Fall 12-4-2023

Imerys: Tube Mill Optimization Project

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Recommended Citation

Waltman, Ryan; Beasley, Dalton; Beasley, Dyson; and McMichael, Tristan, "Imerys: Tube Mill Optimization Project" (2023). *Senior Design Project For Engineers*. 94.
https://digitalcommons.kennesaw.edu/egr_srdsn/94

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Group 5 Final Design Review

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December 4th, 2023

Executive Summary

The Tube Mill Optimization Project is in partnership with Imerys for Tube Mill 81 at their Marble Hill site in Georgia. Tube Mill 81 is a dry ball mill that operates 24/7 and makes an intermediary product for Plant 3. Tube Mill 81 needs quality improvement and a production rate increase to meet demand. Imerys's quality specification is between a particle size of 12-18 microns and an acceptable production rate of 5 tons per hour. This project focuses on the development and implementation of three solutions: increase the amps on the separator to increase production, replace missing classifier blades in the separator to improve quality, and put new media balls in the tube mill to improve grinding efficiency. Before and after each change, product samples are analyzed to measure changes in quality in particle size (microns). A rate check shows the production in tons per hour (TPH). The baseline data analysis revealed the average product size at 41.5 amps is 13.86 microns and production is 3.84 TPH. After increasing the separator amps from 41.5 to 43, the production increased to 5.28 TPH. This is 1.44 TPH more and a 37.5% increase than the baseline results. This change is expected to yield 12,614.4 additional tons produced per year if it is kept at the higher amperage. The increase to 43 amps also shifted the average quality to 14.6 microns, an increase of 0.74 microns or a 5.34% increase. Though this measurement is larger than the baseline result, it is still within the 12 - 18 micron acceptable range. The next steps for this solution include increasing the separator amperage in 2 amp increments until the quality leaves the acceptable quality zone or the fan limit curve threshold is surpassed and the production rate decreases. The classifier blades were ordered and installed to help improve the quality. Quotes for the media balls have been gathered and a decision will be made on the best solution. The addition of fresh media is expected to increase grinding efficiency and production rate. Overall, the team helped increase production and identified ways to help improve the quality.

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Chapter 1: Background and Overview

1.1 Introduction

Imerys is a mining corporation with mines stationed across the world. For this project, our team is working at a Calcium Carbonate mine in Marble Hill, Georgia. The mine crushes marble and produces multiple products at their different plants. Plant 8, the plant where our team is focusing on in this project, currently produces Drikalite, Gameco, Gamaplase, Gama-Sperse 255, and Calwhite. All these products are grinded marble with different specifications including color and particle density with uses ranging from caulking to vinyl flooring. Tube Mill 81 (TM81) is an intermediary process that grinds marble into feed used for Plant 3. TM81 currently produces ~3.84 tons per hour of material. Imerys would like an increase in production while maintaining high quality. This is to keep up with demand for TM81's downstream processes. They would also like a consistent product flow rather than it being variable. If the quality falls out of specifications, it can lead to choking of downstream processes, leading to production delays. As the process changes to increase production, the quality will need to be checked to make sure the product is still within the specifications.

1.2 Process Overview

This section describes the process being impacted by TM81. The feed for TM81 comes from Plant 4 across a screw conveyer. It is deposited into the Feed Bin and enters TM81 to be ground into a smaller particle size. After it is processed, it goes into a pipe up an elevator to a separator called Separator 81 (SM81). SM81 filters out the fine product from the coarse product.

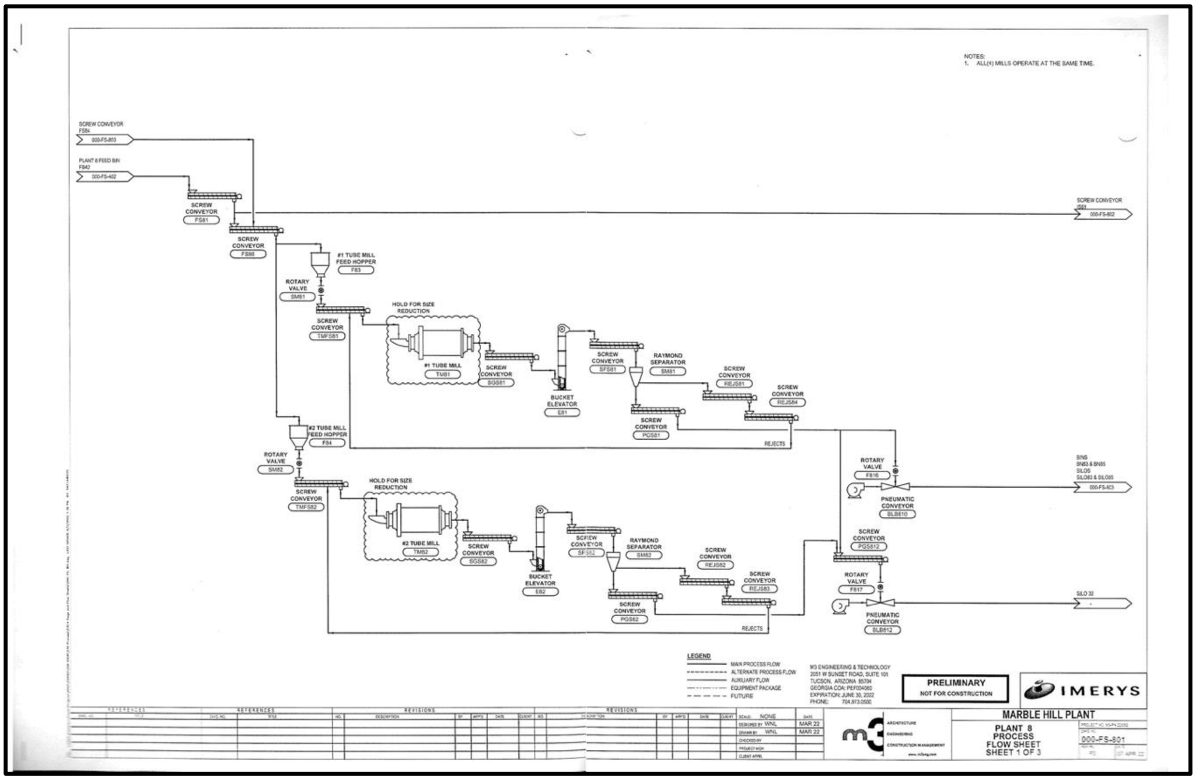


Figure 1: Process Flow Diagram

The product deemed too coarse is rejected and goes back to be ground down again while the fine product moves on to Silo 32 to be stored. Then the product in Silo 32 is used in a wet process over to Plant 3 and then goes through the attrition mill to be milled into CS-11.
Figure 2 depicts a functional decomposisition diagram that relates the operations of Plant 8 machinery to the successful output of CS-11.

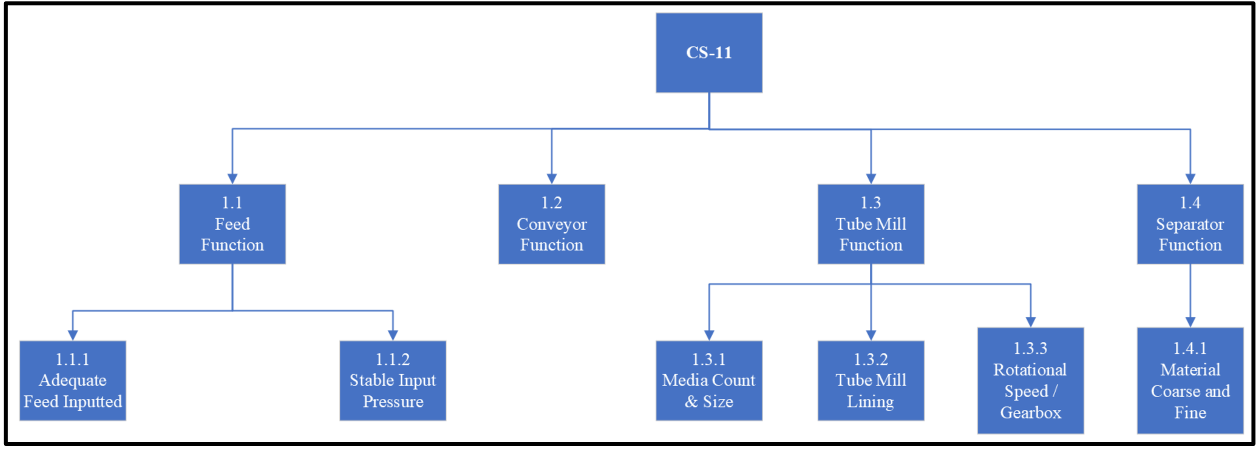


Figure 2: Functional Decomposition Diagram

1.3 Value Stream Map

The creation of the following Value Stream Map helps identify the process of the CS-11 product throughout Imerys's operation at Marble Hill. This comprehensive view of the entire CS-11 production process identifies the initial mining of the marble all the way to the final storage at the CS-11 Silo. Tube Mill 81 is a critical component of this process, where further crushing and refinement of the marble occur. This value stream map highlights several key reasons why Tube Mill 81 is a strategic location for quality and throughput improvement as it relates to the CS-11 product.

