Saint-Gobain Abrasives: Optimizing the Production Process in Bond Plant 7

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Abstract

Saint-Gobain Abrasives, situated in Worcester, Massachusetts, is renowned for delivering advanced abrasive solutions across many markets. Saint-Gobain's bond plant specializes in producing intricate abrasives and bonds for standard and customer-modified grinding wheels worldwide. Our partnership allowed us to provide engineering-driven insights and solutions to the bond plant through meticulous observation and analysis with Saint-Gobain's personnel.

The primary objective of this project was to enhance the operational efficiency of the bond plant and ultimately ensure the timely delivery of finished bonds to clients. The rationale for this project is to optimize the production process by streamlining workflows and improving Saint-Gobain's strong market position. To meet this overarching objective, we narrowed the scope of the project into multiple achievable parts. First, we comprehensively assessed the production process, using value stream mapping techniques to identify and quantify the characteristics of various process steps as well as the bottlenecks within them. Secondly, we focused on optimizing physical workspace organization by utilizing the principles of the 5S methods. On top of this, our efforts were directed towards physically documenting the primary steps in the bond creation process to act as a guide for those unfamiliar with the process. Lastly, we completed a Time Value of Money (TVM) analysis to better understand how our efforts would yield returns.

The conclusions were a projected decrease in non-value-added time, increased workspace organization and capacity, and a documented and streamlined process for Saint-Gobain to use in the future. Our TVM analysis projected an approximate 10% return rate within the initial year. A 5s process improvement can often yield an elevated rate of return relative to a small investment in equipment and labor.

Acknowledgments

We would like to recognize and express gratitude to the Saint-Gobain staff for their support throughout the project. We are grateful to have had the opportunity to work alongside such hard-working professionals. Your willingness to share your knowledge and patience throughout the project has been essential to its completion. We would specifically like to acknowledge the following individuals for their aid:

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1.) Introduction

The Problem Statement

Saint-Gobain's bond plant (Plant 7) specializes in producing various bonds for grinding wheel manufacturing. Adopting a make-to-order approach, the plant receives specific bond orders and formulates the corresponding abrasive mixtures (Gomez, 2023). Our project team, commissioned by plant managers, was tasked with enhancing the efficiency and effectiveness of the bond-making process. This would directly correlate to more on-time deliveries and an increase in overall production.

Project Goals & Objectives

The goal of this project was to impact the production process and increase on-time deliveries directly. To achieve this long-term goal, we concentrated on specific objectives. These objectives were to reduce non-value-added time, improve process organization, and recognize bottlenecks within the process. Visiting Plant 7 regularly and working with frontline operators helped educate us further on bond manufacturing at Saint-Gobain so we could analyze how to achieve these objectives.

Deliverables & Recommendations

Our team aimed to provide Saint-Gobain with coherent deliverables and recommendations that directly impacted the bond plant's operations. After meeting with Saint-Gobain managers and engineers, we understood that the project scope must be narrowed down. After our initial meeting with the Saint-Gobain team, we concluded that our project would consist of three primary components: 5S recommendations, value stream mapping, and documented videos to enforce standard operating procedures.

The scope of each of these components has changed throughout the project, but we ultimately provided Saint-Gobain’s Plant 7 with in-depth 5S recommendations that we compiled during our on-site visits and an easily accessible and visual documentation of multiple steps in the bond creation process. On top of this, we provided a value stream map that outlines the inputs and outputs of the primary process steps.

2.) Background Information

Throughout the team's report, multiple manufacturing and engineering methods are discussed, specifically within the process of creating bonds for the grinding wheels Saint-Gobain produces. The information provided in this section provides a deeper understanding of the process used to create these bonds, providing a foundation for the team's methods and findings.

Grinding Wheels

Grinding wheels are composed of abrasive grains and layers of fiberglass bonded into a wheel shape to efficiently finish metals and other materials (www.weilerabrasives.com 2024). Saint-Gobain's bonded abrasive wheels are "used for a variety of applications, from cutting to rough and high-precision grinding, including cylindrical outer diameter and inner diameter grinding, dimensioning, and sharpening" (www.saint-gobain-abrasives.com 2024). Saint-Gobain specializes in creating mixtures of different colored bonds that have unique abrasives for various grinding wheel manufacturing. As a result, Saint-Gobain has been a leader in the grinding wheel industry across the globe due to its high performance and customization to fit customer needs (www.saint-gobain-abrasives.com 2024).

Figure (1) - Saint-Gobain Grinding Wheels

Bond Plant

Bonds are essential components in the fabrication of grinding wheels, pivotal for their structural integrity and performance. In essence, bonds serve as the glue that binds abrasive grains together, providing cohesion and strength to the wheel during the grinding process (www.noritake.co.jp, 2024). While crafting grinding wheels, manufacturers carefully select bonding materials to meet specific requirements dictated by the intended application. Common bonding agents include vitrified resin, rubber, and metal bonds, each offering distinct properties tailored to different grinding tasks (www.noritake.co.jp, 2024). The versatility of bond materials allows for customization according to specific machining requirements, making them indispensable tools across various industries, from automotive to aerospace engineering. Saint-Gobain is an industry leader in grinding wheel manufacturing, and much of its success is due to the optimization of the multiple bonds it makes (Gomez 2024).

Figure (2) - Finished Bonds

Order Creation

Saint-Gobain employs a make-to-order approach in Plant 7 for the production of bonds and grinding wheels. Orders from both internal and external clients worldwide are processed at this plant (Moll, 2023). For internal customer orders, the production process concludes with the shipment of tested and certified bonds to another Saint-Gobain location where grinding wheel manufacturing occurs. External customer orders, on the other hand, involve the retention of tested and certified bonds at Saint-Gobain's Worcester campus, where they are utilized to create customized grinding wheels for the respective customers (Moll, 2023).

Consideration of both internal and external orders in a manufacturing process introduces additional complexities in generating a master production schedule (Gomez, 2023). Managing inventory shipments, total production duration, and order deadlines heightens the risk of confusion and potential delivery delays. Although our project specifically centers on bond creation, it is vital to highlight this pivotal stage to grasp the entirety of the order creation and fulfillment process.

Silo Preparation & Sack Dump

To initiate the production process, the silos, which lay outside of Plant 7 containing raw materials, are prepared from the control room in the plant's office using a software program. The user inputs the desired materials and routes them from the designated silo outside to the blender on the production floor. The route shows up on the monitor as well as the control panel on the wall, indicated by green lights (Moll, 2023).

Figure (3) - Silos behind Plant 7

Blender & Hopper

Once the desired materials are in the blender, they are sifted thoroughly for the next two hours, ensuring all clumps are churned out and the material is granular and powdery (Gomez, 2023). Upon completion of blending, the raw materials are then transferred to a subsection of the blender called the hopper. The raw materials are stored in the hopper until production is ready for extraction using high-pressure air blasts to move the material (Gomez, 2023).

Super Sack

Certain bonds require varying measurements of raw materials depending on their intended use (Gomez, 2023). In this situation, materials from the super sack are required. The super sack, weighing roughly 120 pounds, is retrieved via forklift and suspended over a grate. This grate funnels directly into the mill. The operator is required to pierce the bottom of the super sack to begin the collection process. Materials from the sack are hand-sifted into the grate using a wooden ruler. This process takes anywhere from 45 minutes to 1 hour, depending on the amount of materials needed (Gomez, 2023). Our group believes this process could be greatly improved to reduce time and enhance proper ergonomics.

