Final Report:

Analyzing the Cost of Norton Saint-Gobain Super Abrasive Grinding Wheels

A Major Qualifying Project
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
In partial fulfillment of the requirements of the
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Report Submitted to:

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Abstract

Saint-Gobain, a grinding wheel manufacturing plant in Worcester, MA, sponsored this project with the overall goal of closely observing the operations of one of their highly specialized grinding wheels. During the project, the team completed time studies for each grinding wheel process, validated the components of the product cost structure, and edited the cost structure when needed. The team also identified several opportunities to reduce costs at specific process steps and developed and evaluated three improvement ideas.

Acknowledgements

We would like to thank the following individuals and organizations who contributed to the overall success of our project.

Tom Moll and Marc Lamoureux, our project sponsors and liaisons at Saint-Gobain for providing us with support and insight into the company. We appreciate their invaluable help, which was critical for the success of the project.

The operators and engineers at Saint-Gobain for taking the time to talk with us, helping us understand all the processes in our project, and allowing us to observe them at work and complete time studies. Their insight helped us identify process problems and solutions that helped us in our final recommendations.

Finally, we would like to acknowledge Worcester Polytechnic Institute for providing us with the opportunity to complete this project and specifically, Professor Sharon Johnson, for her guidance and support throughout this project.

Leadership Statement

This project was completed by a group of five students: Michael Gake, Alex Johnson, Alyssa Mesaros, Kevin O'Driscoll, and Rachel Quinlivan. The time studies and process observations were designed and completed primarily by Michael, Alyssa, and Rachel, with Alex participating. The data analysis was led by Alex, with Alyssa completing a large part. Alex, Kevin, and Alyssa researched and developed the final three improvement ideas, including contacting companies and conducting cost analyses. The entire team worked on the introduction, background, and first draft of the methodology. Michael and Rachel completed a second draft of the methodology and results and the entire team edited the final versions of the paper. Alyssa and Rachel organized and carried out administrative tasks, such as setting agendas, note-taking, and contact with our sponsor.

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Chapter 1: Introduction

Norton Saint-Gobain is a grinding wheel manufacturer that has been operating in Worcester, Massachusetts since 1885. The company produces grinding wheels for a wide variety of customers, including car, aerospace, and software companies. Although technology has changed over time, their manufacturing processes have remained relatively unchanged. Approximately 97% of their products are custom-made based on customer specifications. These specifications include determining the type of abrasive, bonding material, shape, size, and tolerance level of the grinding wheel. Similarly, the grinding wheel market is mature and has remained stable over the years. Most customers in need of a grinding wheel have previously purchased one and have an existing supplier, so the price of products is an important differentiator for targeted customers.

Norton Saint-Gobain Superabrasives offers a highly specialized product: the GPK grinding wheel. Superabrasives are tools used in precision grinding and are considered "super" due to their extraordinary hardness, unparalleled performance, and longevity (Carel, 2017). The GPK wheel is a large grinding wheel made up of small, individual grinding pieces adhered onto a base up to eight feet in diameter. They are made of two components: abrasives and bonding materials. The abrasive materials are bonded together and formed into the shape of a wheel, varying in terms of shape, size, and type of abrasive and bonding materials. The system needed to make these wheels relies heavily on operators and manual work. Time improvements can be made, but Saint-Gobain requires a positive cost-benefit analysis to upgrade their machines or systems (T. Moll, personal communication, September 10, 2019). There are several cost estimation techniques that could prove beneficial if used, but the first goal must be validating the cost sheets their production system is based on. Saint-Gobain's cost sheets rely on the measurement of setup time, machine time, and labor time, and the associated variable and fixed costs for each GPK wheel.

Norton Saint-Gobain seeks to improve their processes to be more cost-competitive by conducting studies of their current process, analyzing the results, and implementing changes based on the findings. Their goal is to maintain a competitive profit margin but identifying possible improvements has been an ongoing challenge. The application of analytical studies, such as value-stream mapping and time-studies, have helped Saint-Gobain understand where changes in their system can be made.

This goal of the project was to validate current data for the GPK wheel and to develop improvements in the super abrasive manufacturing process to reduce product cost by 30 percent. We developed four project objectives to accomplish our goal:

- Process familiarization
- Validation of the current standard costs of products
- Developing and evaluating cost reduction ideas
- Selecting and developing improvements.

The team utilized a DMAIC problem-solving approach in order to improve, optimize, and stabilize the business processes of Saint-Gobain (ASQ, 2020). During the initial weeks, our team worked with Saint-Gobain managers and operators to familiarize ourselves with the process by observing and understanding the layout and standards of the plant. We then worked closely with the operators on the manufacturing floor and our project sponsors to validate the current standard costs of products. This involved the use of cost cakes, created with Excel, and time and observational studies. Based on our cost validations, we identified costs in the process that could potentially be reduced. Following this work, we developed and evaluated the feasibility of cost reduction ideas with the use of a PICK chart, a Lean Six Sigma tool used to categorize process improvement ideas (VERTEX42), and an estimated comparison to their current processes. We then selected and developed ideas for several improvements to the production system with Saint-Gobain's approval, ultimately seeking future reductions in their product costing.

The report first provides a background on Saint-Gobain, grinding wheel production and markets, and information about product costing and process observations. We then discuss the objectives and methodology we followed to complete our project goals. The next section describes the results of this work. Finally, we present our conclusions from the project and recommendations for how Saint-Gobain can move forward.

Chapter 2: Background

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Chapter 3: Methodology

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Chapter 4: Results

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Chapter 5: Conclusions and Recommendations

The overall goal of this project was to closely observe the manufacturing process of Saint-Gobain's GPK wheel and to reduce costs where necessary. In order to achieve such a large goal, objectives were created. After revisiting data, we accomplished the overall objectives set out in section 3.1 within our SMART Chart. We now provide general conclusions and other recommendations for Saint-Gobain to consider.

5.1 Conclusions

Through time studies conducted on the manufacturing process, updating process costs in the Bill of Materials, and cost analysis, this project allowed us to prioritize the steps in the process that had potential for improvement by analyzing what was most costly. Through brainstorming and consulting with our sponsors and advisor, we developed four improvements that can be considered for implementation. For each improvement, we evaluated operational, organizational, and financial feasibility and generated a PDSA to follow in order to see potential impactful changes. Our updated costs would reduce the total process cost by 33%, which exceeds our initial goal of reducing costs by 30%. Any additional implementation of our improvements can further reduce the process cost.

As Industrial Engineering students on the verge of graduation, we were presented with an invaluable opportunity to grow our skill sets in areas of potential future pursuit. Saint-Gobain Super abrasives was willing to sponsor a student-led project on their manufacturing floor, offering us their time, resources, and commitment. This opportunity allowed us to gain first-hand experience conducting studies and analyses, communicating with operators, collaborating with higher level management, and several other activities that we will continue to utilize throughout our careers and lifetimes.

5.2 Recommendations

We recommend Saint-Gobain to manufacture their wheels through only fabrication method 1. We concluded that it is 26% more cost efficient to manufacture utilizing fabrication method 1 as opposed to fabrication method 2 for the GPK wheels and changing from the current production method to fabrication method 1, will reduce the total costs by close to 12%. The reduction of savings from the initial 26% when simply comparing the variable costs of the different fabrication methods can be attributed to the large, unchanged fixed costs throughout the manufacturing process.

We also recommend that Saint-Gobain further investigate the sifting machine. Through our analysis, the sifting machine can further reduce costs by $145 per wheel. However, the total savings across the company would be even higher as the machine can be used for all the wheels that they produce. We recommend that Saint-Gobain complete further analysis by considering all their production and use our completed PDSA to control the implementation of this machine.

The particular wb machine the team investigated was deemed insufficient since it does not run powders well. In other words, when the hoppers of the machine open and close, fine particulars are sent airborne. For Saint-Gobain's abrasive mix, this would result in a lot of lost product and therefore may not be exactly what they are looking for. With the machine, wb will be automated, so the current amount of time it takes to wb fabrication method 2 can be eliminated, but 15% will need to be added to the molding time if the operator is multitasking. We recommend Saint-Gobain to take a deeper look into a similar product and simulate how the machine will change their manufacturing process due to the potential impact.

Our recommendation for the graphite aerosol spray is to implement it into Saint-Gobain's process as soon as possible. We found it saves approximately four minutes in the inspection process. This change is easy to implement, and our testing found that it does not affect the material of the grinding piece or its adherence to the base.

5.3 Reflections

Following the completion of our MQP project, our team responded to reflection prompts that touched upon our experiences with design, constraints, knowledge acquisition, and teamwork. We provided thorough and honest responses in this section.