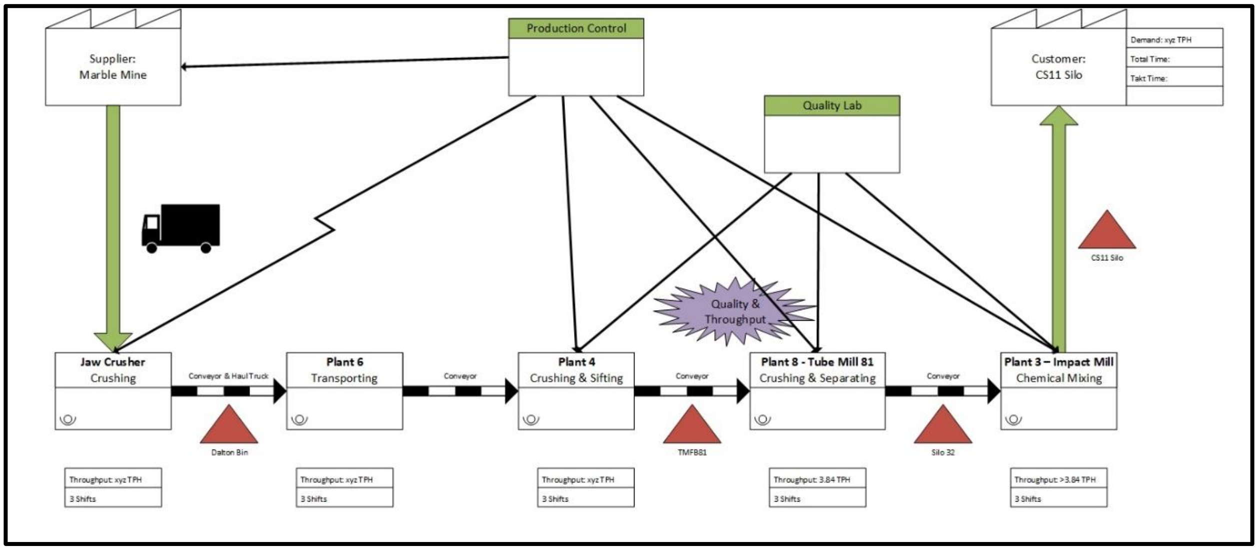


Figure 3: Value Stream Map

TM81 is positioned at a pivotal juncture in the production flow. It's where the fine marble, separated from the coarse material, is processed further. Any improvements made here lead to positive downstream effects on the final CS-11 product. Firstly, if quality is lacking at TM81, the impact mill at Plant 3 will struggle with the coarser material. Secondly, TM81 plays a vital role in controlling throughput, as it's a bottleneck in the process. Tube Mill 82 (TM82) sometimes has to changeover to helping TM81 with its process to keep up with demand. If throughput is increased for TM81, TM82 doesn't have to changeover to help crush feed with TM81, leading to a more consistent flow for other products at Imerys.

1.4 Data Collection Methodology

For Tube Mill 81, there are two major categories of testing done on products: quality testing and throughput rate checks. This section explores how data for each criterion was gathered before and after each change.

1.4.1 Mean Particle Size

When it comes to testing product quality, Imerys tests three criteria to determine if said product is in specification: color, particle density, and particle size. The tests are done at a lab at Marble Hill where all the samples from different parts of the process for TM81 are tested. Color is tested by using a Colorizer machine. For this intermediary process, the goal is to have a color metric of 90, though this quality metric is not a critical consideration for this process. Particle density is tested by using a Ro-Tap, shown in Figure 4. The particle density of the product of TM81 is not actively being tracked, and not considered an important quality metric for this part of the process. Particle size is the most important quality metric for this process being recorded and is tested by using a particle size analyzer, shown in Figure 5. The control limit for the samples' particle sizes is 12-18 microns.

Figure 4: Ro-Tap

Figure 5: Particle Size Analyzer

1.4.2 Flow Rate Check

There are no flow rate sensors attached to TM81, so measurements for production rate in tons per hour (TPH) are collected via rate check with a silo. TM81 feeds into Silo 32 (S32) before it is diverted to later processing steps. The silo can be sealed such that no material passes through and is equipped with sensors that measure what percentage of the silo is filled. For the rate check, S32 is sealed and filled with material from TM81 for one hour. The percentage filled before and after the hour is recorded, and the difference represents the amount of material added to the silo. This test has minimal impact on the production capacity of the plant and will be implemented at each major change to TM81 and adjacent systems during this project. Below is the formula used to calculate percent filled after each change. The maximum capacity of S32 is 120 tons.

Formula:

$$\frac{tons}{hour} = \Delta\,\%\,Fill\ in\ one\ hour\ *\ Max\ capacity\ of\ S32$$

1.5 Objective & Goals

Strategies implemented during this project focus on improving the throughput and product quality of TM81. Throughput refers to the amount of material processed by TM81 and SM81 and is measured in tons per hour. Product quality is defined as the mean particle size of a given sample of marble that has been processed and passed through the separator through the product line. The aimed goals, as shown in Table 1, includes increasing the hourly throughput of TM81 to 4 TPH, maintaining the quality and consistency of the product to 12-18 microns, and achieving a breakeven point of less than 3 years given investment is necessary.

Table 1: Project Goals and Metrics

Goal Description	**Goal Metric**
Increase hourly throughput of Tube Mill 81 (TM81)	4 tons/hour
Maintain quality and consistency of product	12-18 microns
Breakeven Point	< 3 years

1.6 Current State and Problem Statement

TM81 is currently grappling with challenges related to both product quality and production output. Imerys has specified quality requirements for TM81 within the range of 12-18 microns. However, the observed quality frequently deviates from these specifications, adversely affecting downstream product quality. This variance not only results in product wastage but also disrupts the subsequent CS-11 production process, which demands adherence to standardized specifications. The inconsistent quality further contributes to decreased production, stemming from the detrimental impact of variations in quality on the manufacturing process. Addressing these issues is imperative to enhance TM81's performance and align it with the prescribed quality standards.

The production output of TM81 must be improved, as its current capacity falls short of meeting the demand for the intermediate product crucial for the CS-11 manufacturing process.

Compounding the challenge, TM82 frequently needs to compensate for TM81's insufficient production, resulting in TM82 itself failing to meet its product demand. This operational inefficiency incurs additional costs for Imerys, necessitating the utilization of an Interplant Truck System to bolster TM82's production and address the production gaps in the overall process. This issue highlights the need for a comprehensive solution to optimize the production capabilities of both TM81 and TM82.

1.7 Cause and Effect Diagrams

In the pursuit of enhancing the quality of TM81's product and increasing its throughput, our team employed a structured approach by incorporating two cause-and-effect diagrams into our analysis. These diagrams served as invaluable tools for systematically identifying and categorizing factors influencing the desired outcomes. The five primary categories under scrutiny were machine, material, measurement, method, and people. Each category became a focal point for our brainstorming sessions, allowing us to explore various potential options independently. The deliberate decision to defer criteria consideration during this phase facilitated the generation of a diverse array of solutions without restricting our creativity. By exploring all possibilities within each category, we cast a wide net for innovative ideas that could later be assessed and refined. This initial divergent thinking process set the stage for a subsequent convergent evaluation, where the identified solutions would undergo ranking and prioritization using a decision matrix. This two-step approach ensured a comprehensive exploration of options before applying evaluative criteria, ultimately leading to a more robust and well-informed decision-making process in our senior design project.

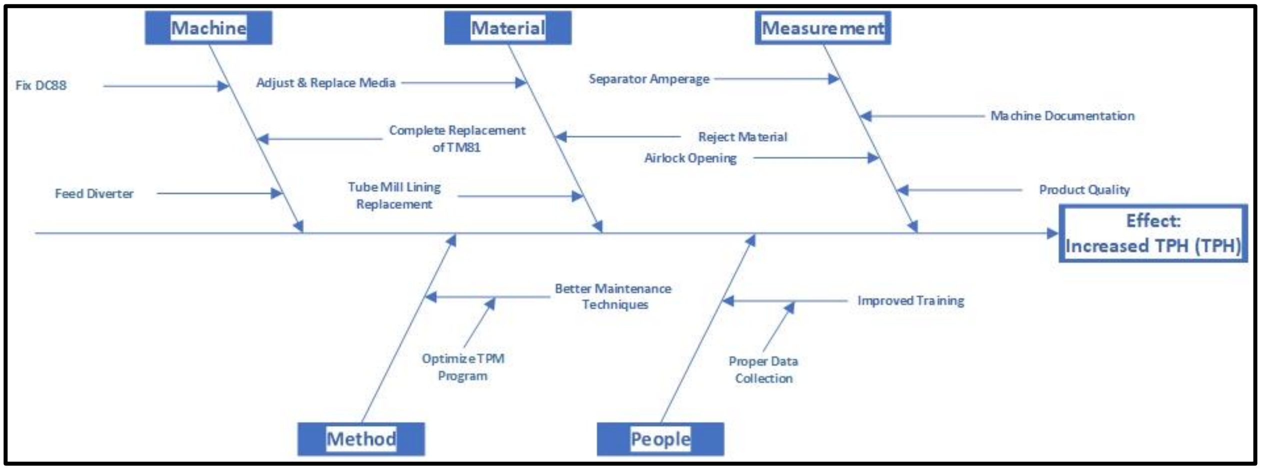


Figure 6: Cause and Effect Diagram - Throughput

For our first cause-and-effect-diagram, we delved into the complexities of enhancing the mean particle size and overall quality of TM81's product. This diagram allowed us to categorize potential factors influencing the mean particle size of the machine, material, measurement, method, and people-related aspects. The thorough exploration within each category yielded a comprehensive list of 13 potential solutions. These solutions represented a diverse range of strategies that could positively impact the desired outcome. Each solution was meticulously derived from the identified factors within the cause-and-effect diagram, ensuring that our approach was systematic and methodical. The cause-and-effect diagram not only facilitated idea generation but also served as a visual roadmap for our team to identify and address the root causes of challenges associated with particle size. The subsequent steps in our project involved evaluating and prioritizing these solutions to formulate an effective and targeted action plan aimed at improving TM81's product quality.