Figure (4) - Super Sack Extraction Sector

ACM Mill

The ACM Mill is an additional machine that is only utilized when specific bonds (S bonds) are required for production. This mill receives raw materials from the super sack and sack dump, where they are thoroughly mixed and sifted until they become more of a flour-like substance (Gomez, 2023). Once the material is ready, it is extracted into barrels one at a time. An operator must man this station to start and stop the mill and to fill barrels. The mill must be emptied to completion after each use so that debris does not build up within the machine. The ACM Mill takes about five hours from start to finish (Gomez, 2023).

Canning

Once the raw materials have been thoroughly mixed, they are ready for packaging. This step in the canning process is automated, utilizing sensors and automatic rollers. Barrels are transported across the rollers until they align under the canner (Gomez, 2023). The canner then dispenses the bond into each barrel, moving sequentially from one barrel to the next every two minutes. Once filled, the barrel proceeds to the end of the line, where a frontline operator awaits, ending automation (Gomez, 2023).

Figure (5) - The team observing the automated portion of the canning process

The canner fills each barrel using volume as the metric instead of weight (Gomez, 2023). Once the team member receives the barrel, they must add or remove material until the final weight of 83 kilos is met. This is typically done with each barrel due to differences in metrics. Once the final weight is met, the barrel is covered and rolled onto a pallet big enough to fit four total barrels. A forklift is then used to place the pallet in storage until bond testing is complete (Gomez, 2023). Our team strongly believes this step to be a bottleneck due to the canner distributing material based on volume instead of weight, forcing frontline operators to alter the weight of each barrel.

Figure (6) - Frontline Operator finalizing the desired weight

Testing of Bonds

Before the bonds can be finalized for shipment or used to create grinding wheels, they need to pass testing (Moll, 2023). Each bond undergoes testing three times: initially before the canning process begins, again during its progression, and finally after canning is complete. This step confirms how the bond(s) will perform when being molded into a grinding wheel (Moll, 2023). Benchmark testing plays a vital role in evaluating performance, ensuring quality, and identifying flaws or cross-contamination. Any bonds that fail will be discarded and decomposed. If a test fails, production halts, prompting an investigation into the cause of the failure (Goding, 2023).

Figure (7) - Bond testing lab

Internal and External Extraction

After ensuring that no bonds have failed during testing, they are packaged for transportation to their destination. If the bond remains at the Saint-Gobain Worcester location to be used in forming grinding wheels, it is packaged in reusable black cans, each capable of holding 83 kg. These cans are cleaned and recycled for sustainable reuse within the plant. Bonds destined for other Saint-Gobain locations across the nation are packaged in durable brown fiber drums suitable for shipping. Bonds intended for shipment to India are packaged into a bag within a brown fiberglass drum. Unlike the reusable cans, these drums holding 80 kg are shrink-wrapped for shipment and are not returned to the plant. This additional step can cause delays and increase complexity in preparing final shipments (Gomez, 2024). This step marks the conclusion of the bond-making process within our scope.

Figure (8) - Bonds Prepared for shipment to India

3.) Methods

Project Scope & Objectives

An initial meeting with Saint-Gobain staff jumpstarted our ability to formulate our project objectives. Following this meeting, we gained valuable insights into the pivotal role of Plant 7's bond production and its utilization, along with the project's objectives. We ultimately left with the long-term objective of improving the bond production rate.

We were able to create smaller, attainable goals by narrowing down the scope of the project through constant on-site research and additional meetings with Saint-Gobain staff. Through analyzing the production process, we split the scope of the project into three achievable sections: value stream mapping, accessible videos for standard operating procedures, and a 5S assessment with recommendations.

Value Stream Map (VSM)

In this study, we adopted the Value Stream Mapping (VSM) method to analyze and visualize the processes involved in our research. Value stream maps are powerful tools based on lean manufacturing principles, utilized for process improvement and optimization across a variety of industries (purdue.edu, 2021). By documenting each step of a process from start to finish, we can collect a comprehensive understanding of value-added and non-value-added activities, bottlenecks, and opportunities for enhancement of production (purdue.edu, 2021). Through collaboration with frontline workers and data collection, our team mapped out the flow of information, materials, and activities within our research domain, identifying areas for efficiency gains and waste reduction. This approach not only provides a holistic view of the current state but also serves as a foundation for future process optimization endeavors, ultimately contributing to improved performance and outcomes.

iPad Videos for Standard Operating Procedure

One of the best ways for our team to get an understanding of the bond manufacturing process was to document Plant 7 via photographs and videos. As visible throughout this report, our photographs help align our understanding with visual guidance. The same can be said for the multiple videos we documented and edited. At first, our team videotaped essentially everything so that we could discuss particular procedures, machines, and observations we made when we arrived at Saint-Gobain. While documenting and editing these videos, our team was able to take a closer look at specific processes we thought could be changed to reduce non-value-added time. Then, once we understood the process in more depth, our team videotaped specific procedures that the frontline operators complete regularly. These videos included how to operate the ACM Mill, the Sack Dump, the Canner's non-automated step, and the Barrel Cleaning Station.

These videos showcased operators using the machinery from start to finish and included a voiceover for each important step. The main goal was to capture standard operating procedures and provide Plant 7 managers with another training tool for new frontline operators. These videos can also be used by current frontline operators who may need a detailed reminder of the standard operating procedure for specific machines. While we may not be able to showcase our videos through this paper, they were still very important and a requested deliverable for the Plant 7 managers and the future frontline operators.

5S Principles

The 5S method is well-defined and can be applied to an infinite number of workplace scenarios. Before we drew conclusions, we conducted preliminary research in the 5S field to familiarize ourselves with the primary principles and how they may apply to Plant 7. We did this through scholarly research and reviewing case studies with a 5S focus.

After this initial research, we began to document areas in Plant 7 that we believe could benefit from 5S implementation. We did this by taking both photos and videos of areas where the 5S principles are applicable and then forming recommendations for Saint-Gobain to implement to reconcile these issues.

At the halfway point of our project timeline, we provided Plant 7's frontline operators with a sheet that tasked them with conveying their personal 5S and process improvement-related recommendations. When we collected the sheet, we found an extremely high number of prevalent machinery issues and potential solutions that they provided. We ultimately combined both the frontline operators' recommendations with our own to provide comprehensive guidance on implementing the 5S methods in Plant 7. We ultimately used Suh's axiomatic design to decompose and develop 5S recommendations and standards in Plant 7.

