycleTimeHours > 0
AND CONVERT(Varchar,FirstActivityTime,1) =
CONVERT(Varchar,LastActivityTime,1)
GROUP BY Operation
ORDER BY Count DESC
```

--Get stats for orders on Large Lathe, grouped by operation

```
SELECT Operation, COUNT(Operation) AS Count,
AVG(EstimatedExecutionTimehours) AS AvgEstEx,
AVG(CycleDiffHours) AS AvgDiff, AVG(ActualCycleTimeHours) AS
AvgCycle,
STDEV(ActualCycleTimeHours) AS StdvCycle, AVG(QueueTimeDays)*24
AS AvgQueue, STDEV(QueueTimeDays)*24 AS StdvQueue, Avg(QtyDue)
AS AvgQty
FROM dbo.WorkCenter$
WHERE WorkCenter = 152
AND ActualCycleTimeHours IS NOT NULL
AND ActualCycleTimeHours < 20
AND ActualCycleTimeHours > 0
AND CONVERT(Varchar,FirstActivityTime,1) =
CONVERT(Varchar,LastActivityTime,1)
GROUP BY Operation
ORDER BY Count DESC
```

--Get stats for orders on OD grinding machine, grouped by operation

```
SELECT Operation, COUNT(Operation) AS Count,
AVG(EstimatedExecutionTimehours) AS AvgEstEx,
AVG(CycleDiffHours) AS AvgDiff, AVG(ActualCycleTimeHours) AS
AvgCycle,
STDEV(ActualCycleTimeHours) AS StdvCycle, AVG(QueueTimeDays)*24
AS AvgQueue, STDEV(QueueTimeDays)*24 AS StdvQueue, Avg(QtyDue)
AS AvgQty
FROM dbo.WorkCenter$
WHERE WorkCenter = 157
AND ActualCycleTimeHours IS NOT NULL
AND ActualCycleTimeHours < 20
AND ActualCycleTimeHours > 0
AND CONVERT(Varchar,FirstActivityTime,1) =
CONVERT(Varchar,LastActivityTime,1)