Design Aspect of the Project

The engineering design process consists of several steps. Examples we have worked with from courses here at WPI include but are not limited to Ask, Research, Imagine, Plan, Create, Test, and Improve. Ask requires participants, or us in this case, to identify the at hand needs and constraints. We were actively asking throughout the duration of our project to fully understand what the company wanted to improve and what would be possible within our allotted time. Research includes compiling details pertaining to the problem. Specifically, we observed each process to identify where the problem was or where there was opportunity for improvement. The information needed for Imagine can be found in Appendix B, in which we brainstormed possible solutions for each of the processes. Plan was completed when we all completed our respective PDSA documents for each recommendation/idea. Create, or creating a prototype, was done either through purchasing the necessary item or reaching out to companies for quotes and details for existing machines. Testing was done through physical testing for the spray and, for other recommendations, through thorough analytical predictions. Improvement of the entire process is something that we hope Saint-Gobain will continue to implement given our specific recommendations.

Constraints in the Project

Economic, health and safety, and manufacturability were the most important constraints that we considered during our project. Economic constraints included the size of the grinding wheel market and the stage it is at, as well as the constraints of the company. We had to consider the amount of sales that Saint-Gobain has in a year and the cost of any improvements that we were considering. Health and safety of the employees is a major concern for any company, especially in the manufacturing industry. We listened to concerns that some operators had about the processes they were involved in and made sure any improvement ideas we considered would not be a detriment to their safety. As a manufacturing company, the ability to continuously improve the manufacturing process was imperative to our goals and methodology. Any ideas and designs we recommended need to be replicable by the company and positively impact their manufacturing process. Our sponsors wanted any improvement suggestions that involved existing machines, so they could easily work it into their current process. Our project might have an economic impact on the grinding wheel market, because reducing costs at Saint-Gobain will force other companies to reduce their costs and lower their time constraints.

Experience in Acquiring and Applying Knowledge

Our project can be divided into two areas when discussing how we acquired knowledge: primary research and secondary research. A large aspect of our report needed to be conducted through secondary research. We took advantage of the academic journals, articles, and papers available through the databases provided by WPI. There was a lot our group didn't fully understand, given our coursework doesn't cover all the intricacies of manufacturing and grinding wheels, specifically. To gain an initial understanding of the project ahead of us, we needed to read through the available material online. We developed a basic understanding through this research.

This project also provided an opportunity for us to work outside of the classroom on a real manufacturing floor, and it gave us the chance to understand the processes through first-hand experience and communication with professionals. We worked very closely with our project sponsors to understand their process from beginning to end, as well as to gain a more detailed understanding of the grinding wheels we were studying. Furthermore, the floor operators that work on these products every day were great resources for insight that wasn't available through researched sources. Through these conversations, presentations we gave, and instruction from sponsors, we developed a rich understanding of the industry that we can take with us into future jobs.

Teamwork in the Project

Working in a team of five WPI students, we each understood the importance of communication and commitment in working to complete a successful and timely MQP project. A key first step was identifying each of our strengths and weaknesses in an honest manner. We discussed how each of us could most effectively contribute given our major, presentation skills, writing skills, etc. Having everyone on the same page ensured that we all felt comfortable contributing in meetings and expressing concerns as the project moved along. This comfort continued through the entirety of the project, as every team member felt that their opinions, recommendations, and ideas were heard and considered fairly. We encouraged open meetings that allowed for everyone to speak and help with each aspect of the project that arose. Another key measure our group took was to have everyone go on visits to the Saint-Gobain manufacturing floor as often as they could. We wanted everyone to be actively interacting with sponsors and participating in the studies and analysis we were conducting on-site. Lastly, we utilized weekly meetings at regular times to discuss goals for the week and progress on long-term deliverables, as well as to plan for future meetings with sponsors. By defining what needed to be completed each week or over the course of a month, each team member was aware of deadlines and expectations. This also meant each of us had ample time to ask questions or ask for help, when needed.

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Figure 6. PDSA Model Science of Improvement: Testing Changes: IHI. (n.d.). Retrieved from http://www.ihi.org/resources/Pages/HowtoImprove/ScienceofImprovementTestingChanges.aspx

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Appendix A: Saint-Gobain Bill of Materials

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Appendix B: Full Calculation Results

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Appendix C: Full Calculation Formulas

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Appendix D: Preliminary Brainstorming Results

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Appendix E: PDSA Recommendation 1

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Appendix F: PDSA Recommendation 2

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Appendix G: PDSA Recommendation 3

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Appendix H: Recommendation 4 Quote

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Analysis of Standard Manufacturing Documentation

A Major Qualifying Project
Submitted to the Faculty of
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in partial fulfillment of the requirements for the
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in
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by

Michael Gake

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Sponsoring Organization:
Saint-Gobain Superabrasives
Worcester, MA

Project Advisors:
Professor Kevin Lewis, PW
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Abstract

This project aimed to compare the standard best practices for documentation in the manufacturing industry with the current documentation practices at Saint-Gobain in Worcester, Massachusetts. Research was conducted in two parts: findings from publications and websites were compared to findings from interviews and observations done on-site at Saint-Gobain. These findings were used to determine conclusions on the best practices of manufacturing documentation in the categories of communication, organization, and adaptability. These conclusions were then used to make recommendations for Saint-Gobain on how their documentation can better meet those standards.

Acknowledgements

I would like to acknowledge Worcester Polytechnic Institute for providing us with the opportunity to complete this project. More specifically, I would like to thank Professor Kevin Lewis and Professor Sharon Johnson for their guidance and support throughout this project. I would also like to thank my sponsors and all of the interviewees at Saint-Gobain for their commitment to my project work and their willingness to participate and help.

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Prologue

I completed this report as an interdisciplinary project for my majors in Industrial Engineering and Professional Writing, conducted while working with Saint-Gobain Superabrasives in Worcester, Massachusetts. This report was reviewed for confidentiality by my project sponsors at the company. As a result, certain names and details have been withdrawn from the report. Rather than refer to employees by name, I refer to them by their job title and gender neutral pronouns.

Chapter 1: Introduction

Different industries use documentation in a variety of ways, depending on the needs of their companies, employees, and customers. For chemists, there is an expectation of clear procedures that detail how lab work was conducted to ensure the process can be repeated by others. Computer science often uses manuals to walk the user through tasks in a software application. Manufacturing documentation, which is documentation specific to manufacturing settings, is crucial for maintaining and improving efficient and safe processes. It is created for every step in the production of a company's products or services, and is dictated by standards, safety regulations, and the customer. Manufacturing companies all rely on processes, so they must all also rely on documentation.

As I began a project at Saint-Gobain Superabrasives in Worcester, Massachusetts, I learned they were using "recipes" to guide the production of their grinding wheels. These wheels are made unique to each customer's requirements, and I wondered how their documentation process compared to other companies in the industry producing similar products. Interestingly, I found that the manufacturing industry does not have prevalent resources for accessing documentation. Companies like Saint-Gobain want to keep their process documents private from their competitors, so they are not available to be used or seen by the public. As a result, the industry is lacking sources relevant to the standard best practices for its documentation.

For those interested in or researching on documentation in these fields, there are sources to be found but they require persistent and extensive searching to find. I carried out research for this project with the intent of using findings from as many useful and relevant sources to answer the research question: **what is the framework for documentation in the manufacturing industry and how does it compare to the Worcester Saint-Gobain?** To develop a framework, this project focused on defining a clear definition and overview of documentation, understanding the benefits and impact of documentation, exploring how documentation has changed over time, and explaining the regulations that guide the creation of manufacturing documentation. This is not the first project centered on making documentation standards more accessible. An article from The TQM Magazine in 2006, "Towards a Better Understanding of Process Documentation," was written with a defined purpose of providing guidelines for effective documentation and making a contribution to an area lacking in definitive research (Ungan, 2006). This project works to build upon Ungan’s research and other similar sources to provide a more in-depth compilation of the best process documentation practices in manufacturing settings.

Many aspects of the manufacturing industry are not widely discussed but are pertinent and necessary to have a full understanding of the documentation standards in the industry. There are unique dangers involved in manufacturing, where, in certain situations, serious injury is a prevalent risk if processes are not followed. Content management systems (CMS) are necessary for companies to develop, manage, and reference historical and current documentation, but are all companies in the industry utilizing similar CMS? Furthermore, when processes are created or changed, how best are these updates communicated to the workforce? In an effort to answer these questions, it became evident that further research was needed. I used Saint-Gobain in Worcester, Massachusetts as a research site for conducting interviews and direct observations over the course of eight months. The company served as a direct window into the manufacturing industry and aided in the development of conclusions about the best practices for manufacturing documentation. Recommendations were also made directly to the company about its documentation practices. These conclusions and recommendations were directed to Saint-Gobain -- a representative of the manufacturing industry.