Axiomatic Design Decomposition

As the 5S portion of our project was heavily requested by Saint-Gobain, we decided to utilize Suh's Axiomatic Design to decompose this section. The axiomatic design allowed for a clear definition of the various steps involved in approaching 5S implementation (Suh 2001). "The design decomposition is complete based upon manufacturing engineering principles, capturing the proper FRs and corresponding DPs" (Towner 2013). They are pictured in Figure (9):

#	[FR] Functional Requirements	#	[DP] Design Parameters
FR[0]	*Develop 5S recommendations and standards for the bond plant at Saint-Gobain Abrasives.*	**DP[0]**	*Project Charter*
FR[1]	*Research 5S methods*	**DP[1]**	*5S Report*
FR[2]	*Learn the intended bond-making process*	**DP[2]**	*Employee Interviews*
FR[2.1]	*Understand the current bond-making process*	**DP[2.1]**	*Observation Report*
FR[2.2]	*Interview current frontline team members*	**DP[2.2]**	*Employee Interview*
FR[2.3]	*Capture photographs and videos on the production floor*	**DP[2.3]**	*Project Documentation*
FR[3]	*Analyze the current organization of the production floor*	**DP[3]**	*Project Documentation*
FR[3.1]	*Track workflow of raw materials*	**DP[3.1]**	*Shadow Employe Report*
FR[4]	*Identify machinery (in)efficiency*	**DP[4]**	*Observation Report*
FR[4.1]	*Document machinery (in)efficiency*	**DP[4.1]**	*Project Documentation*

FR[5]	*Analyze the bond plant's current use of 5S methods*	**DP[5]**	*Employee Interview*
FR[5.1]	*Recognize 5S opportunities on the production floor*	**DP[5.1]**	*Observation Report*
FR[5.2]	*Determine the most essential 5S needs*	**DP[5.2]**	*Employee Recommendations*
FR[6]	*Apply research and observations*	**DP[6}**	*5S Recommendations*

Figure (9)- Suh's Axiomatic Design decomposition

The [FRs] were created first and are intended to start with verbs, as they are actions we are going to take in order to break down and achieve the problem we are assessing. The [FRs] have metrics for evaluation on whether they are improving or not. Our [FR0] is most important, as this functional requirement sets the theme of what we are decomposing, and the following [FRs] break down how we are going to get there. Once our [FRs] were completed, our team collaborated to create the [DPs], which are the actions we took to achieve their respective [FRs]. For example, our [FR2.1] was to "understand the current bond-making process," and the action we took to achieve that was completing observation reports ([DP2.1]). One [DP] may be able to interact with multiple [FRs] causing coupling of the [FRs]. Overall, the axiomatic design decomposition helped us break down a problem into smaller steps to identify the steps needed to solve a larger and more complex problem (Towner, 2013).

Coupling Matrix

After the axiomatic design decomposition was completed, we utilized the functional requirements [FRs] and design parameters [DPs] our group collected to create the coupling matrix shown in Figure (10):

	DP0 - project charter	DP1: 5s report	DP2: Employee interviews	DP2.1 - Observation report	DP2.2 - employee Interview	DP2.3 - project Documentation	DP3: Project Documentation	DP3.2: Shadow employe report	DP3: Observation report	DP4.1: project Document	DP5: employee Interview	DP5.1: Observation report	DP5.2: employee reccomendations	DP6: 5s recommendations
FR0: Develop 5s recommendations and standards for The Bond Plant at Saint Gobain Abrasives.	x													
FR1: Research 5s methodologies		x												
FR2: Learn the intended bond making process			x					x						
FR2.1 - Understand the current bond making process				x					x			x		
FR2.2 - Interview current frontline team members			x		x						x			
FR2.3 - Capture photographs and videos on production floor						x	x			x				
FR3: Analyze the current organization of the production floor						x	x			x				
FR3.1: Track workflow of raw materials								x						
FR4: Identify machinery (in)efficiency				x					x			x		
FR4.1: Document machinery (in)efficiency							x			x				
FR5: Analyze The Bond Plant's current use of 5s methodologies					x						x			
FR5.1: Recognize 5s opportunities on the production floor				x					x			x		
FR5.2: Determine the most essential 5s needs													x	
FR6: Apply research and observations		x		x										x

Figure (10)- Completed coupling matrix

Our reasoning for creating this coupling matrix was to better understand what steps we would need to take to develop 5S recommendations and standards for Plant 7 [FR0]. The left-hand side of the matrix shows what is desired to be achieved through the [FRs], and the right-hand side, which is represented on the top of the matrix, shows how they are planned to be achieved through the [DPs] (Towner, 2013).

Creating the table for our matrix allowed us to visually see the quantity of [DPs] used, which essentially tells us what order we should have done things to achieve our [FR0], also known as sequential coupling (Towner, 2013). For example, [DP2.1] "observation report" is the most commonly used [DP], therefore impacting the most [FRs] ([FR2.1], [FR4], [FR5.1], [FR6], all affected) out of any other [DP's]. This means that this should have been the first step we took to start achieving [FR0]. If we had not made this our first step, then we would have been revisiting this step multiple times down the road in order to fully understand and achieve [FR0]. This is because, to properly achieve our goal, the coupling matrix tells us that the most common [DP's] need to be achieved first. On the other hand, a [DP] like "5S recommendations" is only used once, which tells us that this is something that can be completed when we feel it is necessary. This is because the matrix does not value this as something that needs to be completed first, as it only affects one [FR].

Time Value of Money Analysis

We employed both Time Value of Money (TVM) and Discounted Cash Flow (DCF) analysis to perform our financial evaluations. More specifically, we used these methods to evaluate the financial outcome of our primary process recommendations. These recommendations include purchasing and installing a new ACM mill, a vibrating table for the super sack dump, and a semi-automated shrink-wrap machine. In addition, we recommend recalibrating the canner to use weight instead of volume and utilizing a regular maintenance crew. To perform these calculations, we made informed estimations of the monetary value and cost of these recommendations. Aside from Saint-Gobain's hourly wages, these numbers are purely educated estimations.

Utilizing TVM principles, we assessed money's worth over time, accounting for factors such as interest rates. This allowed us to determine the present value of future cash flows and assess the impact of various investments on our calculations. Subsequently, employing DCF analysis, we projected the future cash flows generated by our investment opportunities and discounted them back to their present value using a 10% discount rate. By integrating both TVM and DCF methods, we were able to perform an estimated financial analysis of our recommendations. We estimated the time saved, fully loaded hourly costs, and potential investments in our process improvement recommendations.

When calculating our TVM, our group used our value stream map to calculate how much time Saint Gobain would save per cycle by integrating our recommendations. For S bonds, we calculated they would save 5 hours, at a shop rate of $75 an hour. This would save them a total of $375 per cycle. For all other bonds, we calculated that they would save 2.75 hours at the same shop rate saving them $206 per cycle. We then estimated that S bonds were made about 40% of the time while the rest of the bonds were about 60% of the time. This allowed us to calculate that they saved on average $274 per cycle.

We also factored into our calculations that the employees at Saint Gobain would have to adjust to using the new equipment that we recommended. Through our observations, we estimated that currently Saint Gobain averages about 16 cycles per month. When integrating our recommendations, we thought that production would lower slightly to 12 cycles per month, due to the workers getting accustomed to the new equipment. By month 4, we believed that factory workers would have gained familiarity with the equipment, and production would reach 16 cycles per month again. At month 8 we believed production would boost to 18 cycles per month, as we estimated this to be when they nearly mastered using the new equipment. For the rest of our calculations, production stayed at 18 cycles per month as this is the amount we believed they could reasonably make with the changes we implemented.