GROUP BY Operation
ORDER BY Count DESC
```

--Get stats for orders at Balance & Oil, grouped by operation

```
SELECT Operation, COUNT(Operation) AS Count,
AVG(EstimatedExecutionTimehours) AS AvgEstEx,
AVG(CycleDiffHours) AS AvgDiff, AVG(ActualCycleTimeHours) AS
AvgCycle,
STDEV(ActualCycleTimeHours) AS StdvCycle, AVG(QueueTimeDays)*24
AS AvgQueue, STDEV(QueueTimeDays)*24 AS StdvQueue, Avg(QtyDue)
AS AvgQty
FROM dbo.WorkCenter$
WHERE WorkCenter = 146
AND ActualCycleTimeHours IS NOT NULL
AND ActualCycleTimeHours < 20
AND ActualCycleTimeHours > 0
AND CONVERT(Varchar,FirstActivityTime,1) =
```

```
CONVERT(Varchar,LastActivityTime,1)
GROUP BY Operation
ORDER BY Count DESC
```

--Get stats for orders at Inspect, grouped by operation

```
SELECT Operation, COUNT(Operation) AS Count,
AVG(EstimatedExecutionTimehours) AS AvgEstEx,
AVG(CycleDiffHours) AS AvgDiff, AVG(ActualCycleTimeHours) AS
AvgCycle,
STDEV(ActualCycleTimeHours) AS StdvCycle, AVG(QueueTimeDays)*24
AS AvgQueue, STDEV(QueueTimeDays)*24 AS StdvQueue, Avg(QtyDue)
AS AvgQty
FROM dbo.WorkCenter$
WHERE WorkCenter = 700
AND ActualCycleTimeHours IS NOT NULL
AND ActualCycleTimeHours < 20
AND ActualCycleTimeHours > 0
AND CONVERT(Varchar,FirstActivityTime,1) =
CONVERT(Varchar,LastActivityTime,1)
GROUP BY Operation
ORDER BY Count DESC
```

Appendix D: Query Results for VSM Timings