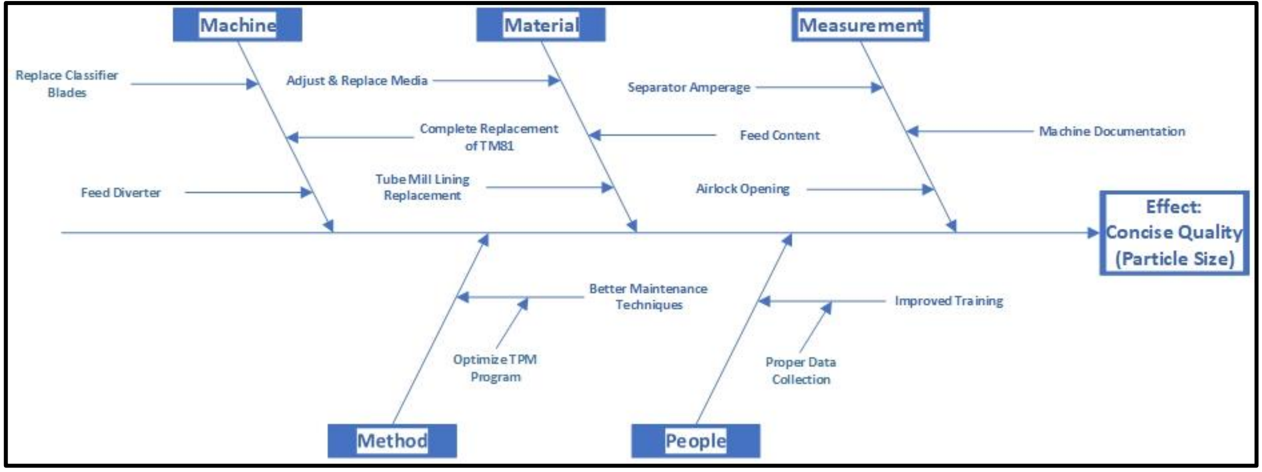


Figure 7: Cause and Effect Diagram - Quality

The second cause-and-effect diagram was created in pursuit of enhancing the throughput of TM81. This diagram served as an invaluable framework to identify and categorize factors affecting throughput. The comprehensive exploration within each category yielded a robust list of 12 potential solutions tailored to boost the production capacity of TM81. Notably, some of these solutions demonstrated a dual impact, contributing not only to the increase in throughput but also aligning with our other objective of improving the mean particle size for enhanced product quality. This interconnectedness highlighted the potential synergies between the two aspects of our project, reinforcing the holistic nature of our approach.

The cause-and-effect diagram provided a visual representation of the intricate relationships between various factors impacting throughput, guiding our team in identifying key areas of intervention. The ensuing steps involved a detailed evaluation of these solutions to help develop a strategic plan that would not only elevate the throughput of TM81 but also optimize its product quality.

1.8 Justification

The imperative for this project stemmed from TM81’s inability to generate enough feed for Plant 3, consequently hindering the production of CS-11 and potentially resulting in missed sales opportunities. TM82 faced a parallel challenge, as it had to compensate for TM81's shortfall by producing feed for Plant 3, leading to compromised production of Gamaco and Calwhite. Quality concerns further exacerbated the issue, with initial samples indicating a subpar feed quality that adversely affected downstream processes, impacting machinery and final product outcomes. The project aimed to identify solutions to restore feed quality to specifications, enabling the production of superior products. This, in turn, would empower Imerys to meet demand, realize economic cost savings, and contribute to environmental enhancements.

1.9 Challenges & Constraints

Time emerged as a predominant challenge throughout this project, with the three-month timeframe imposing limitations on the implementation of numerous potential solutions devised by the team. Another significant challenge involved sample gathering during amperage changes, where the usual 30-sample standard was constrained to 10 samples due to time limitations. Scheduling posed an additional constraint, requiring all mechanical changes to occur on Thursdays during scheduled maintenance downtime. While the project scope was narrowed down, the budget did not pose a strict constraint, as financially driven solutions were well-received by Imerys. Given these challenges and constraints, the team implemented a decision matrix to systematically evaluate and narrow down feasible solutions within the given criteria.

Chapter 2: Literature Review

2.1 Approach

Tube mill optimization includes a wide area of knowledge. When researching preexisting data, our team looked into historical data for tube mills, marble processing, and implementation of optimization techniques.

2.2 Results

This section covers the results of the literature review. Articles are sorted into two categories: milling optimization and general optimization. Milling optimization focuses on existing research projects where tube mill processing was optimized. These articles are not restricted to marble processing. The optimization category analyzes how optimization techniques are used in manufacturing.

2.2.1 Milling Optimization

Article Summary: In a 2008 analysis titled “High Efficiency Ball Mill Grinding,” Arentzen and Bhappu discuss different methods for increasing ball mill grinding efficiency. The three discussed methods are: “use correct make-up media size, operate the mill in cataracting mode, and control milling circuit in a modified mode” (Arentzen & Bhappu 2008). In the analysis of these options, Arentzen and Bhappu state that there is a maximum energy level a tube mill can operate at and still see improved grinding efficiency. This means that there is an optimum energy state for tube mill operation before the efficiency begins to decrease. The rate at which a tube mill rotates, and the make-up of media determines the optimal tube mill settings. Cataracting mode refers to a speed fast enough that forces the media and contents to grind effectively but not too fast such that the contents stick to the tube mill lining via centrifugal forces. The article goes on to describe how to relate tube mill kilowatt consumption to cataracting operational level. Determining that there are no preexisting equations that connect these two terms [2].

Article Summary: In “The Improved System for Automation and Optimization of Solid Material Grinding by Means of Ball Mills,” Dedorshyn, Nykolyn, Zagraj, and Pistun discuss automation of ball mills across a range of mediums. They describe the function of a tube mill and highlight three primary factors that determine dry milling efficiency: properties of the material being processed, dust collection and management system, and the feeding system. They automate the milling process by adding sensors and optimization policies. Sensor additions included accelerometers that measured vibrations, a temperature transducer to measure the output air quality, and a differential pressure transducer which relates to the temperature measurements. They use the vibrations measured via accelerometer to determine product quality. When combined, the temperature and pressure information can predict explosions with enough lead time for countermeasures to be implemented. New implemented optimization policies included regulation of feed material, modified tube mill operating modes, enhanced safety features on the dust collection system, and more. This article provides a comprehensive review of different techniques successfully implemented to improve tube mill operations [4].

Article Summary: In the 1933 book “Grinding Efficiency in Ball Mills,” author O’Shaughnessy aimed to provide a thorough investigation into ball mill grinding efficiency, addressing existing confusion in the literature through a meticulously designed and well-equipped experimental setup. The emphasis on detail, prevision, and the elimination of potential sources of error signifies a robust approach to deriving accurate inclusions for increased efficiency in ball mill grinding. In the conducted experiments on grinding efficiency, the focus was on determining net grinding power using motor efficiency and dead load loss curves. The study also highlights variations in power transmission efficiency under different grinding conditions, emphasizing the need for understanding the absolute efficiency of these components. The experiments involved grinding tests with varying ball charges and wet/dry conditions. Power consumption trends were observed, indicating the efficiency of wet grinding compared to dry grinding. Challenges such as uncrushed material discharge and screen blockages prompted adjustments to optimize ball charge composition. The applications of laws such as Rittinger's Law is assumed, and Taggart's formula for determining tonnages in a grinding circuit based on screen analysis is introduced, with a reminder of its theoretical nature and reliance on balanced circuits. Overall, the study provides insights into optimizing grinding efficiency in a ball mill from the perspective of a 1930s outlook, suggesting practical applications and potential areas for improvement in commercial grinding machines [6].

2.2.2 Optimization Techniques

Article Summary: In the 2010 article "Quality Quandaries: Interpretation of Signals from Runs Rules in Shewhart Control Charts," Albert Trip and Ronald J.M.M. Does explores the use and interpretation of run rules in Shewhart control charts. The Shewhart control chart is a fundamental tool in statistical process control (SPC), and run rules are additional criteria applied to the chart to detect patterns indicative of an out-of-control situation. The authors emphasize the importance of run rules in identifying out-of-control situations before the standard control limits are exceeded. The run rules discussed in the article originated from the Western Electric Company and are designed to identify graphical patterns on the control chart that suggest process instability. The challenge lies in selecting a subset of run rules for practical application, as using too many rules simultaneously may result in an unacceptable number of false signals, leading to confusion among users. The article introduces a framework for understanding the conditional probabilities of failure causes given signals from specific run rules. The authors propose a systematic approach to estimating these conditional probabilities, which involves using probability relations with decision rules in a stable system. Overall, the article underscores the significance of run rules in enhancing the capability of Shewhart control charts to detect process deviations early [7].