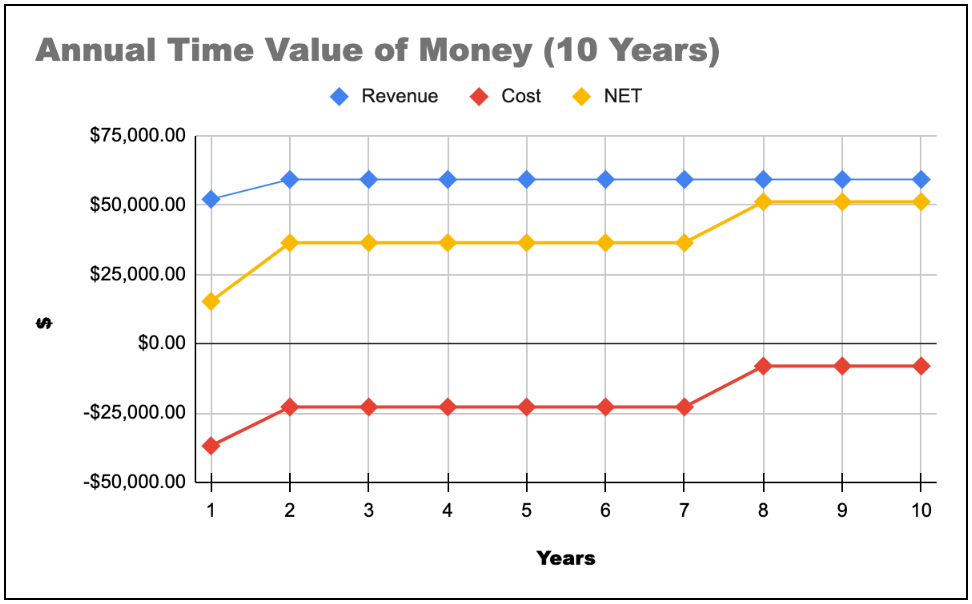


Figure (11) - Annual Time Value of Money (10 Years)

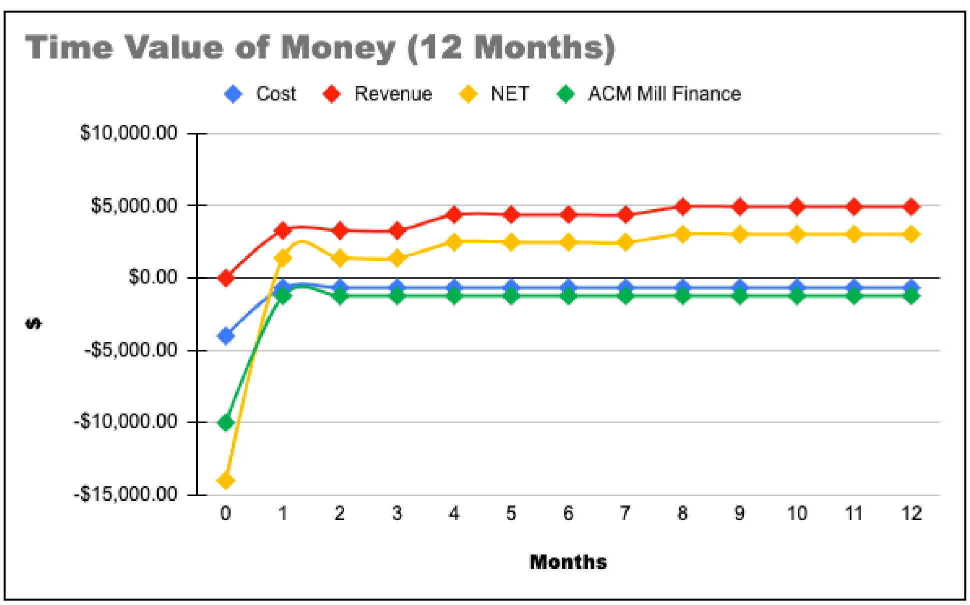


Figure (12) - Time Value of Money (12 months)

Our analysis spanned two time frames, 12 months and 10 years, to evaluate short and long-term impacts. The projected NPV amounts to $15,236 over one year and $386,756 over ten years, as illustrated in the accompanying graphs. These models provide valuable insights into the financial viability of our proposed improvements, despite the inherent challenge of obtaining precise information for our estimations.

4.) Deliverables / Recommendations

5S Recommendations

5S is a methodology derived from five Japanese terms, outlining the primary principles of workplace organization (Jacobsen, 2009). 5S targets small steps in the workplace that ultimately lead to sustainable process improvement to help a system run more efficiently and become leaner. The 5S consists of sorting, setting in order, shining, standardizing, and sustaining (Jacobsen, 2009).

Our team was able to apply these principles to Saint-Gobain's bond plant and provide 5S-related recommendations based on both the data we collected from the plant and our observations while visiting Saint-Gobain.

Sort

Plant 7 should designate a work day to completely remove and dispose of any unnecessary machinery and equipment. The remaining items can be split into two sections: items used daily and items used monthly or rarely. Doing this will allow for less clutter from unnecessary items and create easily accessible locations for frequently used items. "*The defective or rarely used material and equipment in the company cause the demolishment of the workplace's order and decrease in the work efficiency*" (Sancoban, 2006). Sorting and removing unnecessary items from the plant is a crucial starting point for the rest of the 5S methods to be implemented successfully. This is because it will lead to decreased problems and complaints throughout the workflow and simplified communication across personnel (Singh et al., 2014).

Recommendations:

The walkways in Plant 7 are outlined by yellow markings and are utilized for both human and forklift passage. However, throughout working with Saint-Gobain, more often than not, these pathways are used for extra storage space.

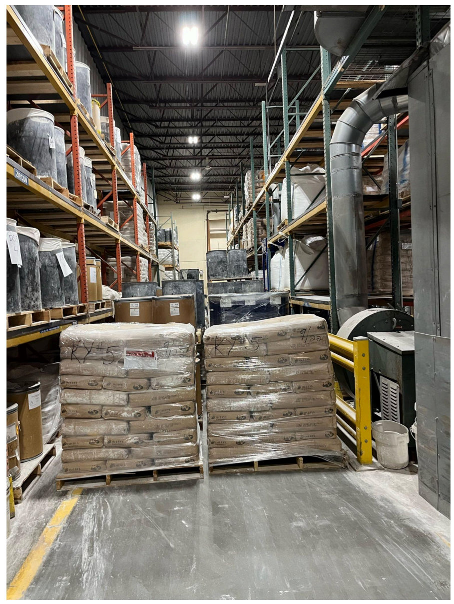


Figure (13) - Inventory blocking pathways

Figure (14) - Waste barrels labeled "dump" taking up space on the production floor

As seen in *Figure (13)*, the walkway between the two storage racks is completely blocked off by large shipments of raw materials. It is imperative that these routes be used freely and without bottlenecks (Singh et al., 2014). In the case of Plant 7, at most times, essentially all of the storage space is filled with finished bonds and materials. Oftentimes, according to the frontline operators, there is simply no extra room to store incoming shipments (Gomez, 2023). On top of this, when bonds are tested and fail, there is minimal storage space for this new waste. *Figure (14)*, displays failed bonds taking up space within the plant. Although failing bonds is a rare occurrence, there is still a need for extra storage space for Plant 7 (Gomez, 2023).