Appendix E: Operator Time Estimates

Appendix F: Standard Work Sample Template

SAINT-GOBAIN	**Standard Work - [MachineName]**		Release Date: Written By:	WCM
	Team/Area/Location:		Key:	
	Process:		Green:	Machine Work
	Process Input or Starting Point:		Blue:	Operator Work
	Process Output or Ending Point:			

Step #		Work Sequence & Description:	Time (minutes) Labor	Auto	Walk	Work Content Graph: Gridlines = Minutes
1		Process Step 1				
2		Process Step 2				
3		Process Step 3				
Repeat process [#] to process [#]	4	Process Step 4				
	5	Process Step 5				
	6	Process Step 6				
	7	Process Step 7				
	8	Process Step 8				
	8.5	Process Step 9				
	9	Process Step 10				
	10	Process Step 11				
	11	Process Step 12				
	12	Process Step 13				
13		Process Step 14				
14		Process Step 15				
15		Process Step 16				
16		Process Step 17				
		Totals:	0	0	0	

PPE required:	Important Points & Critical Checks		Work Layout Or Visual References
	[Inspection Point #1]		[Insert Visual References or Work Layout]
	[Inspection Point #2]		
	[Critical to Safety #1]		
	[Critical to Safety #2]		
	[Inspection Point #3]		
Tools or Measuring Equipment Required			
	Key		
	Critical To Safety		
	Critical To Quality		
	Inspection Point		
	In Process Stock		

For reference only at work station

Appendix H: OD Grinding Machine Standard Work Documents

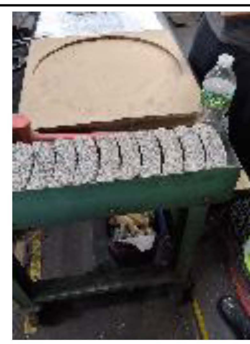