The primary goal of this project was to determine best practices for developing and using process documentation in the industry, for applying standards and regulations to documentation, and for compiling and maintaining the documentation with a knowledge management system. This goal was to make conclusions on the best practices and then recommend changes to Saint-Gobain on how they could better meet the standard best practices. To achieve the project goal, I utilized both primary and secondary research to gain insight into an area lacking in distinguished research.

Chapter 2: Background

I conducted background research to determine the standard best practices for manufacturing documentation to then compare with my findings at Saint-Gobain. The information presented in this chapter provides research pertaining to documentation in the manufacturing industry to help me better understand the basic process of documentation and its importance for companies, like Saint-Gobain. It will also detail the importance of knowledge management in the accessibility and storage of manufacturing documentation within a company.

2.1 Overview of Documentation for Manufacturing

Manufacturing has always existed, but the incentive for recording and changing processes was not as prevalent in its early stages. The first manufactured products, like fishhooks and pottery, were changed little by little out of necessity--there was no reason to document their changes. It wasn't until technologies grew in complexity that detailed recordings and drawings were needed to show key components. Manufacturing documentation, which is documentation specific to manufacturing settings, is now created for every step in the production of products--from electric cars to grinding wheels--and is dictated by standards, safety regulations, and the customer. From the time of fishhooks and pottery there have been vast advancements in the capabilities and size of technology, and the dangers within manufacturing have grown tremendously.

The manufacturing industry places a large emphasis on perfecting a process for developing a product at a low cost and consistent quality. Operators need to meet customer demands and production deadlines, while ensuring they are operating machinery safely for both themselves and their co-workers. This is not an easy process, nor has it been perfected. It is, however, a process with a defined start and end goal: begin with the knowledge of a process, develop a plan for replicating this process, and then implement this plan into the production. Transferring knowledge clearly and explicitly into documentation to guide a process is now crucial for manufacturing companies. Having a process documented ensures that a business can implement changes quickly; a business cannot always implement changes during good times, as processes require maintenance in times of struggle and crisis, too (Weinrach, 2006).

Implementation and process change must be done with reasoning, and documentation provides the details that can offer this reasoning. This reasoning needs to be clear for eliminating a step in the process, as well. If a process can be streamlined with the removal of steps, the documentation also needs to reflect and account for these changes (Weinrach, 2006).

The manufacturing industry is lacking in research about its documentation, and this section explains the basics of manufacturing documentation to develop a better understanding of what Saint-Gobain does. My research for this section helped me understand it at the basic level as a starting point for then understanding the best practices within the industry. It will answer questions on the structure used to develop a document from start to end – including how it is inserted into a system and used by operators on the manufacturing floor. There is then a discussion on the purpose for developing the documentation, including the effect it has on the productivity and organization of a company. It discusses how changes in the industry itself impact the documentation and what it needs to achieve to keep up with changing expectations from customers.

2.1.1 The Development Process of Documentation for Manufacturing

Manufacturing companies, such as Saint-Gobain, see success through their personnel and their processes operating effectively. To understand how manufacturing documentation influences this effectiveness, the development process of documentation is a good starting point. A basic knowledge level needs to be reached before a deeper understanding can be developed.

Paul Strassman, currently working at Strassman, Inc., has experience in manufacturing and supplying computers to customers. He emphasizes the importance of technical documentation in the life-cycle of a product. To ensure each aspect of technical documentation that goes into product development is defined and known, Strassman developed a list of eight steps. Ungan also provides seven steps for designing documentation. Other sources were also drawn from to develop a list for documentation that is specific to manufacturing. Much of these sources overlap, demonstrating the commonality of this process across the manufacturing industry. As a way to visualize one method for developing manufacturing documentation and then compare to Saint-Gobain's procedure, I condensed these sources into the following five steps:

1. Plan

2. Design
3. Document, produce, distribute
4. Train and use
5. Value

Plan

The first step in Strassman's documentation cycle, *plan*, involves developing the documentation plan. Jeff Weinrach, the president of Q-Network Inc., an environmental management and quality systems consulting company, writes: "Documentation helps to ensure that everyone involved in the process knows what they need to know for the process to be effectively implemented." In its development, there needs to be a focus on clarity – *who is reviewing the documentation and what is their purpose?* The goal is to implement a process successfully, and the creation and maintenance of process documentation ensures the avoidance of both error and waste because the involved audience will have the necessary information and instruction (Weinrach, 2006). The plan should include objectives, performance measures, and priorities with an overall goal of maximum productivity. This becomes especially useful when a process is being changed and the details need to be known.

Design

With a process selected and the objectives determined, the second step is the *design* phase. This is the process that proceeds the actual writing of a manual, process map, training class, or instructional video. Assumptions made in this step will affect the cost and overall effectiveness of what is produced, as lack of attention to detail here will only continue into the next phases. Examples of questions to ask are whether to include training courses, whether the skill level can be reduced, or if a technical literacy can be assumed for the eventual users of the documentation. Strassman recommends spending the needed time in this phase to ensure that changes will not have to be made once a concept has been committed to--it's easier to make trade-offs and decisions during the design phase than it is once work is being done (Strassman, 2001).

Ungan emphasizes the documentation needs to be designed with enough detail to successfully communicate with those using it. In manufacturing, an aspect of a process that works well may not require a detailed explanation. In contrast, a part of the process thought to have problems should include sufficient detail to help identify problem areas (Ungan, 2006). A process document or drawing can include a lot of specific information for clarification, and this becomes important for operators on the floor that actually use these drawings. Mike Lynch, Founder and President of CNC Concepts Inc., makes several recommendations to include on process drawings to ensure the necessary information is being communicated. For entry-level operators in particular, Lynch suggests including specific details on what to include, such as: how frequently inspections should be conducted, which attributes to measure, how to adjust a part, which values to target during adjustments, etc. (Lynch, 2017).

Before a process can be documented, how the process works must be understood. This may require the work of a designated team or an interviewer. A team is useful for large and complex processes that may need reengineering, while interviewing is effective for smaller processes that may have problems that need to be identified. A team helps to develop in-depth processes, while an interviewer can work closely with the "process master"--the operator or engineer with the most knowledge about a specific process. The process master describes in-detail the process, so that it can be documented fully (Ungan, 2006).

Following the work of a team or interviewer, a clear definition of the process needs to be made to understand the process goals, inputs, outputs, boundaries, customers, and suppliers. Ungan also stresses the importance of identifying performance measures. These are values recorded to see how a process is working. One set may include cycle time, cost, and quality, while another may include effectiveness, efficiency, and adaptability (Ungan, 2006).

Document, produce, distribute

With the design finished, the third phase in the process includes documenting, producing, and distributing the documentation. The *document* step is where the written, graphic, audio, or video document is prepared. Included are the costs of the writing and editing, and the acquiring of technical information from experts. The *produce* step is when the manuals are printed or the videos are recorded. Next, in the *distribute* step, the final materials are finalized and put into inventory. If the document is a change or update to a process, this step will also involve revising the original documentation and distributing the new version. The distribution – printed or electronically distributed – is important for ensuring the documentation is known by all interested audiences and influences the process, its costs, and its effectiveness as quickly as possible. (Strassman, 2001).

Train and use

The fourth stage in the manufacturing documentation process involves the *train* and *use* phase. For a process to be conducted safely and efficiently, the users of that process--the floor operators or engineers, for example--must learn how to use it. Training should be valued based on applicability and ease of use. These can be determined based on the length of the training, the amount of needed retraining, and the effect on productivity that hiring and training new personnel would inflict (Strassman, 2001). Documentation is then justified when used by the operators, engineers, customers, or service people. The *Use* phase is when manufacturing documentation has been implemented and supports a company in carrying out a process or maintaining a procedure to ensure their objectives are met (Strassman, 2001).

Value

The final phase, *value*, is when the new documentation is evaluated. The cost-effectiveness of the documentation in reaching expected performance levels is ultimately what determines if it was worthwhile or still needs changes (Strassman, 2001). Process improvement through documentation changes is beneficial, but without evaluation there is no distinct measure of the process improving or not (Weinrach, 2006). Evaluation of documentation may determine that the process is broken or ineffective, or it may determine the documentation adds more value than was expected.

This process provides a basic framework for how manufacturing companies develop and evaluate their documentation. It does not include every detail, but does give an understanding of how the process works. In the following section, an overview of why this process is beneficial will be provided to demonstrate why applying documentation best practices is important for manufacturing companies.