A potential solution to the lack of storage space in the plant is to purchase and place a large, weatherproof, and easily accessible shipment container directly outside of it. As Plant 7 is at the end of the complex, there is a large space on both sides of the plant. It would be important that the container be placed close to or against the side wall of the plant. This would facilitate access to the loading dock as well as the two outside doors that lead into it.

A particular shipping container that might suit this demand might be a 40-foot-high cube open-side container. Seen below is an example of this type of container that could be placed outside of Plant 7.

Figure (15) - Interior view of shipping container

This specific container would be ideal for Plant 7's loading station due to its wide doors that open up the entire container horizontally. This allows for easy access for the plant team on foot and through forklifts and provides a weatherproof solution.

The dimensions of the shipment container allow for increased storage space, which would, in turn, free up space inside Plant 7. Using simple calculations, we can find the total volume of this shipment container:

Internal Container Length: 39.475'

Internal Container Width: 7.5’

Internal Container Height: 7.549’

Container Volume: $39.475\times7.5\times7.549$ = **2,234.9 cubic feet**

The total cubic feet of space in the shipment container is 2,234; so if utilized, the purchase would save over 2,000 cubic feet of space. To apply this to Plant 7, this space would likely be used to store barrels of bonds, whether they are waste or outgoing orders. We can use a similar calculation to solve the total volume of a barrel:

Barrel Radius: 2.5’

Barrel Height: 3.5’

Barrel Volume: $\pi r2h \rightarrow \pi\times2.52\times3.5 \rightarrow 21.875\pi$ = **68.7 cubic feet**

The total cubic feet of space in one barrel is 69. To take this a step further, we can estimate the number of barrels (filled or unfilled) that can fit into the shipment container:

Total Barrels able to Fit in Container: 2,234.9758125 / 68.722339297277 ≅ **35 barrels**

By dividing the total shipment container volume by the total barrel volume, we find that a total of 32 barrels could fit into the space. Realistically, the container will not be overloaded so that the crew can easily access the interior, but this space can serve as a convenient location for waste barrels, finished bonds, or other materials.

It can be noted that a brand-new shipment container will likely be too costly for its intended purpose, so we recommend a lightly used container to decrease total expenses. On top of this, a pop-up tent might serve as an alternative option to a container, although they are not as durable and reliable.

This recommendation should act as a contingency plan if Plant 7 continues to struggle with storage space for barrels. We hope that our preliminary recommendations will vastly improve the capacity for storage space within the plant but if not, this will act as an alternative to save space.

Set

Plant 7 should ensure that each item has a designated home and that there is no clutter blocking walkways, entrances, and floors. This includes rooms that contain actively working machines as well as the plant office. The second part of 'Set' is to ensure that labels, tapes, signs, and markings support their respective areas (Singh et al., 2014). We found that having all racks labeled is a request of the Plant 7 frontline operators. Additionally, if applicable, the tools within each station should be placed in the order that they will be utilized to simplify storage (Moradiya, 2020).

Recommendations:

In the case of Saint-Gobain's bond plant, essentially all of the primary production spaces contain large machines that complete the required task after manual preparation. In some of these spaces where the machines are placed, there is no need for any extra items as the machine does not require them, so this step in 5S can be overlooked. However, in other areas of Plant 7, there is an abundance of clutter that we believe can be filtered and sorted out. Seen below is a photo *(Figure (16))* of one of the operating rooms in the plant.

Figure (16) - Walkway Clutter in Workspace

It can be seen that the walkways are spotted with barrels, wood panels, and an extensive amount of dust buildup. The pipes, cords, and machines are excluded from this step as they are stationary. These barrels and panels should be pushed against the wall in a way that frees up the walkway and allows for seamless movement. If these items are not necessary, they should have already been disposed of in the first step, "sort." This is a simple example of how to implement 'set' into Plant 7.

Shine

This step, to 'shine' the workplace, is imperative to continue implementing the 5S methods in Plant 7, but is impossible without properly enacting the previous principles. This step entails a thorough and complete cleaning of the workplace and all items within the workplace. "*Dust, dirt and wastes are the source of untidiness, indiscipline, inefficiency, faulty production and work accidents* (Anon, 2007). Additionally, the principle requires that there be routine cleaning, maintenance, and inspections throughout the workplace.

Recommendations:

To relate this step to Plant 7's current state, we believe that 'shine' will provide the most dramatic change to the workplace. When all items are sorted and set, the plant will be far easier to properly clean than it was previously. In *Figure (16)*, not only is there excessive clutter, but there is dust covering the entire area of the floor. If the clutter is removed and/or sorted, then cleaning the floor will be infinitely easier. This is a simple example of how to apply 'shine' in Plant 7 after 'sort' and 'set' have been completed, but it is not the extent of our recommendations for this step.

To continue, the 'shine' process is not solely to clean the workplace once, but to *regularly* clean, inspect, and maintain. We believe that Plant 7 should implement a routine cleaning schedule to be explicitly followed. Plant 7 contains only three frontline operators, which limits the amount of time and effort focused on cleaning. As it currently stands, the Plant 7 team only has the capacity to clean and maintain the essential areas and machines, leaving a large portion of the bond plant unkempt.

We believe that designating a small cleaning team to regularly clean the bond plant would greatly benefit the overall cleanliness and workflow of the plant. Having a crew clean the plant twice a week, for example, would vastly improve movement throughout the plant as well as create a safer work environment. On top of this, the frontline operators in Plant 7 would have additional time to focus on the production of bonds, ultimately reducing non-value-added time. To avoid the cleaning crew and frontline operators overlapping their respective work, we believe that the cleaning should take place during an evening shift in preparation for the next day. The cleaning crew must remain constant so the job can be completed efficiently each time. The frontline operators should explain to the cleaning team which areas to clean and how to properly clean them. They should also share other important information and tactics for working in Plant 7.

Implementing regular cleaning in the plant will decrease the set-up time for production as well as improve working conditions for the team members and the machinery. Ultimately, there will be a decrease in non-value-added time, allowing the frontline workers to increase production.

Standardize

After the workplace has been newly ‘set’, ‘sorted’, and ‘shined’, these changes must become part of standard operating procedures. “*Standardize makes 5S repeatable. It transforms 5S from a one-off project to a reproducible set of activities*” (Lean Production 2024). All of the previously completed 5S steps can positively impact the workplace. However, if these principles are not standardized in a long-term plan, the affected area will revert to its unkempt current state.

Recommendations:

We have two primary recommendations for Saint-Gobain to standardize these 5S practices. The first, as mentioned previously, is to implement a routine and designated cleaning team for Plant 7. The frontline operators can work with the cleaning team to select the frequencies to clean. Consistent cleaning will help create a higher standard within the plant and facilitate smoother production and workflow.

Our second recommendation is to implement a similar routine schedule that focuses on both preventative and corrective maintenance. According to the frontline operators, a majority of the machines in Plant 7 are outdated. Throughout the period we have worked with Saint-Gobain, there have been many instances of machine failure. Following the collection of Plant 7 team members' recommendations, we were able to compile a complete list of all 5S and process improvements from the team themselves. To view a complete list of all of the identified machine-based issues in Plant 7, visit **Appendix A**. Highlighted below is the most prevalent machine issue that we identified within Plant 7.