Appendix I: OPL for the Siding Machine

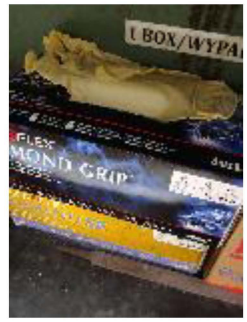
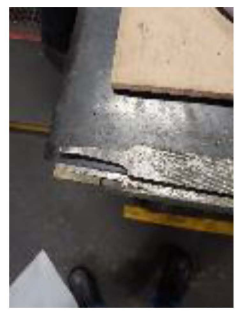
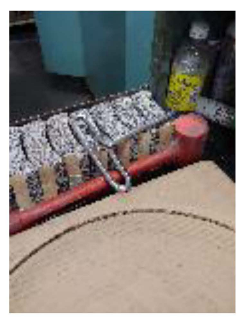
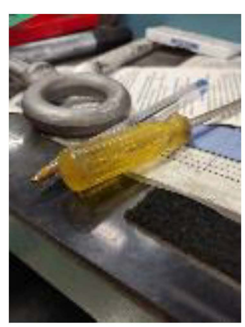
Appendix J: OPL Skeleton for the OD Grind

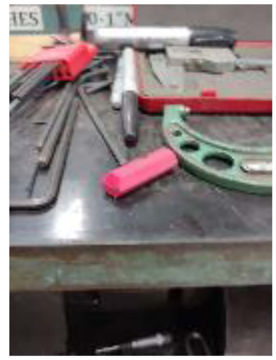
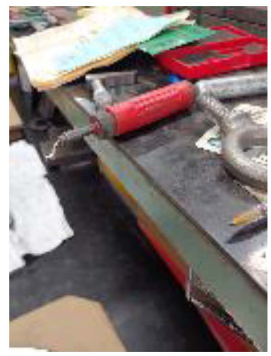
	Material	Resin		Univel		Aluminum		Paradigm	
	[Wheel Factor]								
Grit Size	> 60								
	> 100								
	> 120								
	> 150								
	> 280								
	> 400								
	> 500								
	Micron								

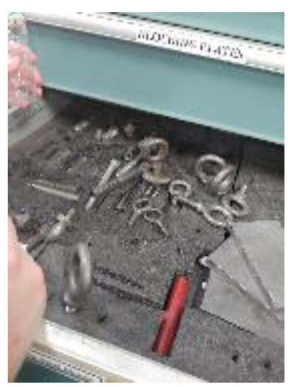
Work Wheels
100 H
60 H
60 K
30 L

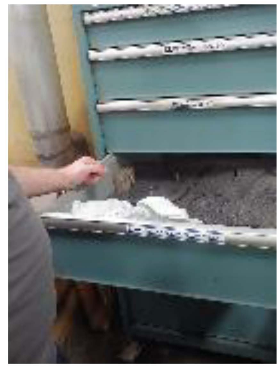
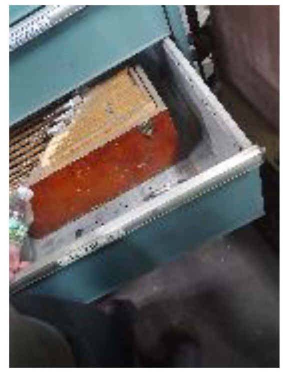
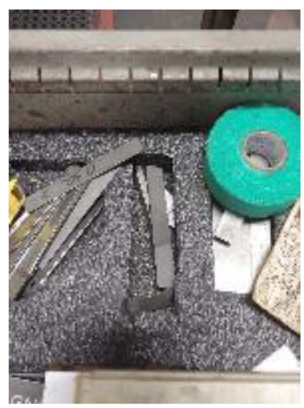
Appendix K: List of Item Usage Frequency in the Siding Operation Area

Item	Current Location	Frequency	Photos	Notes
		*Note that per wheel depends on the order details		
Caliper		Monthly		Micrometers are the appropriate tools
Segments	Workbench (WB) left	Monthly		
Mallet	WB left	Daily		
Citrus Cleaner	WB left	Daily		
Spray Adhesive	WB left	Never		
WD-40	WB left	Weekly		
Formula 50	WB left	Weekly		

Blocking plates	WB center	Per wheel*		Could be sorted and labeled more
Gloves	WB center right	Per wheel*		
Wypalls	WB right	Weekly		
Files	WB right	Per wheel*		
Rags	WB right	Daily		
Key	WB center	Daily		Used with the mallet to adjust segments