Article Summary: In the 2009 article "An overview of theory and practice on process capability indices for quality assurance" by Chien-Wei Wu, W.L. Pearn, and Samuel Kotz, it delves into the exploration of process capability indices (PCIs) such as C_p, C_a, C_{pk}, C_{pm}, and C_{pmk}, which serve as vital measures for assessing manufacturing processes based on criteria like process consistency, departure from a target, process yield, and process loss. The study specifically focuses on the behavior of the actual process yield concerning the number of non-conformities (in ppm) for processes possessing fixed index values but with different degrees of process centering. The article contributes to the existing body of knowledge by extending previous research and presenting a comparative analysis among PCIs based on various criteria. Additionally, the paper discusses several extensions and applications of these indices to real-world problems, underlining their significance in contemporary quality assurance practices. This study reinforces the importance of process capability analysis in understanding and quantifying process performance, which is crucial for quality improvement initiatives. The paper underscores the evolution of various process capability indices, each designed to address specific aspects of manufacturing processes, such as prevision, accuracy, and targeting. The comparison and analysis of different indices contribute to a nuanced understanding of their roles in assessing process capability, yield, loss, and variability. The article concludes by discussing the relevance of these indices in practical applications across diverse manufacturing sectors [9].

Article Summary: The article titled "Implementation of Statistical Process Control in a High Volume Machining Center: Importance of Control Charts" by Haipei Zhu discusses the application of statistical process control (SPC) and control charts in a high-volume machining center at Waters Corporation. The SPC methodology employed a flow chart designed specifically for the company, based on a theoretical review of SPC methods and baseline data collection. The implementation included the use of individual control charts for real-time inspection in the long term. The significance of control charts in the SPC methodology is emphasized throughout the article. Control charts are highlighted as a key element in monitoring the manufacturing process in real time, eliminating assignable variation, and reducing natural variation. The use of control charts contributed to the identification and resolution of issues such as non-standardized tooling change timing and tool offset. The implementation of control charts facilitated defect reduction and continuous improvement in manufacturing processes. The results of the case study demonstrate the effectiveness of SPC in enhancing process control, reducing costs, and positioning the company as a world-class manufacturer [10]

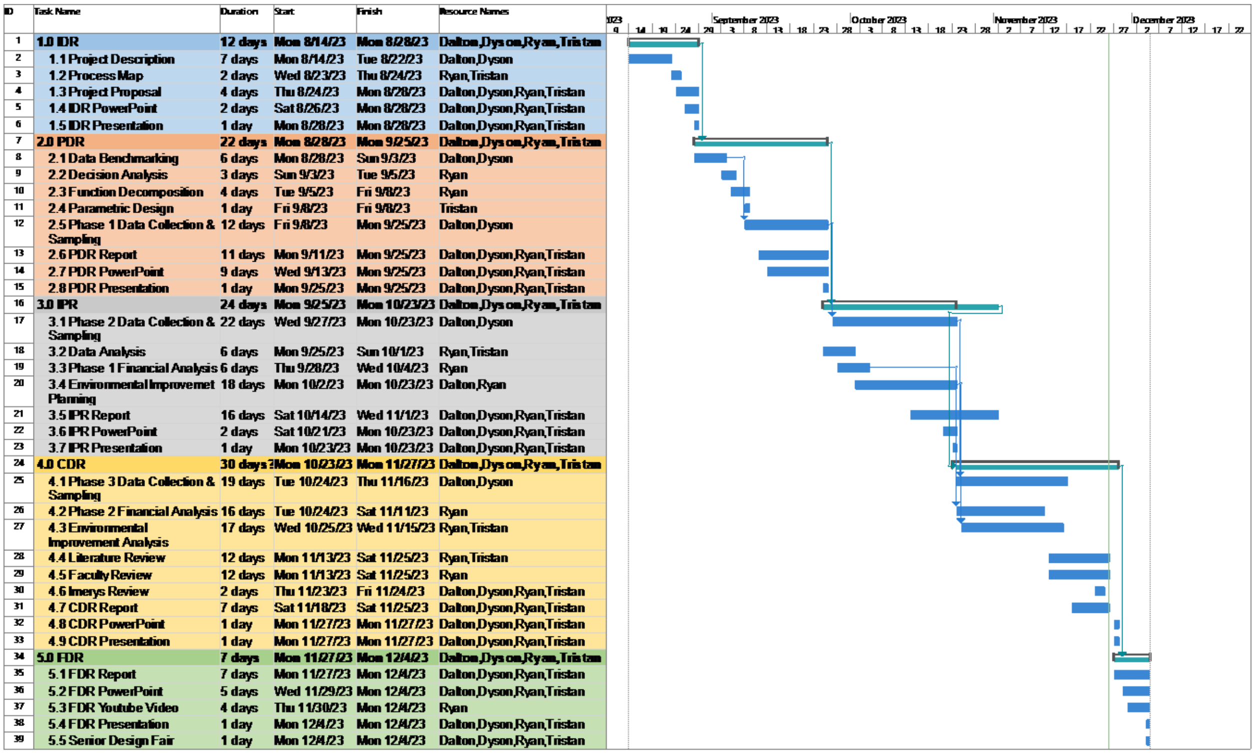
I.P.S. Ahuja and Pankaj Kumar analyze the successful implementation of total productive maintenance (TPM) in the 2009 paper: "A case study of total productive maintenance implementation at precision tube mills." The paper serves two main goals: analyze the implementation of TPM in a small-scale tube mill scenario and relate the results to the feasibility for improving India's overall manufacturing capacity. Ahuja and Kumar highlight the necessity of TPM techniques to keep India's production capabilities competitive on an international scale. Along with improving production, the implementation of TPM practices improved company safety, employee morale, and product quality. This results in this paper display the importance of total quality techniques and show the benefits of system improvement techniques in a milling environment [1].

Chapter 3: Project Management

3.1 Overview

In project management, our team systematically explored various resources and tools to effectively schedule major assignments and delegate responsibilities among team members. We opted for a Gantt Chart as the most suitable scheduling tool, facilitating the systematic distribution of the workload by phase and team member over three months. Additionally, we developed a comprehensive project budget to meticulously track costs associated with both team and company contributions. To enhance project management efficiency, a work breakdown structure was formulated, breaking down major project elements into smaller, more manageable segments.

3.2 Schedule



ID	Task Name	Duration	Start	Finish	Resource Names
1	**1.0 IDR**	**12 days**	**Mon 8/14/23**	**Mon 8/28/23**	**Dalton,Dyson,Ryan,Tristan**
2	1.1 Project Description	7 days	Mon 8/14/23	Tue 8/22/23	Dalton,Dyson
3	1.2 Process Map	2 days	Wed 8/23/23	Thu 8/24/23	Ryan,Tristan
4	1.3 Project Proposal	4 days	Thu 8/24/23	Mon 8/28/23	Dalton,Dyson,Ryan,Tristan
5	1.4 IDR PowerPoint	2 days	Sat 8/26/23	Mon 8/28/23	Dalton,Dyson,Ryan,Tristan
6	1.5 IDR Presentation	1 day	Mon 8/28/23	Mon 8/28/23	Dalton,Dyson,Ryan,Tristan
7	**2.0 PDR**	**22 days**	**Mon 8/28/23**	**Mon 9/25/23**	**Dalton,Dyson,Ryan,Tristan**
8	2.1 Data Benchmarking	6 days	Mon 8/28/23	Sun 9/3/23	Dalton,Dyson
9	2.2 Decision Analysis	3 days	Sun 9/3/23	Tue 9/5/23	Ryan
10	2.3 Function Decomposition	4 days	Tue 9/5/23	Fri 9/8/23	Ryan
11	2.4 Parametric Design	1 day	Fri 9/8/23	Fri 9/8/23	Tristan
12	2.5 Phase 1 Data Collection & Sampling	12 days	Fri 9/8/23	Mon 9/25/23	Dalton,Dyson
13	2.6 PDR Report	11 days	Mon 9/11/23	Mon 9/25/23	Dalton,Dyson,Ryan,Tristan
14	2.7 PDR PowerPoint	9 days	Wed 9/13/23	Mon 9/25/23	Dalton,Dyson,Ryan,Tristan
15	2.8 PDR Presentation	1 day	Mon 9/25/23	Mon 9/25/23	Dalton,Dyson,Ryan,Tristan
16	**3.0 IPR**	**24 days**	**Mon 9/25/23**	**Mon 10/23/23**	**Dalton,Dyson,Ryan,Tristan**
17	3.1 Phase 2 Data Collection & Sampling	22 days	Wed 9/27/23	Mon 10/23/23	Dalton,Dyson
18	3.2 Data Analysis	6 days	Mon 9/25/23	Sun 10/1/23	Ryan,Tristan
19	3.3 Phase 1 Financial Analysis	6 days	Thu 9/28/23	Wed 10/4/23	Ryan
20	3.4 Environmental Improvemet Planning	18 days	Mon 10/2/23	Mon 10/23/23	Dalton,Ryan
21	3.5 IPR Report	16 days	Sat 10/14/23	Wed 11/1/23	Dalton,Dyson,Ryan,Tristan
22	3.6 IPR PowerPoint	2 days	Sat 10/21/23	Mon 10/23/23	Dalton,Dyson,Ryan,Tristan
23	3.7 IPR Presentation	1 day	Mon 10/23/23	Mon 10/23/23	Dalton,Dyson,Ryan,Tristan
24	**4.0 CDR**	**30 days?**	**Mon 10/23/23**	**Mon 11/27/23**	**Dalton,Dyson,Ryan,Tristan**
25	4.1 Phase 3 Data Collection & Sampling	19 days	Tue 10/24/23	Thu 11/16/23	Dalton,Dyson
26	4.2 Phase 2 Financial Analysis	16 days	Tue 10/24/23	Sat 11/11/23	Ryan
27	4.3 Environmental Improvement Analysis	17 days	Wed 10/25/23	Wed 11/15/23	Ryan,Tristan
28	4.4 Literature Review	12 days	Mon 11/13/23	Sat 11/25/23	Ryan,Tristan
29	4.5 Faculty Review	12 days	Mon 11/13/23	Sat 11/25/23	Ryan
30	4.6 Imerys Review	2 days	Thu 11/23/23	Fri 11/24/23	Dalton,Dyson,Ryan,Tristan
31	4.7 CDR Report	7 days	Sat 11/18/23	Sat 11/25/23	Dalton,Dyson,Ryan,Tristan
32	4.8 CDR PowerPoint	1 day	Mon 11/27/23	Mon 11/27/23	Dalton,Dyson,Ryan,Tristan
33	4.9 CDR Presentation	1 day	Mon 11/27/23	Mon 11/27/23	Dalton,Dyson,Ryan,Tristan
34	**5.0 FDR**	**7 days**	**Mon 11/27/23**	**Mon 12/4/23**	**Dalton,Dyson,Ryan,Tristan**
35	5.1 FDR Report	7 days	Mon 11/27/23	Mon 12/4/23	Dalton,Dyson,Ryan,Tristan
36	5.2 FDR PowerPoint	5 days	Wed 11/29/23	Mon 12/4/23	Dalton,Dyson,Ryan,Tristan
37	5.3 FDR Youtube Video	4 days	Thu 11/30/23	Mon 12/4/23	Ryan
38	5.4 FDR Presentation	1 day	Mon 12/4/23	Mon 12/4/23	Dalton,Dyson,Ryan,Tristan
39	5.5 Senior Design Fair	1 day	Mon 12/4/23	Mon 12/4/23	Dalton,Dyson,Ryan,Tristan