2.1.2 Benefits of Documentation in Manufacturing

Manufacturing documentation can aid a company in improving, standardizing, reengineering, and describing their processes. Each of these results of documentation serve to benefit companies in varying ways; with a full understanding of how a process operates, action can then be taken to change or improve the process. Mustafa Ungan, in his article "Towards a Better Understanding of Process Documentation," states of documentation: "In other words, it is the ability to see what kind of changes occur in an item as a result of changes on the interactions among its components." Ungan's article was written with the purpose of shedding more light on manufacturing documentation; many studies had acknowledged its effectiveness, but few had focused on them (Ungan, 2006). I understood why Saint-Gobain was using documentation, but I wanted to fully grasp why following their "recipes" for their customers was so important. Each of the benefits Ungan listed are described below:

- **Improving**

  Process documents provide a clear picture of a process that can help in finding problems or areas of potential improvement. Examples of this include unnecessary movement of parts, defective output, and unnecessary waiting. In short, process documents can aid in detecting value adding and non-value adding parts within a process that can lead to simplifying or redesigning processes (Ungan, 2006).

- **Standardizing**

  Standardizing means developing standard procedures that will ensure consistency within processes. It also means there is a clear definition for each process, decreasing the likelihood of disagreement of conflict or how a task should be carried out (Ungan, 2006).

- **Reengineering**

  Reengineering is defined as the fundamental rethinking of business processes to achieve noticeable improvements in specific measures of performance, including cost, quality, speed, and satisfaction. This redesign requires a concrete understanding of the current process – meaning accurate and detailed documentation (Ungan, 2006).

- **Describing**

Process documents provide a description that can be used for training purposes or sharing processes with other companies (Ungan, 2006).

These benefits can be seen in many cases across the industry. A prevalent example are the manufacturing companies striving to make identical parts every run, every year, even when working on different machines. John Bozelli, the founder of Injection Molding Solutions in Midland, Michigan, acknowledges that replication is not an easy thing to achieve and expresses the benefit of documentation for his specific company. He recognizes its importance: it would allow his company to more successfully compete within the world markets. He also recognizes there is not a best practice available for achieving the replication. He states: “if you visited 16,000 molding shops in the United States, you’d wind up with 16,001 different setup sheets.” Bozelli emphasizes that there is no operator that knows better than science. To run a successful process, there needs to be clear documentation that gives values and targets for each parameter of the product--fill time, plastic pressure at transfer, cushion, recovery time, cycle time, whole-part temperature. Bozelli identified that for injection molding, if these six parameters met how the documentation called for them to be, each run of the product would come out very similarly (Bozelli, 2018). Documentation sets a standard to be followed; the finished product will then meet that standard, over and over.

Defining these standards will aid in consistency of operations by providing guidelines for floor operators to follow – as a result, productivity will also increase. Jeff Weinrach states: “Creating and maintaining process documentation can be tedious. But it reduces error and waste, while increasing productivity” (Weinrach, 2006). By having an organization entirely on the same page about its processes, the focus shifts away from explanation and towards producing. Productivity in manufacturing is defined as achieving the desired results against a specific amount of costs. By this definition, the results of a system are compared to the system’s costs and to the flow time of the process. Productivity as a result of documentation is a consistent outcome, even as the industry and its demands change over time.

2.1.3 Changes to Documentation in the Manufacturing Industry

Manufacturing processes rely on their documentation to ensure the successful creation of identical products over and over. The operators have the documentation, or the “recipe,” that clearly specifies the timing, materials, and steps needed to produce the part correctly. However, recently the industry has seen an increase in specialized customer demands. When a customer wants a product designed according to their unique specifications, a company needs to adjust their process, and thus their documentation, to meet these specifications. During the 1980s, companies acknowledged the opportunity product-breakdown offered for optimizing the ratio between results and costs. Many products began to offer various types and options that extended the product-lifetime-cycle and matched customer requirements. With advancements in manufacturing and information, customers now want and expect individual-specific products more than ever. In turn, companies have gone from producing cheap and effective products that reach a high volume of customers to producing customized products at low cost. There is a necessity of meeting all requirements of the customer, manufacturing, and process planning at once; these requirements need to be accounted for in the documentation. This is particularly challenging given the goal of maintaining as low of costs and flow time as possible in the engineering process while still meeting the changing needs of the customer (Bikker, 1987).

The article “Manufacturing Documentation for the High-Variety Products”, published in the Management and Production Engineering Review by Professors Janusz Mleczko and L’uboslav Dulina, emphasizes the importance of managing change in the preparation and distribution of documentation in high-variety production settings. Mleczko states: “The contemporary customer requirements determine the production systems.” A high-variety production setting can mean a car company producing cars with varying interiors depending on what a customer selects or a grinding wheel company like Saint-Gobain changing the size of the wheel based upon customer requirements.

To reduce the time between a customer deciding on a product and then receiving the product involves several factors: a satisfactory offer being presented, an acquisition order, the process of preparing product data and issuing the manufacturing documentation, the manufacturing process, and the delivery of the product (Mleczko, 2014). If document paperwork, drawings, parts lists, and work instructions are structured, common and repeated orders of products can be processed without interference from the design and engineering departments (Bikker, 1987).

Automatic, paperless generation of process documentation has become increasingly common and important in the industry. In traditional manufacturing, communication through factories moved through physical documents, like blueprints and routing sheets, or through word of mouth. The paper was expensive to process, took up space, and slowed the organization's speed to the speed of the paper as it moved through the factory. In response, paperless factories are becoming a trend for manufacturing companies. With the Internet introducing vast possibilities in terms of order customization, configurable products have emerged as made-to-order products in recent years. Companies are now implementing configuration models that include all possible combinations of components for a product and the technical and economic constraints. This has been made possible with the application of existing wireless technology communication through the factory floor and the introduction of web-based systems. Interactions now happen largely through the computer: purchases are made through electronic invoices and signatures, data is exchanged between partners through e-mail or websites, and customers select their products through product configurators with predefined options. A customer can specify which constraints they want, as well, such as which properties they want in a part. To be effective, a company needs an order submission interface that is clear, dynamic, and flexible to customer requirements (Mleczko, 2014).

Documentation in paper form has not been entirely eliminated, however. There is a need for manufacturing systems to be able to produce as quickly as possible. This often works most effectively in a system that does not require the production and distribution of paper documentation, and in a system that eliminates redundant documentation. Often, documentation is emitted to link business processes when it is still needed. This can be managed with a planning system through a computer, but this requires investment. Substituting paper requires improving the management processes in the factory and operator capabilities on the shop floor. There needs to be knowledge base preparation if using configurable products, as well as an improvement on existing technologies, such as data security (Mleczko, 2014).

As manufacturing documentation and its market change, so do the governing regulations that set its standards and require its safety protocols. Chapter 2.2: Regulations for Manufacturing Documentation go into detail on these factors.

2.2 Knowledge Management in Manufacturing

Knowledge management (KM) is the identification and analysis of available and required knowledge, followed by the planning and control of actions to develop knowledge assets to fulfill the objectives of the company or organization. As I worked with Saint-Gobain, I wanted to understand how knowledge was typically stored and used in industry and then compare this understanding to their system. Product development in manufacturing relies on creating a product that can be sold, so knowledge of the customer is needed to achieve profit (Piorkowski, 2013). These knowledge assets are the markets, products, technologies, and organizations that a company has or wants to enable its processes to consistently be profitable (Gunasekaran, 2007). Knowledge acquisition is a preliminary step of manufacturing documentation (Ungan, 2006). Maintaining and updating the knowledge assets once they have been acquired and documented requires interdependent, but distinct work. A successful KM process for a manufacturing company will act similarly to the documentation process: identify the objectives of knowledge acquisition, create a team for KM, ensure all relevant audiences understand the process, adapt the company culture to implement the KM, and provide access to the knowledge network or technology (Gunasekaran, 2007).

There is a growing attention to information technology and information systems (IT/IS) that comes from quality and supply chain management and the re-engineering of business processes. IT/IS can allow for a greater breadth and depth of knowledge creation, transfer, storage, and application in a company (Gunassekaran, 2007). As discussed in *Chapter 2.1.3: Changes in the Manufacturing Industry*, company performance depends on the relationship between the company and its customers and stakeholders. Achieving this relationship is believed to be increasingly reliant on computers and information. For strategic, tactical, and operational decision-making, IT/IS plays a key role in developing manufacturing environments, such as supply chain (Gunasekaran, 2007).

The upkeep and storage of documentation benefits from the implementation of a KM system, or a CMS. CMS are used for creating, maintaining, and storing documentation across all industries. These systems provide an infrastructure of web pages, image storage, and other functions that users can then create, edit, and publish on. A CMS provides organization, ensuring there is one defined place for all documents to be stored and found. They allow for concrete workflow management, which means assigning privileges based on who can author, edit, or view a document. In turn, employees in a company can collaborate efficiently, as multiple users can be contributing and editing. CMS are typically applications through a browser, so they can be accessed from anywhere. Furthermore, they give users without programming-knowledge the ability to still create and contribute to the web content (Content Management System, 2020). These allow knowledge to exist on a server with a connected and accessible infrastructure. Documentation is securely stored and can then be retrieved and updated by employees efficiently. People at all levels of the company can access information and know that it is stored safely and available for later use (Piorkowski, 2013).