Screw driver	WB top center	To open boxes		

LOTO lock	WB top left	Daily		
Allen wrenches	WB top left	Per wheel*		
0-1" Micrometers	WB top center	Per wheel*		
Sticky notes	WB top center	As needed		
Pens/Pencils/Markers	WB top center	Per wheel*		
Burr Remover	WB top right	Daily??		
Green Cone	wheel shelf center	Never		Unknown use
Time tags	left wheel shelf, right side	Daily		
Bias plates	right cart top shelf	Never		Uses one of these

Grinding segments + other items	Tool cart top	Never		
Misc bolts	Tool cart drawer 1	Never		(Top to bottom)
Blocking plates	Tool cart drawer 2	Never yet	 	
Eyebolts/bolts/steel blocks?	Tool cart drawer 3	Biweekly		

Rags + other	Tool cart drawer 4			Only uses the rags not the extra items
0-12" Micrometer set	Tool cart drawer 5	Monthly		
Unknown items	Tool cart drawer 6	Never, not his		
Shims	Personal drawer	Rarely		
Gearbox oils	Left	Daily		

Appendix L: The List of Items Removed from the Siding Operation Area

- 2 boxes of segments
- 3 adhesive cans
- Stack of papers covers
- 5+ sets of blocking plates
- 2 trays of screws
- 2 trays of bolts
- Shim
- Unused cardboard pieces
- 30+ old grinding segments
- Chisel
- Sandpaper
- 2 old bias plates
- 2 old rags
- Set of rubber rings
- Miscellaneous junk items

Appendix M: 5S Implementation and Roadmap for the Siding Operation