This first issue was highlighted by team members as the "most dangerous issue" in Plant 7. "*AC amps gauge cannot exceed 28 AMPS. If it does exceed it, that means the canner is full of material and will strain the belt on the uppermost part of the canner. This is the most dangerous issue; this can make belts snap off*" (Gomez, 2024)**.** With the problematic tendencies of the canning process, the team members have an arduous solution to this problem: "*Decrease the timing of how fast the hammers are turning to zero and immediately turn off the screw (by changing it from 'auto' to 'off'). You need to get an empty can underneath the canner as soon as possible. Run the canner with the screw off until the canner is not full of material*" (Steve Gomez, 2024). These steps must be followed to solve this issue. Although there is a clear solution, the frontline operators had to troubleshoot this issue themselves and figure out how to resolve it on their own. When paired with the daily tasks of producing bonds, machine maintenance, and troubleshooting can contribute to non-value-added time and create additional roles for team members.

There were several other machinery-based issues that the frontline operators conveyed and quantified into non-value-added time. Reference **Appendix A**. These examples have fueled our recommendation to implement a routine preventative maintenance schedule in Plant 7. The frontline operators hold crucial knowledge of each machine and how to troubleshoot and fix it. If they are not directly performing this preventative maintenance, they must convey all relevant information to whomever it may be. Implementing this preventative maintenance schedule as well as the cleaning schedule will ultimately help standardize the 5S principles.

As a result of this maintenance, whoever identifies a mechanical issue in Plant 7 should document this issue in the designated area iPad. On top of this, they should record the reason for the issue as well as the solution when it is identified. Recording the machine downtime will directly portray accurate information relating to Plant 7's machine efficiency and provide evidence of poor or positive production. After a period spent recording this information, it will become clearer which machines act as bottlenecks in the bond production process. On the other hand, this information will also prove which machines are operating at a high level of efficiency. Having machinery-focused issues documented and analyzed will facilitate decision-making across all levels in Plant 7.

Sustain

‘Sustain’, in the 5S methods, is a principle that enforces the continuous improvement of 5S culture. Developing a sense of 5S-related self-discipline in employees across all levels at Saint-Gobain will constantly improve the other steps in 5S over time. To sustain itself, Plant 7 must place great importance on the previous 5S principles in all areas of the workspace.

Recommendations:

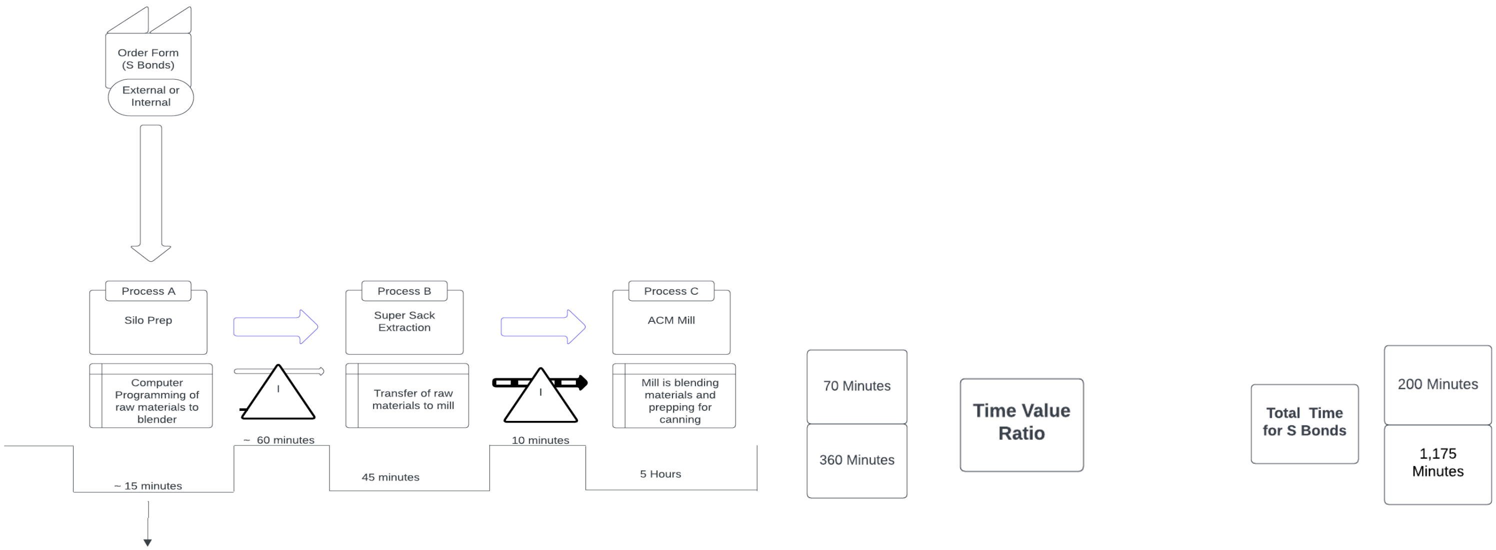
We believe that enacting and consistently utilizing both a cleaning and preventative maintenance schedule will immediately contribute to the shift in 5S culture and practice.

Regularly, Plant 7 should undergo cleaning and machinery inspection to address any issues before frontline operators commence bond production. Plant managers can provide routine checkups with the frontline operators to make sure that the cleaning and maintenance process is efficient. These two recommendations will directly impact the ability to sustain the 5S culture in Plant 7.

Value Stream Map (VSM)

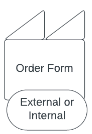
Multiple on-site visits to Saint-Gobain’s bond plant allowed us to create a value stream map relevant to the operations that take place within the plant. We worked with the Saint-Gobain staff to gain an understanding of how bonds are created in the plant and carefully recorded each step of the process for visualization. Creating a value stream map allowed us to deliver a more comprehensive and visual understanding of the complex bond creation process. Additionally, the VSM acts as a guide and reference for Saint-Gobain employees across all levels.