Manufacturing companies approach KM in different ways. The International Journal of Production Research published an article discussing the value of KM for the high value manufacturing industry. In the article, four styles of KM seen in manufacturing companies are defined by name: system-oriented, people-oriented, dynamic, and passive. The passive style exists in a company or organization that hasn’t implemented any formal KM system or process. System-oriented exists when a company relies on a structured information system or database. People-oriented refers to a company that relies on its people discussing their knowledge before, during, and after events occur. The dynamic style utilizes both people-oriented and system-oriented and depends on information to flow between both people and multimedia. Dynamic requires the most resources to implement effectively, but is also the most effective because it utilizes varying methods of KM (Piorkowski, 2013).

There is the same problem that exists in other facets of manufacturing: KM in manufacturing lacks extensive research. This gap in literature exists for both general manufacturing documentation and manufacturing KM. KM has seen significant research conducted in the software, education, health, and tourism industries; however, there has been limited research done in the manufacturing field (Gunasekaran, 2007).

Chapter 3: Methodology

In this chapter, I focus on the purpose and application of research to determine conclusions about the standard best practices for documentation in the manufacturing industry and provide specific recommendations to Saint-Gobain in Worcester, Massachusetts. The primary goal of this project was to determine standard best practices for manufacturing documentation. I took the opportunity to expand my research further by directly being on a manufacturing floor at Saint-Gobain. I became interested in the process documentation, or their "recipes"--the documentation that specifies all needed materials and sizing for a wheel and details the time each step in the process should take to produce the wheel for a customer. I wanted to compare Saint-Gobain's documentation process with the process of other companies in the industry to determine if they met the standard best practices.

To determine my findings, I used available publications, including journal articles, academic articles, and organization websites. I wanted to use sources published by manufacturing professionals, manufacturing companies, and organizations relevant to manufacturing to gain a better understanding of industry practices and draw conclusions about standard best practices for documentation. I then conducted interviews and made direct observations made at Saint-Gobain. These were first-hand sources that gave me specific information to further my conclusions and directly compare with my findings from publications and websites.

3.1 Publications

A major aspect of my research was compiling sources on manufacturing documentation. The first step when beginning my project was utilizing available databases to find and document magazine publications and journal articles from manufacturing professionals. These were made available through the WPI Gordon Library collection of sources. I used the research databases Business Source Elite, Engineering Village, and ABI/INFORM Collection--all databases centered around business, management, and engineering. The professionals that published these articles typically focused their writing on the specific company they were working for, which aided in developing an understanding of the best practices for documentation within the industry. I also found several reports that had researched a specific company or topic in the manufacturing industry. My goal with these sources was to find commonalities between professionals working in differing situations. Manufacturing is a broad industry, ranging from grinding wheel manufacturers to computer chip manufacturers. I felt the important aspect of using these publications was to identify how these manufacturers were similar in the approach they took to documenting their processes.

3.2 Websites

After reading through sources from manufacturing professionals, I identified specific companies and organizations pertinent to the manufacturing industry that I wanted to research further. Manufacturing documentation is guided by accepted standards and regulations to ensure overall quality, safety, and efficiency of its products, services, and systems. In understanding the standards Saint-Gobain is following in their documentation, I needed an understanding of pertinent organizations dictating these laws. A major organization was OSHA: a crucial aspect of manufacturing documentation is safety, and this organization dictates a lot of the regulations in the workplace. I went to their website in search of examples of safety visuals they recommend or workplace accident data they record. I followed a similar process in pursuing more information about manufacturing standards, and researched the websites of organizations such as ISO and ANSI.

3.3 Interviews

To gain insight into the manufacturing documentation at Saint-Gobain specifically, I conducted personal interviews with a safety manager and a technical writer at the company. Through these interviews, I posed specific questions pertaining to my research and gained personal insights that wouldn't be available through published academic sources. They were limited by the interviewees' personal knowledge, what they were willing to share, and their schedule of availability for being interviewed. I conducted interviews with a technical writer, safety manager, manager, and an engineer at the company.

3.2.1 Technical Writer at Saint-Gobain

For my interview with the technical writer at the company, I prepared a detailed list of questions related to their role. The full list of questions can be found in Appendix A. These questions focus on finding out how Saint-Gobain develops, updates, and maintains their documentation. Specifically, I asked the interviewee about the CMS the company is using, and if it is a commonly used CMS in the industry. I persisted by asking how the CMS had changed over time. I then focused my questions on the documentation process with the intent of finding out who is responsible for developing the documentation, who contributes, and what the process is like. By interviewing the technical writer, I felt I could get an alternate perspective to the documentation process. The technical writer’s primary role is writing and maintaining documentation, so they have insights that a manager or engineer may not have within the company.

3.2.2 Safety Manager at Saint-Gobain

I also scheduled an interview with the safety manager at the company. In this interview, I focused my questions on the safety procedures and regulations the company enforces on the factory floor. The full list of questions is available in Appendix B. I centered the conversation on how Saint-Gobain’s documentation is influenced by safety regulations and accident prevention. Specifically, I wanted to know how new operators are trained for using the machinery, and if this training focuses on the documentation. The safety manager was an important person to speak with because their work centers around ensuring the safety of floor operators working with machinery--a major aspect of manufacturing documentation--and they had data available to share pertaining to safety.

3.2.3 Manager at Saint-Gobain

I conducted informal interviews with a manager of the Superabrasives branch between September of 2019 and March of 2020. The manager was the sponsor of a cost validation project I was conducting at the same time as this research, so the overlap of these projects allowed for regular interaction and questioning. Conversations about my project work shed light on specific aspects of manufacturing and its documentation that I wouldn’t have found through academic sources. I wanted to learn about their customers, their process, and how they implement changes to their manufacturing system and documentation. Specifically, I asked the manager how documentation is produced to be customer-specific and how and when it is updated.

3.2.4 Engineer at Saint-Gobain

I met with an engineer in the Superabrasives branch weekly. They were the secondary contact in my cost validation project, so I worked closely with them over the course of my several months at Saint-Gobain. This engineer was the “process master” for many of the processes I observed, and they provided specific insights about why the process was designed the way it was and what it would take to implement a change. The engineer had a main interest in the efficiency of the production line and if each process was at the standard they had set in the documentation. I did not prepare formal questions, but focused our conversations around how the process documentation is updated based on changes, how a change is made and how long it takes to implement, and how the engineer influences documentation.

3.4 Direct Observations

I recorded notes and details from direct observations I made from my time on the manufacturing floor at Saint-Gobain, and specifically about the work floor operators were conducting. These observations came from my motivation to learn the layout of the Saint-Gobain floor and better understand how the documentation is used in practice.

I was able to regularly speak with machine operators and watch as they worked on machinery--utilizing documentation in real-time. The operators have a unique perspective from a manager or engineer because they are responsible for producing the parts for the company. They are the human factor involved in producing a grinding wheel part in a specific amount of time, and I wanted to understand how their role worked. I was not able to formally interview them, but I worked with them and observed their processes. I watched many operators interact with the “recipe” as they worked, following the documented instructions as they selected their tools and materials and as they set-up their station. While observing, I had conversations with the operators centered around how a process could be improved based on their personal feelings and experiences while working with the machinery.

Chapter 4: Research Results

Through the completion of my research, I developed a framework of documentation for manufacturing and determined many key findings relating to the best practices for documentation in the manufacturing industry. These findings are discussed in the following sections, which include the research conducted on publications by manufacturing professionals and the interviews and observations done at Saint-Gobain in Worcester, Massachusetts.

4.1 Publications

The academic publications from professionals in the manufacturing industry had many important takeaways in determining the best practices in documentation for manufacturing. There wasn't one exact method for creating, updating, and maintaining documentation that I found, but there were repeated recommendations that often overlapped among different sources. The results have been divided into subsections based on the topic, as follows:

- Documentation Process
- Evaluation of Documentation
- Knowledge Management (KM)

Documentation Process

The documentation cycle is a process, in which every detail is important and all knowledge plays a role. The following list summarizes the key takeaways in terms of standard best practices:

- Strassman emphasized the importance of clarity: determine the objective, the audience, the format, and the performance measures every time. As only about 9 percent of technical writers have formal education in engineering, knowledge acquisition is a crucial step in the process (Strassman, 2001).
- Weinrach stressed that when the operators, engineers, and management all actively communicate between one another, there is less chance of an oversight or disagreement (Weinrach, 2006).

- The manufacturing industry is often expected to accommodate customer-specific orders, so documentation that can be changed based upon a request will allow for faster production of products and less time wasted (Mleczko, 2014).
- If document paperwork, drawings, parts lists, and work instructions are structured, orders can be made without the need for interference or approval from engineers or the design team (Ungan, 2006).
- Bikker stressed that, when adapting to customer specifications, the custom-product should be derived from existing documentation for best efficiency and adaptability (Bikker, 1987).