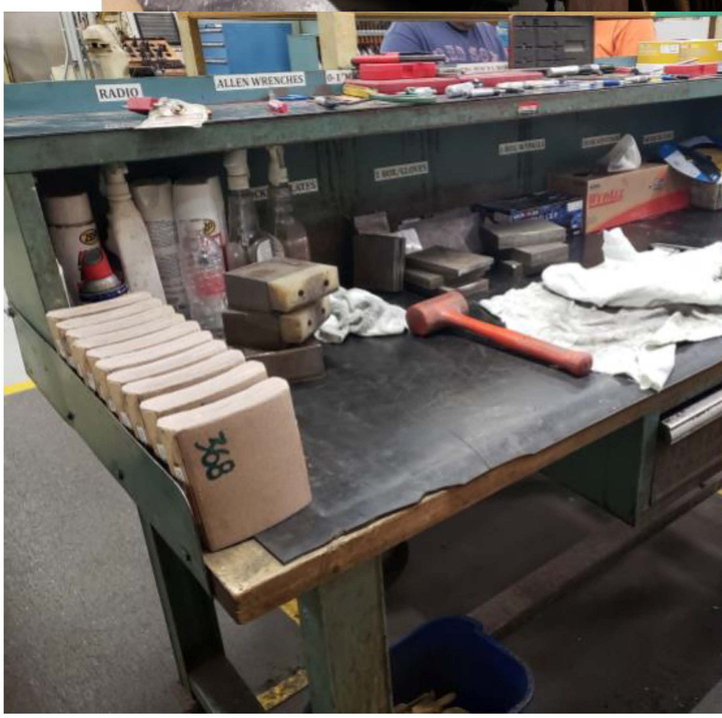
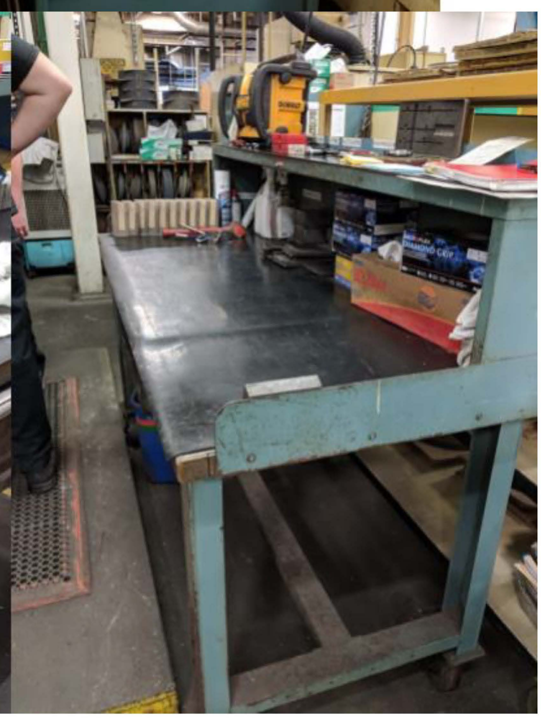
5S Roadmap

Sort

Red tagged items

- 2 boxes of segments
- 3 adhesive cans
- Stack of papers covers
- 5+ sets of blocking plates
- 2 trays of screws
- 2 trays of bolts
- Shim
- Unused cardboard pieces
- 30+ old grinding segments
- Chisel
- Sandpaper
- 2 old bias plates
- 2 old rags
- Set of rubber rings
- Miscellaneous junk items


GRINDING SEGMENTS
BLOCKING PLATES
0-12" MIC. SET

GRINDING SEGMENTS
BLOCKING PLATES
0-12" MIC. SET

RADIO
ALLEN WRENCHES
368


Set in Order

Blocking plates

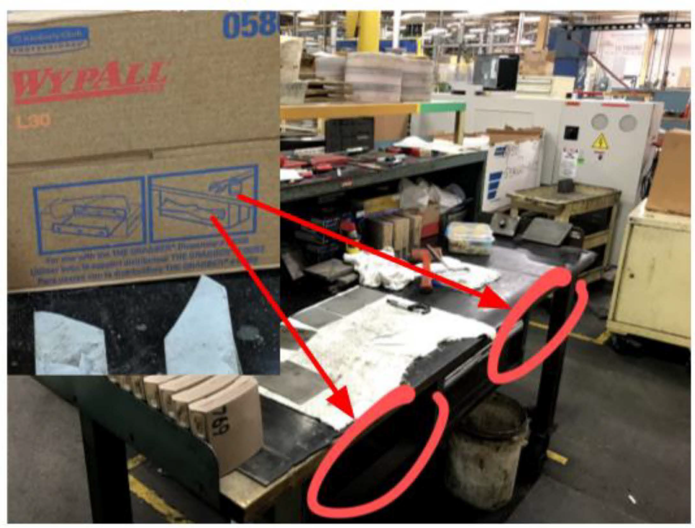
- Set up rack
- Color code plates by height (thickness)
- Spray paint or markers should stay on long-term
- Reduces
  - Desk clutter
  - Time taken finding correct plates

Bias plate rack

- Build rack for bias plates
- Rack placed on the ground

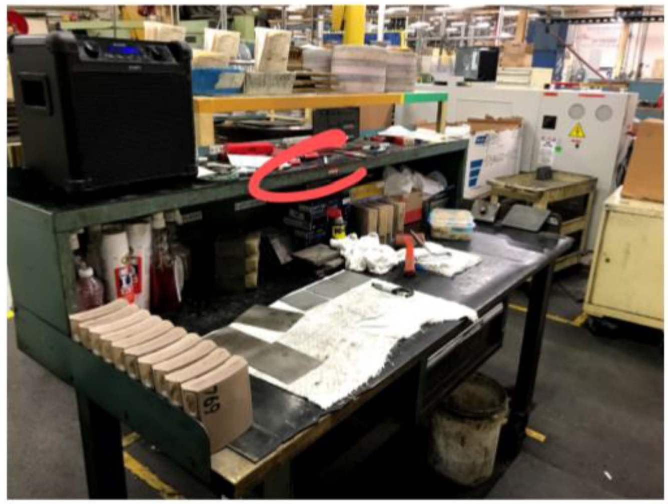
Gloves and Wipes

- Place a drawer with the open side facing outwards
- Increases:
    - Ergonomics
    - Ease of access
    - Potential workbench space
- Clears desk space



Pens, Sharpies, Crayons, Misc Stationery

- Tray on the side of top level of the desk (indicated in the picture to the right) to store writing items
- Can extend to hold micrometers as well



Grinding Segments

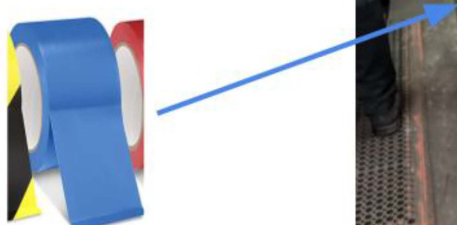
- Instead of putting them on pallets, put them on wheeled jack lifts