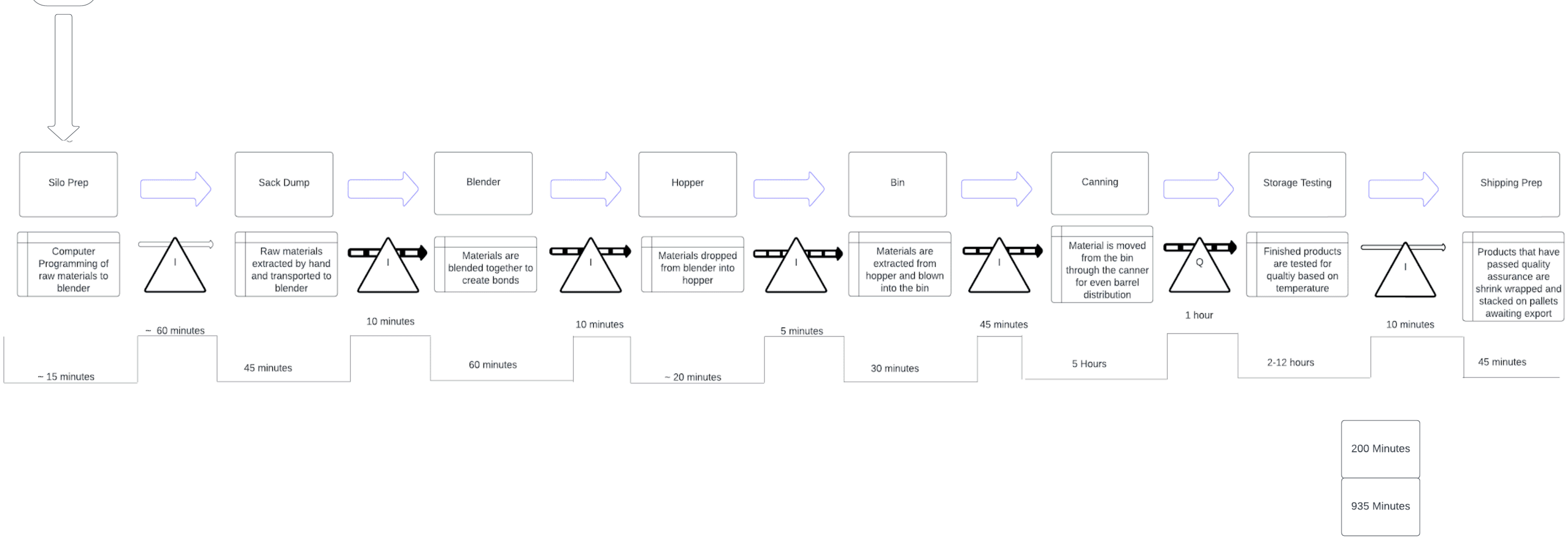
The beginning of the Value Stream Map for "S" Bonds only.



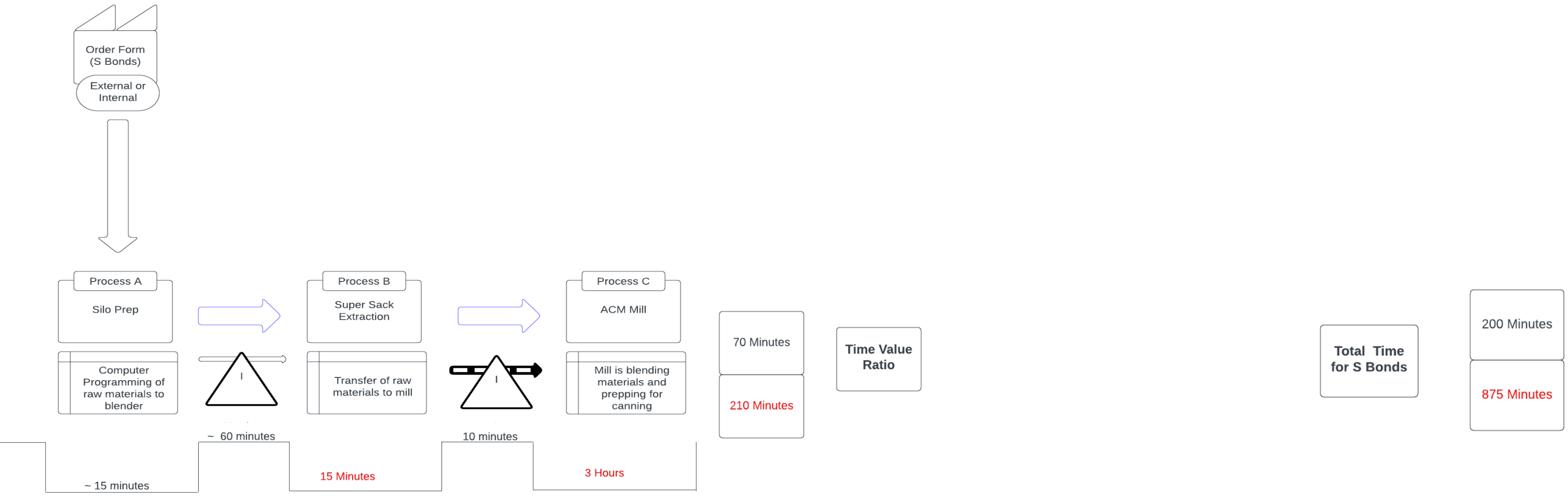
The beginning of the Value Stream Map for all other bonds.

(S Bond still runs through process shown below starting at "Hopper")





The beginning of the Value Stream Map for "S" Bonds only. (Optimized)



The beginning of the Value Stream Map for all other bonds. (Optimized)

(S Bond still runs through process shown below starting at "Hopper")

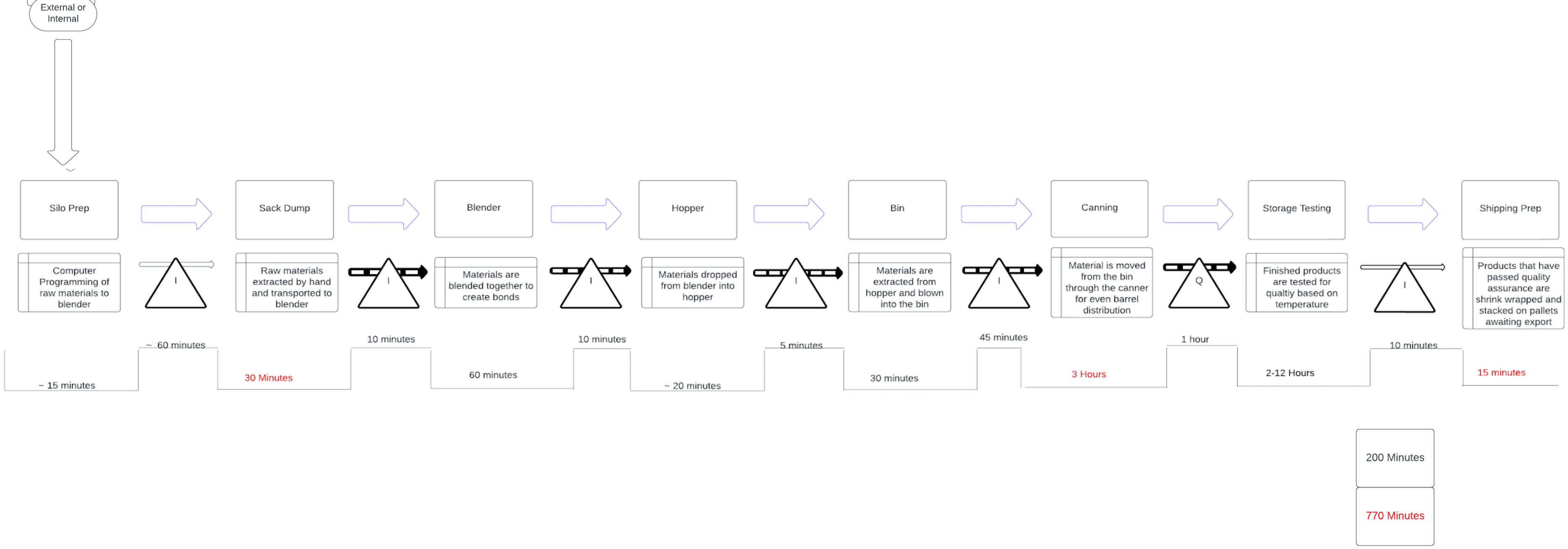


Figure (17) - Plant 7 VSM

Our team's value stream map concluded that several areas in the production process are contributing to non-value-added time, bottlenecks in production, and a lack of ergonomic benefits for floor workers. The largest disruption in production is the canning process. The canner's sensors currently operate based on volume metrics, posing various challenges for the floor workers. Using volume as the metric, the floor worker is required to manually adjust each barrel's weight which can take multiple hours to complete depending on the quantity of the order, which results in non-value-added. If the metric used were weight rather than volume, this process would be at a more optimal operation level.