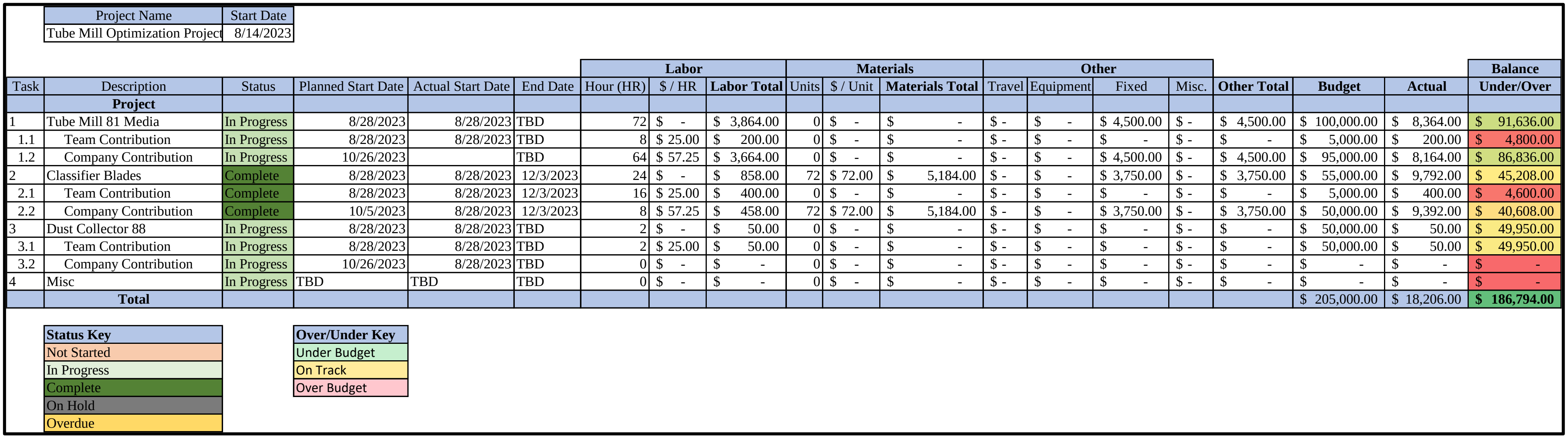
Figure 8: Gantt Chart

The Gantt Chart outlining the project encompasses five distinct phases: Initial Design Review (IDR), Preliminary Design Review (PDR), In-Progress Design Review (IPR), Critical Design Review (CDR), and Final Design Review (FDR). Each phase is strategically aligned with specific project objectives. During the IDR phase, spanning two weeks, the project proposal and initial goals were formulated. The PDR, a four-week phase, centered on data benchmarking and process mapping. The subsequent IPR phase, also four weeks, delved into comprehensive data collection, initiating analyses across financial and environmental domains. The pivotal CDR phase, extending for five weeks, marked the conclusive data collection, finalization of analyses, and the onset of literature and faculty reviews. Lastly, the FDR phase, concluding the project in one week, involved final report and presentation edits, the creation of a demonstrative video, and participation in the senior design fair. This phased approach ensures a systematic and goal-oriented progression throughout the project lifecycle.

3.3 Budget

The table presented delineates the current budgetary estimates for planned critical changes. It is noteworthy that specific improvements intentionally omitted from the budgetary sheet do not entail a monetary investment. This strategic approach ensures a focused and transparent overview of the financial considerations associated with essential project modifications.

Table 2: Project Budget



Project Name	Start Date
Tube Mill Optimization Project	8/14/2023

						Labor			Materials			Other							Balance
Task	Description	Status	Planned Start Date	Actual Start Date	End Date	Hour (HR)	$ / HR	**Labor Total**	Units	$ / Unit	**Materials Total**	Travel	Equipment	Fixed	Misc.	**Other Total**	**Budget**	**Actual**	**Under/Over**
	Project																		
1	Tube Mill 81 Media	In Progress	8/28/2023	8/28/2023	TBD	72	$ -	$ 3,864.00	0	$ -	$ -	$ -	$ -	$ 4,500.00	$ -	$ 4,500.00	$ 100,000.00	$ 8,364.00	$ 91,636.00
1.1	Team Contribution	In Progress	8/28/2023	8/28/2023	TBD	8	$ 25.00	$ 200.00	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 5,000.00	$ 200.00	$ 4,800.00
1.2	Company Contribution	In Progress	10/26/2023		TBD	64	$ 57.25	$ 3,664.00	0	$ -	$ -	$ -	$ -	$ 4,500.00	$ -	$ 4,500.00	$ 95,000.00	$ 8,164.00	$ 86,836.00
2	Classifier Blades	Complete	8/28/2023	8/28/2023	12/3/2023	24	$ -	$ 858.00	72	$ 72.00	$ 5,184.00	$ -	$ -	$ 3,750.00	$ -	$ 3,750.00	$ 55,000.00	$ 9,792.00	$ 45,208.00
2.1	Team Contribution	Complete	8/28/2023	8/28/2023	12/3/2023	16	$ 25.00	$ 400.00	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 5,000.00	$ 400.00	$ 4,600.00
2.2	Company Contribution	Complete	10/5/2023	8/28/2023	12/3/2023	8	$ 57.25	$ 458.00	72	$ 72.00	$ 5,184.00	$ -	$ -	$ 3,750.00	$ -	$ 3,750.00	$ 50,000.00	$ 9,392.00	$ 40,608.00
3	Dust Collector 88	In Progress	8/28/2023	8/28/2023	TBD	2	$ -	$ 50.00	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 50,000.00	$ 50.00	$ 49,950.00
3.1	Team Contribution	In Progress	8/28/2023	8/28/2023	TBD	2	$ 25.00	$ 50.00	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 50,000.00	$ 50.00	$ 49,950.00
3.2	Company Contribution	In Progress	10/26/2023	8/28/2023	TBD	0	$ -	$ -	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
4	Misc	In Progress	TBD	TBD	TBD	0	$ -	$ -	0	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	Total																$ 205,000.00	$ 18,206.00	**$ 186,794.00**

Status Key
Not Started
In Progress
Complete
On Hold
Overdue

Over/Under Key
Under Budget
On Track
Over Budget

The budget allocation for the acquisition and installation of classifier blades for TM81 was approximately ~$55,000, and this phase of the project was successfully executed under budget. The blades were purchased for $5,184. Labor expenses for installation, involving two workers at an hourly rate of $57.25 for 4 hours each, resulted in a total labor cost of $458. Additionally, the team's labor cost, estimated at an hourly rate of $25 for 16 hours, amounted to $400, considering team compensation. The services of a balancing specialist, crucial for the new blades, incurred an additional cost of $3,750. Consequently, the total expenditure for the classifier blades was $9,392, excluding the team's contribution due to the unpaid nature of our work.