Ungan further emphasizes that manufacturing documentation is only effective when those documenting the process need to be knowledgeable about the information they will acquire. Knowledge can come in two forms: explicit knowledge and tacit knowledge (Ungan, 2006). In the manufacturing setting, tacit knowledge would be seeing the material list and knowing the product being built. Explicit knowledge would be reading the product description and then understanding which product is being built. Explicit knowledge comes directly from the "process master." This can be transferred through written or verbal form, and is an articulation of how they perform the process to the documenters. Tacit knowledge is typically learned through experience, so it can be harder to acquire. The process of articulating a tacit knowledge into an explicit knowledge is called externalization. This process usually involves those documenting the process to accompany the process master as they complete the process. Those accompanying can examine the process and discuss directly with the process master how best to articulate the process. They then can agree upon and verify how they will document the process, and the externalization is complete (Ungan, 2006).

Evaluation of Documentation

Weinrach and Ungan both discussed the need for evaluation of documentation, especially over time after a process has been implemented. Being able to determine aspects of a process that aren't operating as quickly or effectively as possible and then changing them accordingly will see improvements (Ungan, 2006). For companies following specific drafting standards, their processes are also improving based on the given requirements, specifications, and guidelines for proper use of materials, products, processes, and services. Strassman listed valuing a process as one of the most essential steps in the documentation cycle. Without reflection and measurement on a process document, there could be no further improvement for a company (Strassman, 2006).

To evaluate and better achieve productivity, Bikker emphasized there must first be competent product-breakdown to develop process documentation that covers all aspects. Products consist of modules, assemblies, and parts. These aspects contribute to the fulfillment of product functions, and these functions work together to achieve the desired performance (Bikker, 1987).

Knowledge Management (KM)

Gunasekaran and Piorkowski discussed KM and the specific practices that best utilized KM in the manufacturing industry. Gunasekaran emphasized the features of a CMS, which proves effective for documentation if a company understands how to use the system fully (Gunasekaran, 2007). Ungan expresses a similar sentiment: managing process documents in an organized way is crucial to effectively carrying out operations (Ungan, 2006).

Research into the effectiveness of KM, through discussions with project stakeholders at BAE Systems, indicates the dynamic style of KM would be the most impactful if used at the start of the product lifecycle before key decisions were made. It is clear that for KM, a greater understanding could see the increased development of personal and product knowledge for manufacturing companies (Piorkowski, 2013). Similar efforts by General Electric, Motorola, and Toyota support the indication that manufacturing success is helped by dynamic-style improvement efforts (Gunasekaran, 2007).

4.2 Websites

For manufacturing, organizations like ISO and ANSI represent the industry “consensus” standards for best practices. In regard to safety, OSHA develops documentation consisting of regulations and processes to ensure workplace safety. The following sections provide my findings on these organizations and detail the influence they have on the industry standards and its documentation.

4.2.1 OSHA

The Occupational Safety and Health Administration (OSHA) serves as part of the United States Department of Labor. It was created by Congress in 1970 following the Occupational Safety and Health Act of 1970, which covers private sector employers and their workers, and some public sector employers and workers, in the 50 states and certain territories under federal authority. Under the OSH Act, employers must comply with all applicable standards set by OSHA and keep their workplace free of serious recognized hazards.

OSHA defines a standard as a regulatory requirement established and published by the agency to serve as criteria for measuring whether employers are following the OSH Act laws. There is a defined rulemaking process for a regulation to become official, which is available on their website, and included in Appendix C. The chart defines a seven-stage process for the passing of a new regulation for industry to follow. This process typically begins with a specific concern for employee safety in the workplace--such as over exposure to a hazardous chemical--which is identified as a health or safety hazard. The most common accidents OSHA has documented have been incidents like fall protection, respiratory protection, powered industrial trucks, machinery guarding, and eye and face protection (OSHA, 2020). There are still accidents occurring: in 2018, the rate of injury and illness per 100 full-time workers was 3.4 and the total workplace fatality count was 343 (U.S. Bureau of Labor Statistics, 2020).

Stage 1 in the process for developing a new regulation is identifying the hazard and determining, through research, if it’s a widespread problem over multiple industries or not. There is an analysis period, typically conducted over 12 to 36 months, during which OSHA and its stakeholders look at the health effects and potential cost of resources and technology necessary to deal with the hazard. In Stage 2, OSHA develops a new rule over the course of 12 to 36 months. This step involves drafting of the rule’s text and further discussions with stakeholders and organizations that may be affected by the proposed rule. The next aspect, Stage 3, is to obtain approval for publishing the rule and submitting it to the Federal Register, which is a legal journal run by the National Archives and Records Administration containing federal agency regulations, rules, public notices, executive orders, and other presidential documents. This happens over two to three months.

At this phase in the process, OSHA brings a rule to the public. Stage 4 takes between 6 to 24 months, during which the agency holds public hearings to garner feedback that will be reviewed and compiled for analysis. Once the comments have been received and summarized, all analysis has been completed and the next 18 to 36 months in Stage 5 are used to develop the regulatory text and preamble for the new rule. In Stage 6, the final rule is published to the Federal Register and sent to the Small Business Administration, Congress, and the Government Accountability Office over the span of two to three months. The final step, Stage 7, is about four to 12 months of distributing outreach and training materials, letters of interpretation, and compliance directives (The 7 Stages, 2017).

These regulations are enforced through inspections conducted based on worker complaints about a hazard or if they believe an employer is not following OSHA standards, or if there is a dangerous situation or fatality. In accordance with their health and safety standards, OSHA provides a public domain “Training Requirements in OSHA Standards” manual. The manual covers the varying industries OSHA regulates and contains excerpts and descriptions of mandatory safety and health standards to be followed, requirements for posting information and warning signs, and training standards. Its purpose is to assist employers and other professionals impacted by OSHA’s regulations. In its introduction, the manual states: “Documentation can also supply an answer to one of the first questions an incident investigator will ask: ‘Did the employee receive adequate training to do the job?’”

As of June 2015, OSHA’s Hazard Communication Standard (HCS) requires pictograms on labels to alert users of hazards they could potentially be exposed to. Several of these pictograms are shown in Figure 1.

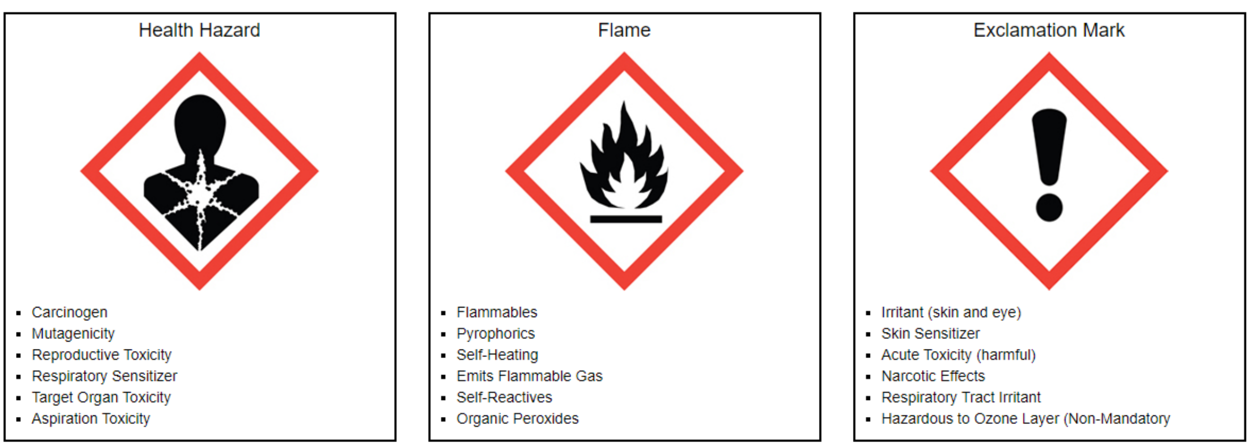

Figure 1. Hazard Pictograms

4.2.2 ISO

The International Organization for Standardization (ISO) develops and publishes requirements, specifications, guidelines, and characteristics to be used in ensuring the proper use of materials, products, processes, and services. Its documents cover almost every industry, including manufacturing. It began in 1946 with delegates from 25 countries deciding to create an organization that would "facilitate the international coordination and unifications of industrial standards." In February of 1947, the ISO officially started with a goal of finding the best way to do things. There are now members from 164 countries and 781 technical committees and subcommittees that help in developing standards. The technical committees are typically responsible for a specific subject area that works to develop standards to meet a market need, and consist of experts from the relevant industry, consumer organizations, academia, and government (Standards, 2020).