- Eliminates time taken to find jack lifts and time to move from jack to pallets

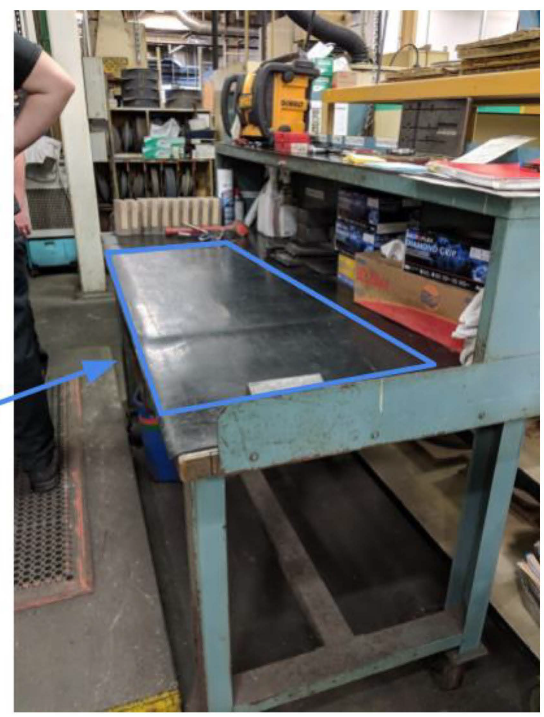
Tools

- Mallet used almost only to fix blocking plates in place - should be close to the rotary table
- Key for replacing grinding segments can go here as well
- Tool pin board here to hold them

Workbench

- Mark out free area with tape - avoid clutter creep



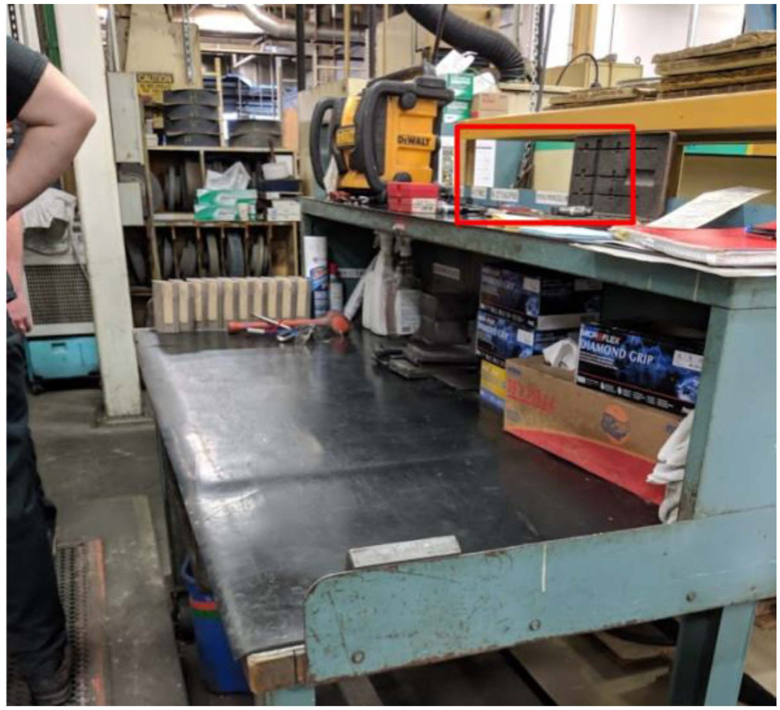


Shine

Implement visible broom rack

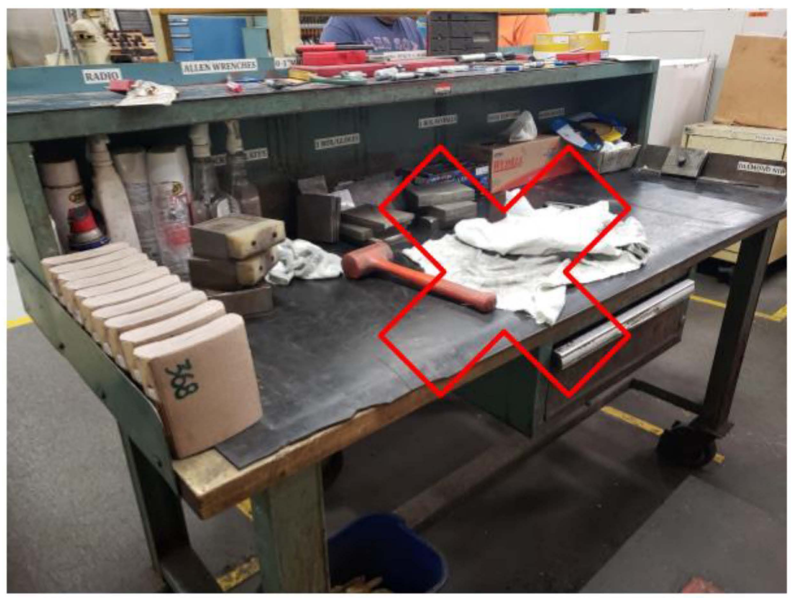
-

Implement additional Shine checklist



- Checklist outlined in next section

Prevent workspace contamination



-

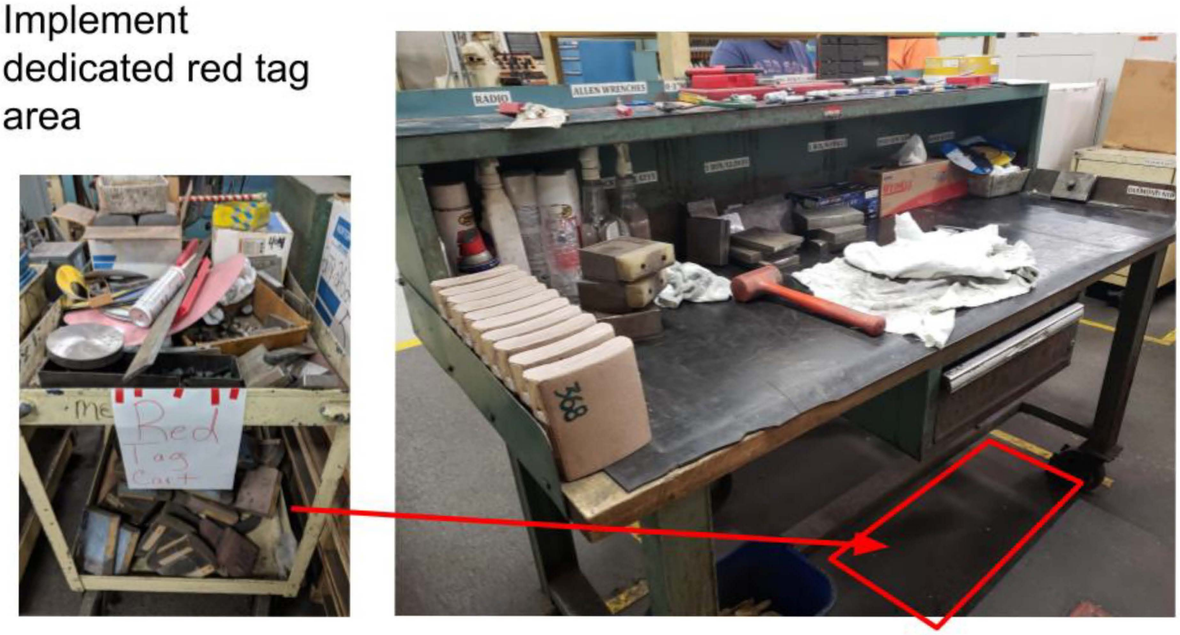
Standardize

Implement additional cleaning standards

		Mon	Tue	Wed	Thu	Fri
		03/04	03/05	03/06	03/07	03/08
Checks	**Frequency**	**Initials**				
Sweep area of dust	Daily					
Wipe turntable of residue						
Clean tools						
Organize tools						
Toss dirty rags/gloves/wipes						
Clear workbench of clutter						
Toss empty stationery						
Empty trash can						

Sustain

Implement dedicated red tag area



Implement periodic 5S team audits

Proposed actions:

- Monthly red tag reviews
- Biweekly Set in Order reviews
  - Are items in correct places?
  - Are new items labeled?
  - Do we need more organizational tools?
- Weekly Shine reviews
  - Is the workspace clean?