The budget designated for the procurement of additional media for TM81 is approximately ~$100,000. Installation expenses encompass the engagement of four workers at an hourly rate of $57.25 for 16 hours each, resulting in a total company labor cost of $3,664. As for our team's involvement, our estimated labor cost, considering an hourly rate of $25 for 8 hours, stands at $200.

Regarding the material cost for media acquisition, a thorough evaluation of quotes from various companies is underway, with a decision expected by the end of the year or early next year. This aspect of the project has been excluded due to time constraints, making it outside of the project's scope. However, both the procurement and installation of the media are slated for future implementation.

The allocated budget for the reconnection of Dust Collector 88 (DC88) is approximately ~$50,000. Currently in the initial planning stage, this segment of the project has been temporarily deemed out of scope due to time constraints. Our estimated labor cost stands at $25 per hour for 2 hours, totaling $50. The reconnection of DC88 is scheduled for early 2024; however, the process remains in the planning phase, and quotes are yet to be explored at this stage.

3.4 Work Breakdown Structure

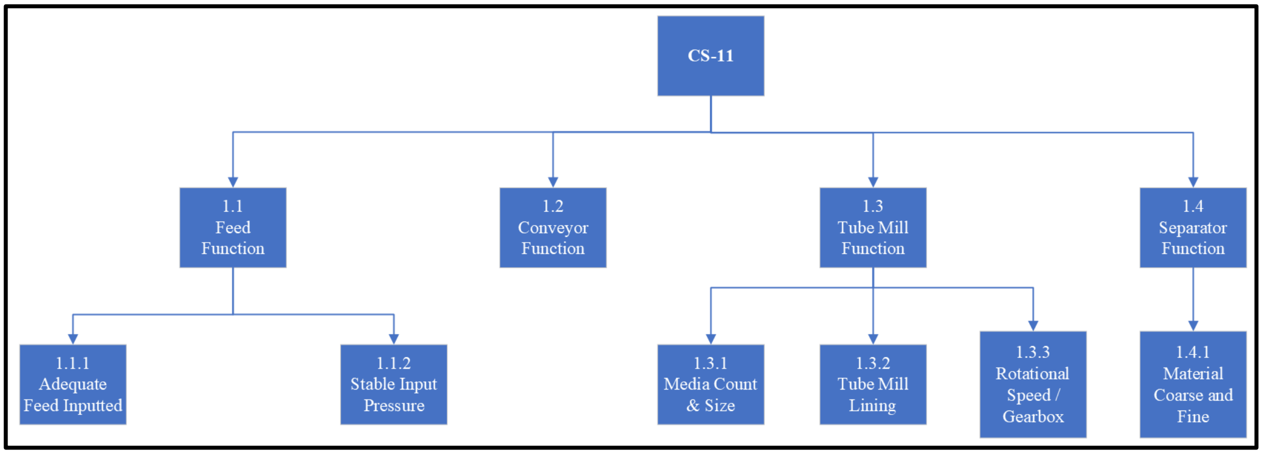


Figure 9: Functional Decomposition Diagram

This project is centered on enhancing the quality and throughput of the intermediary product crucial for Plant 3's CS-11 process. The steady production of feed and the precise sizing of CS-11 are essential requirements. The feed, generated by the Tube Mill, is transported by a screw conveyor to the silo for storage before its use. Critical factors influencing the production include the Tube Mill's media, its size, and the integrity of the lining, all impacting grinding efficiency and feed size. The mill's speed is a pivotal parameter affecting the CS-11 process feed production. Furthermore, the Separator is instrumental in segregating the correct feed from rejects. The latter is efficiently recycled back into the mill for reprocessing, while the approved feed proceeds to the silo through a screw conveyor for storage.

Chapter 4: Solution Analysis and Implementation

4.1 Explanation of Options

4.1.1 Separator 81 Amp Increase

Elevating the amperage on SM81 holds the potential to increase the product flow into TM81, thereby enhancing throughput and supplementing the product quantity for Plant 3's operational needs. This solution incurs no monetary cost, involving a straightforward adjustment by activating a control screen button.

4.1.2 Media Replacement

The media balls play a crucial role in reducing marble rocks to smaller sizes within TM81. However, the current media has seen a decline in quantity and size since its last replacement in 2019. Renewing the media balls, ensuring an optimal ratio and composition, is imperative to enhance production output by providing more effective rock-crushing capabilities. This improvement, while effective, does involve a monetary cost for procuring and installing the new media balls.

Figure 10 shows the inside of TM81 when it was opened for inspection. The media balls are mixed with marble powder on the bottom. The picture is taken from the perspective of the marble entrance and is facing the exit point.

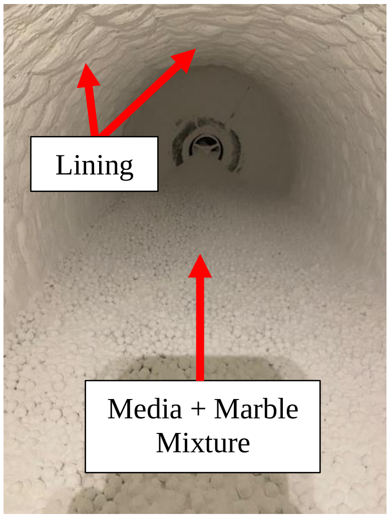


Figure 10: Inside TM81

4.1.3 Classifier Blades

The classifier blades on SM81 play a crucial role in rejecting products that do not meet specifications. The absence of six classifier blades has led to a decline in the quality of the final product, falling below specified standards. The replacement of these missing blades is essential to ensure consistent and improved product quality within specifications. However, this improvement incurs a monetary cost, involving the procurement and installation of the necessary blades.

Figure 11: Inside Classifier

4.1.4 Dust Collector 88

The dust collector (DC88) plays a vital role in removing dust and waste from the process, facilitating a closed-loop system where waste is reintegrated into the process. Unfortunately, DC88 has been disconnected from TM81, resulting in unnecessary waste removal costs, storage expenses, and a decrease in throughput due to the exclusion of waste from the process. Reconnecting DC88 would eliminate the need for external contractors for waste removal, reduce storage costs, and enhance TPH by reintegrating waste into the system. However, this improvement incurs a monetary cost associated with the reconnection of DC88.

4.1.5 Bin 81 Airlock

Feed Bin 81 serves as the primary storage for the feed destined for TM81. Over time, product accumulation on the bin's walls may impede the smooth flow of material through the process to TM81. An inspection is warranted to identify and address potential blockages. If blockages are detected, a thorough cleaning process will be initiated to ensure unimpeded product flow. It's important to note that addressing this issue incurs a monetary cost associated with manpower hours dedicated to the inspection and cleaning procedures.

4.2 Iterative Design Process

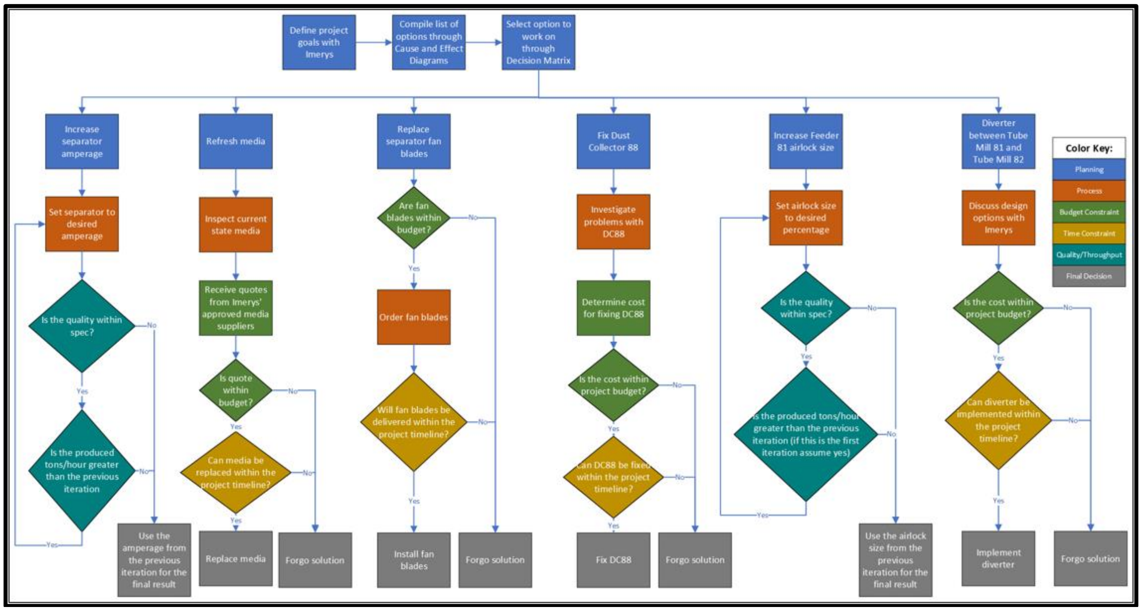
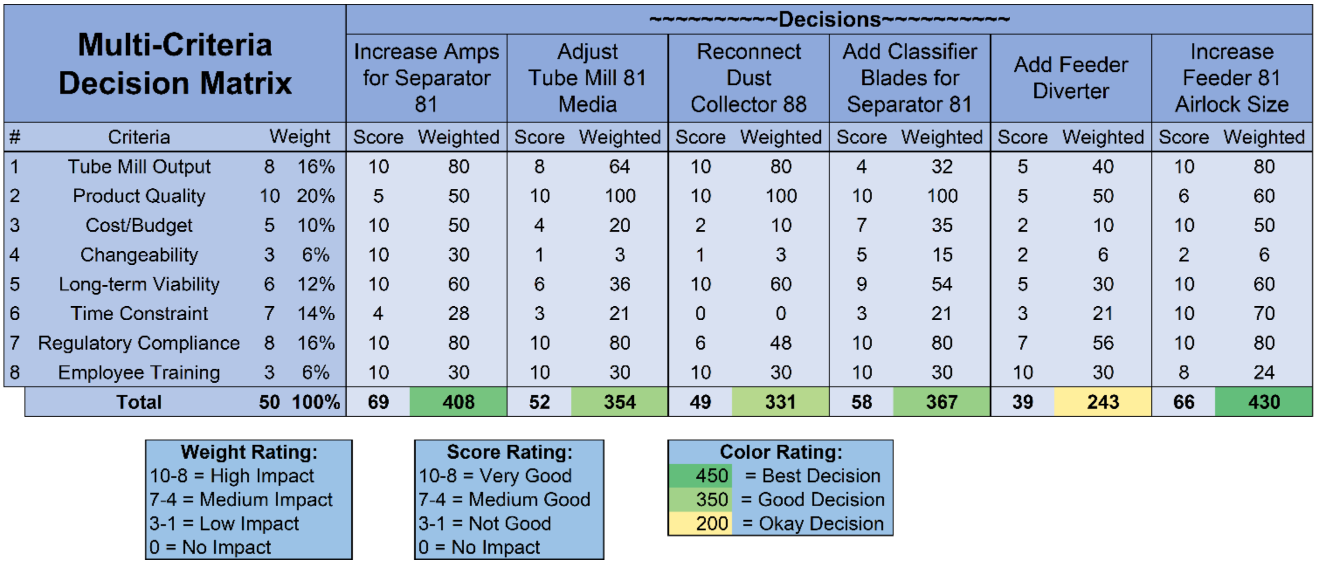