From start to finish, it takes about three years for an ISO standard to be published. The process begins based on a request from industry or stakeholders, who see the need for a new standard. Experts within the technical committee then discuss the scope, content, and key aspects of the standard. A voting process decides if a draft will become an ISO standard; if consensus is not reached, the draft will be modified further. In its infancy, the ISO dealt with basic standards for weights and measures and has since developed standards for Wi-Fi networks, road safety, toy safety, manufacturing, and more (Standards, 2020).

The most prevalent ISO standard in manufacturing is ISO 9001, which relates to quality management. Over one million businesses around the world have received certification for this standard. This certification provides both tools and guidance for meeting customer requirements. ISO standards mandate that a business continue to improve, so companies with this certification are motivated to identify, document, and improve systems that address safety standards, environmentally friendly manufacturing, production efficiency, and dimensional and functional specifications. ISO Standards and documentation work together to achieve high quality products at as low costs as possible – the goals of manufacturing. These companies see higher customer satisfaction, less errors, and lower cost. They are helped in identifying errors or areas of possible improvement in their processes, which can then be adjusted to meet the standards in the documentation (GreenLeaf, 2017).

4.2.3 ANSI

The American National Standards Institute (ANSI) works to enhance the global competitiveness of U.S. business and quality of life. It serves as the U.S. representative of the ISO. ANSI aims to provide a framework for fair standards development and quality conformity assessment systems that meet international standards, so American machines and equipment can be used worldwide. It is composed of Government agencies, organizations, companies, academic and international bodies, and individuals. In total, ANSI represents over 270,000 companies and organizations and 30 million individuals worldwide. All standards are developed through a consensus process, meaning they remain accessible and responsive to the needs of stakeholders. This process allows all parties to participate and protects the public interest (American National Standards Institute, 2020).

As of January 2020, ANSI had more than 240 standards developers accredited to their organization, and more than 11,500 American National Standards. There are estimated to be hundreds of standards developing organizations (SDOs) in the U.S. currently. 90% of the standards were produced by the 20 largest SDOs. Reflecting the consensus process, the U.S. participation in these standards is wide, as the SDOs consist of committees of experts addressing the technical requirements within their areas of expertise. In manufacturing, the most pertinent ANSI standards cover safety standards for conveyors, electrical standards for industrial machinery, requirements for electrical safety for workplaces, general requirements for safety of machinery, and control of hazardous energy (Machinery Safety, 2020).

4.3 Interviews

Through the interviews I conducted with the employees at Saint-Gobain, I expanded the findings from my research conducted on publications and websites with findings specific to Saint-Gobain's documentation methods. These findings include information from a technical writer, safety manager, manager, and engineer at the site.

4.3.1 Technical Writer at Saint-Gobain

In my interview with the lead technical writer, there was an emphasis on the functionality of the CMS. At the Saint-Gobain in Worcester, Massachusetts, the technical writer explained that the CMS is typically used by technicians or engineers in collaboration with the floor operators. They work with the operator to determine the process instructions and details, take full notes and pictures, and then upload to the system. Further, when a missing step or inaccuracy is noticed in the process, the documentation is then updated by a team of several employees. An operator is always included in this team because every person with an interest in the change must be approving for the change to be made. The technical writer then makes the final updates to the manuals and process documents in the CMS, finalizing the change.

The technical writer discussed his efforts to transition his branch of Saint-Gobain from using Oracle Webcenter Content to using Dozuki as their main documentation system. They described Oracle Webcenter Content as restrictive, both in its search features and instruction writing capabilities. Many of the search fields were never used and others were restrictive, making document retrieval difficult. It also doesn't allow for real-time editing, meaning a prior step cannot be changed without deleting all of the following steps. The major difference that they emphasized was the incorporation of multimedia that Dozuki offered; Oracle Webcenter Content lacked features that allowed for videos to be uploaded. Dozuki not only allows for videos, but offers features that allow for direct photo upload and mark-up through a mobile app on cell phones. They stressed how simple and easy to learn Dozuki felt compared to Oracle Webcenter Content: when tested, they reported that untrained users were able to develop documentation instructions very easily within one week.

The technical writer also cited that Dozuki was currently being used by several other Saint-Gobain sites, as well as by other major companies in the manufacturing industry, such as Coca-Cola and 3M. They expressed that not all companies were using the same CMS, but that those in the industry are aware of the most commonly-used systems.

4.3.2 Safety Manager at Saint-Gobain

Through an interview with the safety manager at Saint-Gobain, I had a better understanding of the emphasis placed on safety in a manufacturing setting. For operators to know the safety procedures and stay safe while working on the floor, there needs to be clear and detailed documentation. The safety manager shared the company's training documentation used when a new operator at the facility is hired. The training focuses on providing an understanding of the risks involved with using machinery and emphasizes the correct procedures to follow to avoid accidents and injury. New employees are exposed to examples of workplace injuries that occurred due to "non-routine activities" while operating machinery. The safety manager shares these incidents to emphasize the importance of wearing proper personal protective equipment (PPE) and following safety instructions fully. There are labels on machines that indicate the risk of injury based on a certain behavior. These are ISO-standard warning stickers, and the meaning of the labels is taught during training. For example, the mixing machine displays a sign warning of possible finger laceration. The safety manager then walked me through a safety model that states for every 30,000 at-risk behaviors by employees, there are 3,000 near misses of accidents, 300 recordable incidents, 30 lost-time accidents, and 1 fatal accident in the workplace. A lost-time accident means the employee missed time in the workplace. The plant also follows a 5-S initiative, which is an organizational methodology for keeping the workplace in order. This stands for sort, set in order, shine, standardize, and sustain.

4.3.3 Manager at Saint-Gobain

As a result of my time spent working with the manager at Saint-Gobain in Worcester, and through our casual interviews across seven months, I learned several key details related to best practices for manufacturing documentation. As a manager, they facilitated meetings that brought upper management, engineers, and technical designers and writers together to discuss weekly progress or process change. The meetings did not always include everyone; they include only the relevant and essential people related to the topic at hand. They illustrated to me the importance of allowing interested parties to contribute their opinions and ideas in an open manner.

The manager also demonstrated the importance of record-keeping and a CMS for KM purposes. He was able to find old orders of grinding wheels to show me, including the cost, design, and date of order for each type of wheel. These wheels are made by following their documentation "recipes." The recipes are based on the type of wheel required by the customer, but are typically made by borrowing aspects of past, successful recipes. Approximately 97% of their products are custom-made based on customer specifications--the type of abrasive, bonding material, shape, size, and tolerance level of the grinding wheel. Following the above criteria, Saint-Gobain receives the customer specifications and applies their needed functions directly to their existing framework.

4.3.4 Engineer at Saint-Gobain

My interviews with an Engineer gave first-hand insight into how an engineer views processes, process improvements, and subsequent change to the process documentation. They were the "process master" for many of the Worcester Saint-Gobain processes in the development of grinding wheels. Because they were so knowledgeable about the processes, they shared a lot of explicit knowledge about why the process functioned as it did and why specific changes would or wouldn't work. The engineer ultimately was willing to make changes to the processes, and thus the documentation, but the changes had to first be carefully brainstormed, tested, and planned. The engineer had collected cost and time data in spreadsheets, and these were re-used to estimate the costs of new wheels. Because all their wheels are unique, the documentation for past wheels is used to develop the new documentation. At times, the engineer's cost data was not updated to their current standards and processes.

4.4 Direct Observations

Findings from directly observing floor operators as they worked with machinery were primarily focused on sharing of knowledge and changing documentation.

4.4.1 Operators at Saint-Gobain

Operators at Saint-Gobain demonstrated a deep knowledge of the machine they were working with, its documentation, and its capabilities. I found that half of the operators had a suggestion for a tool, part, or improvement for their machine or station that they felt would increase their efficiency. These suggestions have not been worked into the documentation yet, but the operators said the operations could be standardized with these changes eventually. I also learned that operators working on different shifts directly communicate to each other about orders, order progress, and machine errors. If an operator knows about an error with a machine but doesn't share the information, the production rate will decrease when the other operators work on the same machine. Operators write notes on the “recipes” to indicate their progress on a part and record how much time they spent on the machine.

Chapter 5: Conclusions

Companies in the manufacturing industry rely on confidentiality to ensure their processes remain unknown by their competitors. To develop an understanding of manufacturing documentation best practices, one must either be employed within the industry or extensively search for the limited sources available. It is not that manufacturing documentation is not an important area: repeated production and distribution of products rely on documentation for precision, efficiency, and safety. Rather, the industry lacks abundant voices of professionals and experts within the field sharing their knowledge of manufacturing and its documentation. Following my research and work within the industry, I want to add another voice to this industry. Within this report, I have made several findings about the best practices being used by manufacturing companies and have divided these findings into three main categories: communication, organization, and adaptability.