  - Are there clutter items that should be in the red tag area?

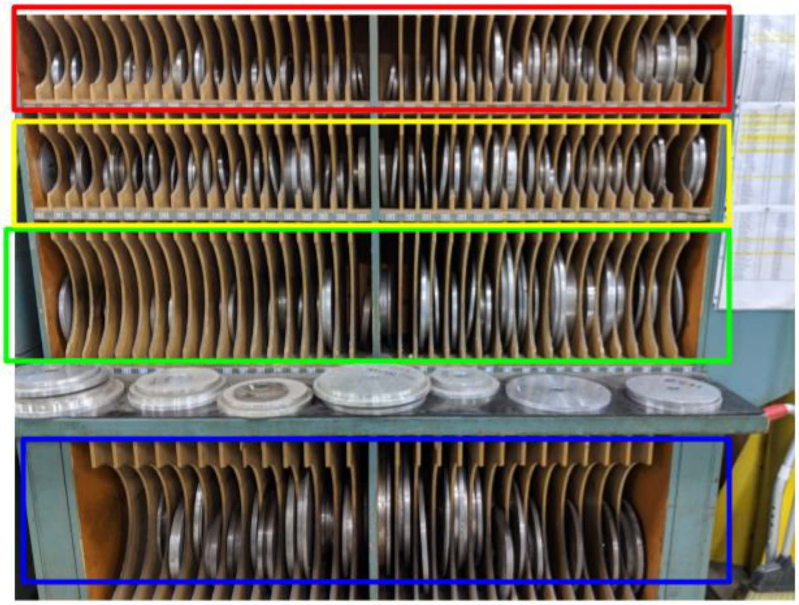
Appendix N: 5S Implementation and Roadmap for OD Grinding Machine

5S Roadmap

Set in Order

Bushings

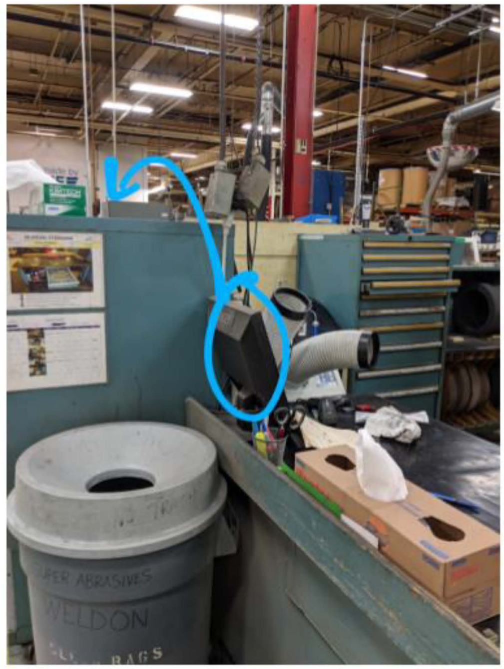
- Sort by diameter
- Color-code by diameters



Mount gloves and wipes under desk

Computer

- Move computer monitor to cabinet top
- Clears workbench area



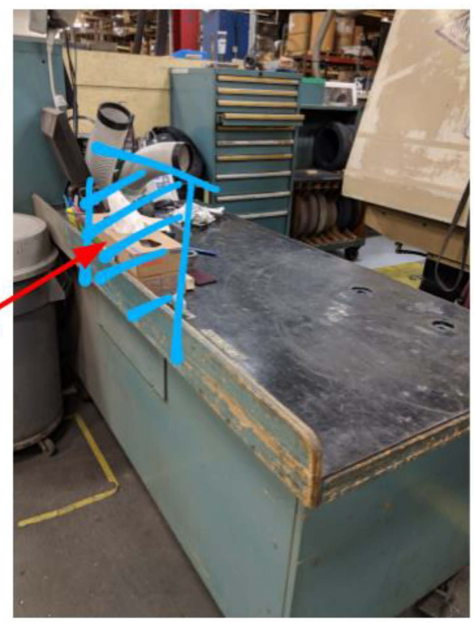
Replace clean rag bin

- Current solution resembles garbage bin
- Proposed solution increases:
    - Clarity
    - Ergonomics
    - Ease of use
- Can also be reached over workbench

Trays for stationery
and small tools

Tools

- Most common tools currently in drawer under desk
- Reduce motion of opening by mounting a tool board on desk



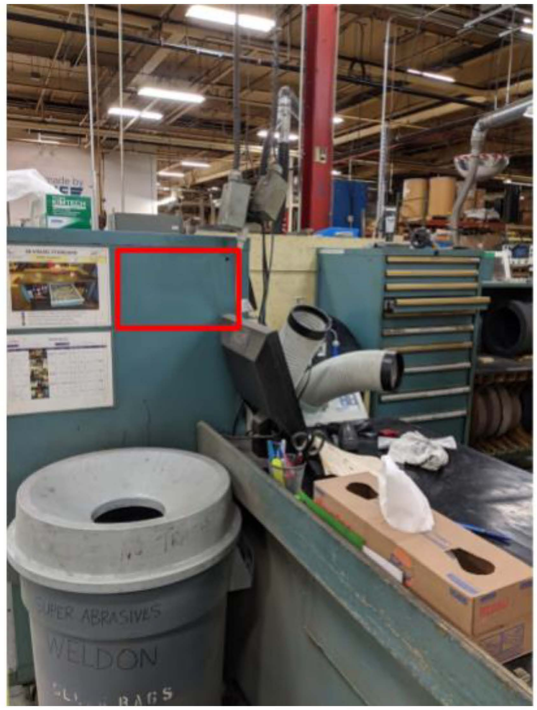
Workbench

- Mark out free area with tape - avoid clutter creep

Shine

Implement additional Shine checklist

- Checklist outlined in next section



Standardize

Implement additional standards (edit)

Checks	Frequency	Mon 03/04	Tue 03/05	Wed 03/06	Thu 03/07	Fri 03/08
		Initials				
Sweep area of dust	Daily					
Clean tools						
Organize tools						
Toss dirty rags/gloves/wipes						
Clear workbench of clutter						
Toss empty stationery						
Empty trash can						

Sustain

Implement dedicated red tag area