Figure 12: Iterative Design Process

Once each solution was thoroughly analyzed, we created an iterative design process flow chart to visually convey how we could implement each solution. Each path includes a termination point if at any phase in the process we discover that the idea is ineffective. An idea is terminated if forces the quality outside of the specification, lowers TM81 throughput below the starting 3.84 TPH, is out of budget, or is unable to be implemented during the project timeline. Figure 12 shows the complete iterative design process flow chart.

4.3 Comparison of Options

After discussions with Imerys's management and site workers, our team created a decision matrix. This matrix, shown in Figure 13, compares each solution with different criteria. Some of the criteria include tube mill output, product quality, etc., and are weighted on importance. The six potential solutions were then compared to each criterion and given a score that showed how well that solution would impact that criterion.



Multi-Criteria Decision Matrix				~~~~~~~~~~Decisions~~~~~~~~~~											
				Increase Amps for Separator 81		Adjust Tube Mill 81 Media		Reconnect Dust Collector 88		Add Classifier Blades for Separator 81		Add Feeder Diverter		Increase Feeder 81 Airlock Size	
#	Criteria	Weight		Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted	Score	Weighted
1	Tube Mill Output	8	16%	10	80	8	64	10	80	4	32	5	40	10	80
2	Product Quality	10	20%	5	50	10	100	10	100	10	100	5	50	6	60
3	Cost/Budget	5	10%	10	50	4	20	2	10	7	35	2	10	10	50
4	Changeability	3	6%	10	30	1	3	1	3	5	15	2	6	2	6
5	Long-term Viability	6	12%	10	60	6	36	10	60	9	54	5	30	10	60
6	Time Constraint	7	14%	4	28	3	21	0	0	3	21	3	21	10	70
7	Regulatory Compliance	8	16%	10	80	10	80	6	48	10	80	7	56	10	80
8	Employee Training	3	6%	10	30	10	30	10	30	10	30	10	30	8	24
	Total	**50**	**100%**	**69**	**408**	**52**	**354**	**49**	**331**	**58**	**367**	**39**	**243**	**66**	**430**

Weight Rating:
10-8 = High Impact
7-4 = Medium Impact
3-1 = Low Impact
0 = No Impact

Score Rating:
10-8 = Very Good
7-4 = Medium Good
3-1 = Not Good
0 = No Impact

Color Rating:
450 = Best Decision
350 = Good Decision
200 = Okay Decision

Figure 13: Decision Matrix

After calculating the weighted score of each option, a clear ranking appeared. The ranking is shown in Table 3.

Table 3: Solution Ranking

Rank	Idea
1	Increase Feeder 81 Airlock Size
2	Increase Amps for Separator 81
3	Add Classifier Blades for Separator 81
4	Adjust Tube Mill 81 Media
5	Reconnect Dust Collector 88
6	Add Feeder Diverter

In conclusion, the team selected 3 solutions to implement: increase the amperage for SM81, add classifier blades to SM81, and adjust TM81's media. Though increasing the feeder 81 airlock size ranked highest, after further discussions with Imerys employees, the team elected to forgo that solution since it is computer automated, and already held at the optimal opening size. The feeder valve was instead held constant throughout the duration of the project.

4.4 Implementation of Separator Amperage Changes

4.4.1 Process

In our systematic endeavor to enhance the performance of TM81, a pivotal aspect of our approach involved a judicious adjustment of the SM81 amperage, with the initial benchmark set at 41.5 amps. Recognizing the significance of a methodical and controlled process, our team opted for incremental increases, adhering to the principles of kaizen, wherein adjustments of approximately 1.5-2 amperes were made at each iteration. This deliberate approach served dual purposes – mitigating the risk of introducing significant quality issues during transitions and preventing complications in downstream processes, thereby ensuring a seamless integration of changes. Rigorous measures were implemented to validate the impact of each adjustment, involving the collection of 10 quality samples and a rate check following every modification. The subsequent step involved a meticulous comparative analysis, evaluating the quality and throughput data against the preceding results. This methodological approach not only provided a nuanced understanding of the immediate effects of amperage changes but also laid the groundwork for the detailed analysis presented in Chapter 5, showcasing our commitment to a comprehensive and data-driven decision-making process.

4.4.2 Results

Table 4 shows the results of the rate check performed before and after the amperage increase from 41.5 amps to 43 amps. The change in percent filled of Silo 32 (S32) shows that operating the separator at 43 amps increased the throughput rate. At the start of the project, the throughput of TM81 was approximately 3.84 tons of marble processed per hour. After increasing the separator amperage, this value rose to 5.28 tons per hour.

Table 4: Results from Amperage Increase

Amperage	Start % Filled S32	End % Filled S32	Δ % Fill	Tons/hour
41.5	18.7	21.9	3.2	3.84
43	24.2	28.6	4.4	5.28

After the first amperage increase, the amount of material processed by TM81 in one hour increased by 37.5%.

The quality of marble product also showed a distinct difference. Where at 41.5 amps, the mean particle size was 13.99 microns, and after the change, the MPS rose to 14.60 microns. This change is still within the desired 12 – 18 micron range and has been deemed acceptable by Imerys workers and the optimization team. Further data analysis for these changes is performed in Chapter 5.

4.5 Implementation of Media Replacement

4.5.1 Process

In the pursuit of optimizing the grinding process in TM81, a critical step involves the acquisition of new media balls. To ensure a well-informed decision, our team proactively engaged with reputable suppliers in the industry, reaching out to Norstone, MCS, and the Industrial Kiln and Dryer Group for their expert recommendations on suitable media. To provide these companies with a comprehensive understanding of our milling requirements, a meticulous sampling of both the feed and product was conducted, generating valuable data that was subsequently shared with the suppliers. The data encompassed precise specifications of the feed and the desired product. Leveraging their expertise, Norstone proposed a set of recommendations for media balls, specifying a mix of 1-1/2’’ balls at 25-30%, 1-1/4’’ balls at 40-45%, and 1’’ balls at 25-30% mix. Furthermore, Norstone facilitated the decision-making process by presenting alternative options from two European manufacturers and one Chinese manufacturer. Ongoing discussions within the team are centered on evaluating these recommendations to identify the optimal choice, considering factors such as performance, cost, and availability. This meticulous approach underscores our commitment to sourcing media that aligns seamlessly with the unique operational requirements of TM81.

4.5.2 Expected Results

The anticipated outcomes following the replacement of media in TM81 are poised to significantly enhance the overall grinding process. The introduction of new media is expected to yield a notable increase in grinding efficiency, characterized by a more streamlined and expedited raw material breakdown. The replacement of worn-out media with fresh counterparts is anticipated to facilitate quicker grinding, translating into a heightened production output. Moreover, the anticipated reduction in power draw is a direct consequence of the improved efficiency, as the mill will encounter reduced resistance during the grinding process. This optimization aligns with the kaizen philosophy of continuous improvement, as incremental adjustments to the media composition aim to achieve an optimal balance between grinding efficiency and power consumption. Additionally, the enhanced product quality emerges as a direct consequence of the precision achievable through the use of the right media. With the raw material ground to the specified size, the resulting product is expected to exhibit improved consistency and adherence to quality standards. The collective impact of these improvements underscores the strategic significance of media replacement in optimizing the operational performance of TM81.