Another step in the process that is non-value-added is the super sack extraction. This process requires an operator to sift all of the raw materials being transferred from the super sack to the ACM Mill. This is an hour-long task that requires an operator for the entire span. This super sack process is not ergonomic and can cause strain on the employee as they are required to pierce the sack without proper tools to do so and kneel beside a grate to sift raw materials with a yardstick.

The final step in the production process is another area to consider concerning ergonomics and non-value-added time. The final step requires floor workers to shrink-wrap large pallets to prepare for shipping. This step takes upwards of half an hour to complete. If these steps were automated and the non-value-added time was converted into value-added time elsewhere, this would optimize total production time and yield a much greater production load at an increased rate.

As a way for our team to display the value-added time that could be used more efficiently, we assembled a second VSM. As shown above, all of the steps in the process that are highlighted in red are production steps that have suboptimal lead or wait times in the suboptimal VSM. By trimming down these times through machinery upgrades and facility improvements, our team's results indicate that the Time Value ratio can be brought down significantly, leading to a more efficient production cycle.

Overall, the VSM guided us to identify areas that can be improved within the bond production process and highlighted areas of improvement within these steps. The VSM is also crucial for Saint Gobain to enhance documentation of the entire bond-making process. It can be modified to fit future production models in Plant 7 and, in time, provide evidence of an overall improved system.

5.) Conclusion

Overview

As a result of our project, we were able to provide Saint-Gobain Abrasives with both evidence-based recommendations and deliverables that we believe will provide invaluable and positive impacts to Plant 7's operations. Through meetings with Saint-Gobain team members, we narrowed the scope of our project into three attainable sections: 5S principles, value stream mapping, and professional documentation of Plant 7 processes.

By creating a value stream map of Plant 7's primary bond production processes, we were able to provide a complete overview of each step in the process. This completed value stream map highlights the flow of materials through two types of bond production processes and provides a processing time for each step. This provided us with the ability to navigate bottlenecks and facilitated our approach to the 5S methods. In addition, the VSM acts as a guide for Saint-Gobain's staff as they continue improving Plant 7's operations.

We were able to provide Saint-Gobain with a set of detailed videos that carefully explain the primary steps in the bond production process. These videos provide Saint-Gobain with another tool for understanding the complex operations in Plant 7 and are projected to be extremely useful in teaching newly hired employees across all levels.

As a result of our 5S recommendations, we hope to see a corresponding improvement in the utilization of all workspaces in Plant 7. By following and sustaining the core 5S principles as well as our personal recommendations, we believe we can see a positive shift in 5S culture. A standardized 5S structure will decrease both human and machine downtime, thus reducing non-value-added time and overall production bottlenecks.

Our suggestions should result in Saint-Gobain saving more time and money, increasing on-time deliveries to customers. Our Time Value of Money calculations show about a 10% increase in rate of return in the initial year and is estimated to save the company $386,756 over ten years. We believe this number is just the start, and could be increased as they continue to collect more raw data to analyze.

We believe that our research has laid the groundwork for increased throughput and on-time deliveries in the near future. Saint-Gobain now has additional tools to utilize in its goal for an improved bond production process, and these recommendations are ready to be implemented.

As our group reflects on our entire MQP experience we are grateful to Saint Gobain for allowing us to work on an intricate and complex project. We believe our actions will serve to be meaningful and useful for years to come. Working alongside Plant 7's frontline operators and managers gave us a behind-the-scenes look at the relationship between both parties and their particular roles within the organization. Working within our project team has helped us sharpen our skills: time management, group and individual communication, role assignments, leadership, and teamwork. Participating in this project has amplified our real-world experiences and tested these skills on a larger playing field, with real-world tasks and results. Our project has certainly been challenging, but it was ultimately extremely rewarding. Interactions with Saint Gobain's frontline operators, managers, and our project group have proven to be valuable learning experiences that we can reflect on after graduation from WPI.

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Appendix A (Direct Quotes)

A.1 - Silos

A.1.1 - "*Process Improvement for Filling Silos: having a hopper that already has a way to pierce the super sack that's being inserted into it would make things easier and faster*" (Steve Gomez 2024)..

A.1.2 - "*Process Improvement for Filling Silos: having a place to store the raw material will help us with transporting material*" (Steve Gomez 2024).

A.1.3 - *"Process Improvement for Filling Silos: the line that is used for transferring spodumene has holes in it (top of Silo #1) that needs to be fixed*" (Gomez, 2024).

A.2 - Canner

A.2.1 - "*AC amps gauge cannot exceed 28 AMPS. If it does exceed it that means the canner is full of material and will strain the belt on the uppermost part of the canner. This is the most dangerous issue, this can make belts snap off*" (Gomez, 2024).

A.2.2 - "*Resolve this by: Decrease the timing of how fast the hammers are turning to zero and immediately turn off the screw (by changing it from 'auto' to 'off'). You need to get an empty can underneath the canner as soon as possible. Run the canner with the screw off until the canner is not full of material*" (Gomez, 2024).

A.2.3 - *"2 hours (downtime): needed to clean machine for change of bond"* (Gomez, 2023).

A.2.4 - *"2 ½ - 3 hours (downtime): needed to clean machine and had to change the screen for change of bond"* (Gomez, 2023).

A.2.5 - *"3 - 4 hours (downtime): needed to change the hammers located in the uppermost part of the canner. These hammers will wear out within 5 months or so and the metal thins out"* (Gomez, 2023).

A.3 - India Orders

A.3.1 - "*India is the only place where we make bonds that require us to put a plastic bag (liner) into the drum"* (Gomez, 2024).

A.3.2 - "*When sending the drum through the canner, the air lances that help compact the bond in the drum make the liner in the drum come up the drum and touch the sensor. This results in the canner thinking the drum is more full than it actually is. Instead of a drum coming out at 60-70 kgs (normal), it will come out at 15-30 kgs, forcing us to put the drum through another cycle with the canner and ultimately tripling the time it takes to complete the order as well as straining the belts used within the canner, with the possibility of breaking the belts. Broken belts are guaranteed 2 hours + of downtime for canner*" (Gomez, 2024).

A.3.3 - "*Recommendation for India Order: there is an actual liner made from the same company that makes drums that allows for the bags to stay in the drum air tight, alleviating what happens when air lances suck up the bag inside the drum*" (Gomez,2024).

A.4 - Sack Dump

A.4.1 - *"4 - 5 hours (downtime): changed bond type from dark to light colored - need to clean sack dump"* (Gomez, 2024).

A.5 - VBlender

A.5.1 - *"4 - 5 hours (downtime): needed to change agitator with vessel due to oil seals getting too much bond in them"* (Gomez, 2023).

A.5.2 - *"4 - 5 hours (downtime): Maintaining the VBlender is necessary for continued usage. Using both dry and wet rags as well as an air gun to clean inside the vessel to avoid oil seals from taking in excessive amounts of bonds"* (Gomez, 2023).