5.1 Communication

Through comparing my findings from publications from manufacturing professionals and organization websites with my findings from Saint-Gobain, I have drawn conclusions on standard best practices for manufacturing documentation in relation to communication. By communication, I am referring to how documentation is created, updated, and followed by the different members of a company.

All relevant parties collaborate in the development of documentation

There was agreement amongst several professionals in the industry that involving each level of a factory floor will ensure documentation is developed in the most detailed and effective manner. Weinrach and Strassman concurred that having operators, engineers, and management offer input during development, there is less chance of an oversight or dispute. The manager at Saint-Gobain brings as many people with interest in a process together for a meeting to determine the specifics of a document, and all relevant parties must approve a change before it can be made. There is always an operator and engineer present to provide specifics on the machinery and current process. There are many benefits to having all interested parties contribute: everyone with information about the process can offer input, no one will feel excluded from or caught offguard by a change, and all discussion, planning, and designing can be done at once. The documentation can be agreed upon in as few meetings as possible with everyone with an interest in the document present and voicing their opinions. Collaboration in this manner ensures communication through the company is as effective and efficient as possible.

Safety procedures and regulations are known and enforced

Ensuring all employees are aware of and following safety procedures requires the company to be clear on OSHA standards. The safety manager at Saint-Gobain communicates these standards and expectations through documentation--such as ISO-labeling on machinery--and training. Having found that OSHA requirements are designed to increase accident prevention and awareness, as well as ensure safe practices when using machinery, it is crucial that safety guidelines are communicated and then followed. The safety manager at Saint-Gobain has examples of accidents that occurred due to “non-routine activities,” demonstrating the reality of negligence. They work to maintain safety labeling throughout the plant and provide new employees with safety training. All of these efforts contribute to an overall safer manufacturing floor. Furthermore, if an operator doesn’t understand or forgets a procedure, there is an abundance of resources available: a safety manager, labelling in their station, fellow operators, and training manuals and documentation detailing the processes and their dangers. It is all being done in an effort to limit accidents and illness, and ultimately that is the end goal of OSHA and a company enacting their standards.

5.2 Organization

I have drawn conclusions on the standard best practices for manufacturing documentation in relation to organization based on the findings I have made from publications and websites and the findings I’ve made at Saint-Gobain. These conclusions focus on how a company should manage and maintain its documentation and knowledge.

There must be a set process for creating, editing, and maintaining documentation

When the entire company is aware of the documentation process, the process itself becomes more efficient and effective. According to Weinrach and Strassman, having a standard method that is followed every time documentation is worked on will make things easier. Bikker expands this point in his discussion about structuring the documentation so it can be used and changed without needing the engineers or designers every time. At Saint-Gobain, all documentation is developed with an operator, engineer, and design team collaborating to determine process details. They work together to identify all needed steps, take photos, and reach an agreement with all relevant parties to make a change. By maintaining this process, everyone at the company is on the same page when a change or improvement is needed and knows how to report it. Once the process begins, all parties know what to expect and it can move forward quickly.

The method of knowledge management must be known and consistent

There needs to be an agreed upon method for sharing knowledge, which often means a CMS. As Ungan expressed, operations rely on effective management of process documents. Gunasekaran and Piorkowski were in agreement that a company should select a KM style that reflects its people. When used to its full extent with high quality and relevant information, the system will be effective. Further, the use of a CMS ensures all documentation is following the same style and format, and will be available in the same database for access by all relevant parties. Saint-Gobain is currently using Oracle Webcenter Content as their CMS, and relies mainly on their technical writer to keep it updated and maintained as changes are made. The technical writer wants to move to Dozuki to allow for easier collaboration, as they feel the current CMS is limited in its features and accessibility for those working on the manufacturing floor.

5.3 Adaptability

From my findings on manufacturing documentation from publications and websites and from Saint-Gobain's practices, I have made conclusions on the standard best practices for manufacturing documentation for adaptability. These conclusions are focused on how a company should change its documentation based on customer requirements, industry standard, or value.

Documentation is adjustable for customer specifications

Manufacturing companies rely on documentation to produce consistent and quality products. For a company like Saint-Gobain that produces customer-specific grinding wheels, there is a crucial need for this documentation to be flexible based on the requirements of the customer. Bikker stressed that by creating new documentation by using pre-existing documentation, there will be less time spent on developing it and it will prove more adaptable. With a full breakdown of a product, documentation will cover all aspects and ensure a fulfillment of customer requirements. Saint-Gobain follows this thinking by adapting new wheels based on the recipes they've used for past ones. They have a designated design team that adjusts past documentation to meet new orders by customers, allowing for production to start more quickly.

Documentation and its system are regularly measured and improved when needed

A major part of manufacturing is profitability, which relies on the efficiency and quality of processes. Because the processes are guided by the documentation, it's important for this documentation to be evaluated regularly and reworked when needed. Ungan emphasized that identifying slow aspects of a process will see improvements if acted upon. Strassman cited this as one of the key documentation steps, pushing a company to continue improving. In regards to managing this documentation in a CMS, the technical writer at Saint-Gobain noted that there is a desire to upgrade to a new software, Dozuki, to ensure full accessibility and use by all staff, availability of multimedia features, and efficiency. Furthermore, the engineer at Saint-Gobain maintains standards for all processes, which reflect the time each process should take an operator to complete. They were in the process of validating and updating these standards to better reflect current times

Chapter 6: Recommendations

Following the conclusions I made on standard best practices for manufacturing documentation, I am able to recommend changes Saint-Gobain could make to better meet industry standards. These recommendations are directed specifically to Saint-Gobain and include details pertinent to their current processes and situation. They could, however, be applied to other companies in the industry.

Implement Dozuki as the CMS

For a company producing customer-specific grinding wheels, I recommend that Saint-Gobain implements Dozuki. The technical writer at Saint-Gobain has been pushing for a transition to Dozuki, a CMS that offers photo and video features and direct upload of documentation by anyone with the application on their phone. As concluded, documentation needs to be adjustable and the KM should be known and consistent. Saint-Gobain's current CMS, Oracle Webcenter Content, does this, but not as efficiently as possible. Given other branches of Saint-Gobain are using this system, implementation is viable if management chooses to make the change. By having photo and video features, companies can have a variety of options for documenting processes. In practice, those documenting can choose the most effective method for documentation without any limitations. Dozuki will give Saint-Gobain the option of multimedia documentation, which may be more effective for training or communicating a change for certain processes. This upgrade will improve the company's technology and increase its flexibility for creating documentation.

Implement recommendations from floor operators

By discussing process changes and listening to thoughts from floor operators who are actually operating the machinery, important knowledge can be gained. During my time on a manufacturing floor, I heard many ideas for process change from operators that use the machinery every day. This was reflected in the opinions of manufacturing professionals. If the people not on the floor are developing the documentation, they may be unaware of needs an operator has, such as a new part or piece. Saint-Gobain does communicate with operators about process changes, but these changes are typically implemented based on the findings of engineers.

The operators have specific requests for tools that could be viable options for standardizing documentation and improving its overall efficiency.

Document all knowledge about processes

Ensure that important knowledge about a process, a machine, or procedure is written or uploaded in an accessible place. By utilizing a CMS to its full extent, all necessary information will be accessible to all employees. Further, utilizing a CMS like Dozuki that allows for floor operators to upload photos and information directly will ensure small details about machines and processes are not forgotten. The engineers serve as “process masters,” but their information depends on their availability when it is needed. Further, operators know specific information about the machinery that is not widely-documented. If more of this information is reflected in the documentation, there will be less chance of error or forgotten details.

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Appendix A: Questions from Interview with Technical Writer

- What type of content management system is your company using?
    - Is this a standard system for the industry?
    - Does it have benefits compared to other systems? Downsides?

- What were older systems like? How have they changed?
    - Is it primarily web-based?

- Are there a lot of safety regulations that need to be complied with when developing documentation?
    - Have these standards changed over time?

- Who uses the documentation in the company?
    - Who manages the system?

- What is the process for making a change to documentation?
    - Who contributes to changes being made?
    - Is everyone involved when the system changes?

- Are there processes that should be documented in the system that aren't?

Appendix B: Questions from Interview with Safety Manager

- What is the role of safety manager for Saint-Gobain?
    - What are your day-to-day responsibilities?
    - Do you play a role in the documentation?

- How prevalent are accidents in the workplace?
    - Are they avoidable?
    - What leads to the most injuries?

- What is the training process like for new operators?

- Are there specific programs that Saint-Gobain runs on its floor for safety purposes?

- Are accidents recorded?
    - What is the system?
    - Are operators honest about injuries?

Appendix C: OSHA Rulemaking Process Diagram