4.6 Implementation of Classifier Blades

4.6.1 Process

The procurement and implementation of new classifier blades for TM81 involved a meticulously planned and executed process aimed at optimizing the mill's performance. The decision to source the blades from Central Machine & Fabrication, a reputable provider, was driven by considerations of both quality and reliability. The acquisition of 72 blades, at a cost of $5,184, was a strategic investment in enhancing the mill's efficiency. The subsequent installation process, conducted by two skilled workers over eight hours, incurred a labor cost of $916, reflecting a commitment to precision and expertise in the implementation phase. Following the installation, a critical step involved the meticulous balancing of the blades by a professional, incurring an additional cost of $3,750. This attention to detail is paramount in ensuring the longevity and optimal functioning of the classifier blades. The comprehensive investment, totaling $9,850, encapsulated both the acquisition and the skilled labor required for installation and balancing.

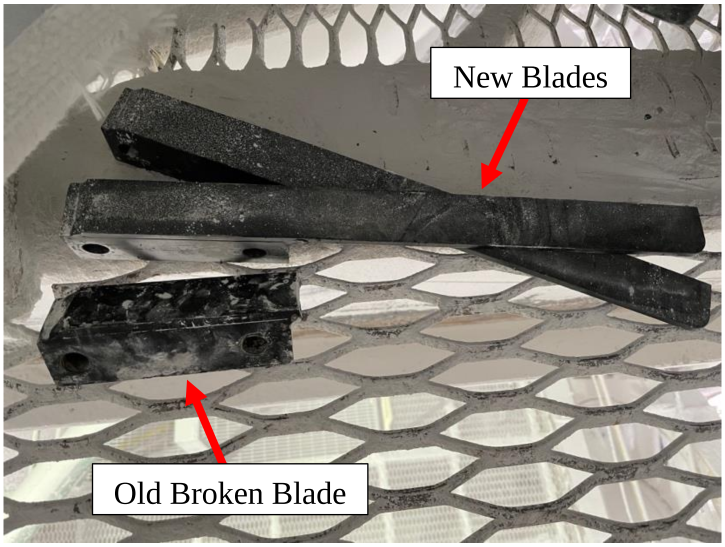


Figure 14: Classifier Blades

The incorporation of the six missing blades, carried out seamlessly, further underscored the meticulous planning and execution of the upgrade. Figure 14 shows two new fan blades before installation and one old blade being replaced. Subsequent to the implementation, a thorough assessment of quality and throughput metrics was conducted to gauge the impact of the new classifier blades on the overall operational performance of TM81. This comprehensive approach to the blade replacement process aligns with the overarching goal of continuous improvement, contributing to the mill's sustained efficiency and output quality.

4.6.2 Results

The integration of the six missing classifier blades into TM81 marks a pivotal enhancement in the operational dynamics, resulting in a more consistent and improved quality of the milling process. The addition of these blades contributes significantly to reducing variability in samples, establishing a steady and controlled milling environment. This reduction in variability is paramount for achieving a more uniform product, aligning with the desired quality standards. The impact of this improvement extends to the rejection rate of coarser material. With the enhanced functionality of the classifier blades, the rejection of coarser particles is now more efficient and reliable. This not only leads to an overall improvement in product quality but also translates into a reduction in waste, as the rejected material is seamlessly reintegrated into the milling process. This closed-loop approach minimizes material wastage, contributing to a more sustainable and resource-efficient operation.

4.7 Supplemental Solutions

4.7.1 Mill Lining Inspection

Recognizing the age and operational history of TM81, a comprehensive inspection is deemed essential to assess its structural integrity thoroughly. This examination, encompassing the mill, mill lining, blow lines, screws, and air pressure lines, aims to identify potential cracks or faults that may have developed over time. Considering Industrial Kiln and Dryer Group for their expertise in mill inspection, this meticulous process will focus on wear patterns, material degradation, and potential points of failure in the mill lining. The inspection extends to critical components influencing overall functionality, such as blow lines, screws, and air pressure lines.

The anticipated results of this inspection will provide crucial insights into the mill's current condition, guiding informed decisions on maintenance or upgrade strategies to ensure optimal performance, safety, and longevity.

4.7.2 Feed Bin Inspections

A thorough inspection of Feed Bin 81 was conducted to identify and rectify any material blockages that could impede production efficiency. The presence of material adhered to the bin's walls not only has the potential to decrease production rates but may also compromise product quality by retaining coarser material. The inspection revealed a minor blockage, promptly addressed by a two-person team who dedicated four hours to meticulously clearing the material. After this intervention, both the quality and production output exhibited marked improvement, underscoring the significance of proactive measures to ensure uninterrupted and optimal mill performance.

Chapter 5: Quality Data Analysis

5.1 Methodology

For each modification in the process, a thorough examination of the quality aspect was undertaken through data analysis. Specifically, six Statistical and Quality Control (SQC) charts were generated for each change, encompassing the Individuals chart, Moving Range chart, Observations chart, Capability Histogram, Normal Probability Plot, and a Process Capability Plot.

5.1.1 Shewhart Control Chart for Individual Measurements

The initial choice in our chart selection process was the implementation of a Shewhart Control Chart for Individual Measurements. This preference was dictated by the deliberate consideration of the relatively sluggish and inconvenient sample collection process, which incurred a substantial time cost. Hence, a control chart requiring less data with smaller subgroups was deemed more fitting. This chart facilitated the continuous monitoring of TM81's output in relation to its quality over time, employing a subgroup size of 1 (n=1). It serves the purpose of indicating whether the process remains in control over multiple samples, based on the detection of any individual quality sample exceeding the upper control limit (UCL) or falling below the lower control limit (LCL). Consequently, this chart aids in sifting through the data to discern potential out-of-control data points and ascertain whether they are attributable to assignable causes. If such causes are identified, a revised chart can be formulated.

5.1.2 Moving Range Chart

The selection of a Moving Range (MR) Chart as the second analytical tool in our investigation was a deliberate choice based on its distinct advantages in capturing and elucidating the dynamics of data variability over consecutive subgroups. Unlike other statistical control charts, the MR Chart is particularly effective in shedding light on the inherent spread within the data set, offering valuable insights into the patterns of variability between successive data points. The decision to integrate the MR Chart into our analytical framework was predicated on the recognition of its suitability in scenarios where the focus lies on understanding the changes in variability over time. This chart becomes particularly pertinent when evaluating the impact of alterations introduced in the process, providing a comprehensive view of how concise or scattered the data becomes after each modification. Its utility lies in its ability to not only detect shifts in the central tendency but also to capture alterations in the dispersion of data, thereby facilitating a nuanced understanding of the process behavior and aiding in the identification of potential sources of variation.

5.1.3 Data Dot Plot

The third plot in our analysis was a dot plot, which essentially plots all data points between successive subgroups. The strategic inclusion of a dot plot as the third visualization tool in our analytical arsenal was motivated by its distinctive attributes that complement our overarching goals in process evaluation and improvement. The dot plot, by graphically representing all individual data points between successive subgroups, offers a straightforward and uncluttered depiction of the data distribution. Unlike the Shewhart Control Chart for Individual Measurements, the dot plot eschews the imposition of control limits (UCL, LCL) and the interconnecting lines between data points. This intentional omission serves to emphasize the raw distributional characteristics of the data without the overlay of predefined statistical boundaries, allowing for a more intuitive visual assessment.

5.1.4 Process Capability Histogram

The fourth plot employed was a Capability Histogram. The deliberate inclusion of a Process Capability Histogram as the fourth analytical tool in our methodology stems from its unique ability to provide a comprehensive and visually intuitive assessment of the distribution of data in relation to predefined quality specifications. The histogram serves as a powerful tool for discerning the interplay between the control chart's upper and lower control limits (UCL, LCL) and the quality specifications established by Imerys, encapsulated by the upper specification limit (USL) and lower specification limit (LSL). This graphical representation allows for an immediate identification of the concentration of data within the specified limits, offering a clear overview of the distribution's central tendency and variability.

5.1.5 Normal Probability Plot

The fifth plot, the Normal Probability Plot, assumes significance in ensuring that individual control charts are constructed with data following a normal distribution. This is imperative, as deviations from normality, even moderately, can significantly impact the chart's performance. Moreover, process capability relies on the assumption of normality in the data. Consequently, this plot serves as a vital check to validate the suitability of the data for use in the aforementioned plots.

5.1.6 Process Capability Plot

The sixth plot is the Capability Plot. The inclusion of a Process Capability Plot as the sixth and final component of our analytical framework is motivated by its instrumental role in assessing the process's ability to meet business requirements, providing a holistic perspective on its performance against specified limits. This plot employs the USL and LSL as benchmarks for evaluation, offering a direct and tangible link to the quality standards set by Imerys. The potential capability (C_p) reflects the data spread, while actual capability (C_{pk}) indicates its centrality. Both are important measurements that need to be considered when determining whether a process is capable. The choice to incorporate this plot reflects a commitment to aligning our analyses with real-world business considerations.

5.2 41.5 Separator Amperage / 30 Classifier Blades

The first quality data analysis was done on the benchmark dataset. As a reminder, the benchmark dataset started the SM81 amps at 41.5, and SM81 had 30 classifier blades. The six quality graphs and charts described before were used to analyze the dataset taken for this benchmark.

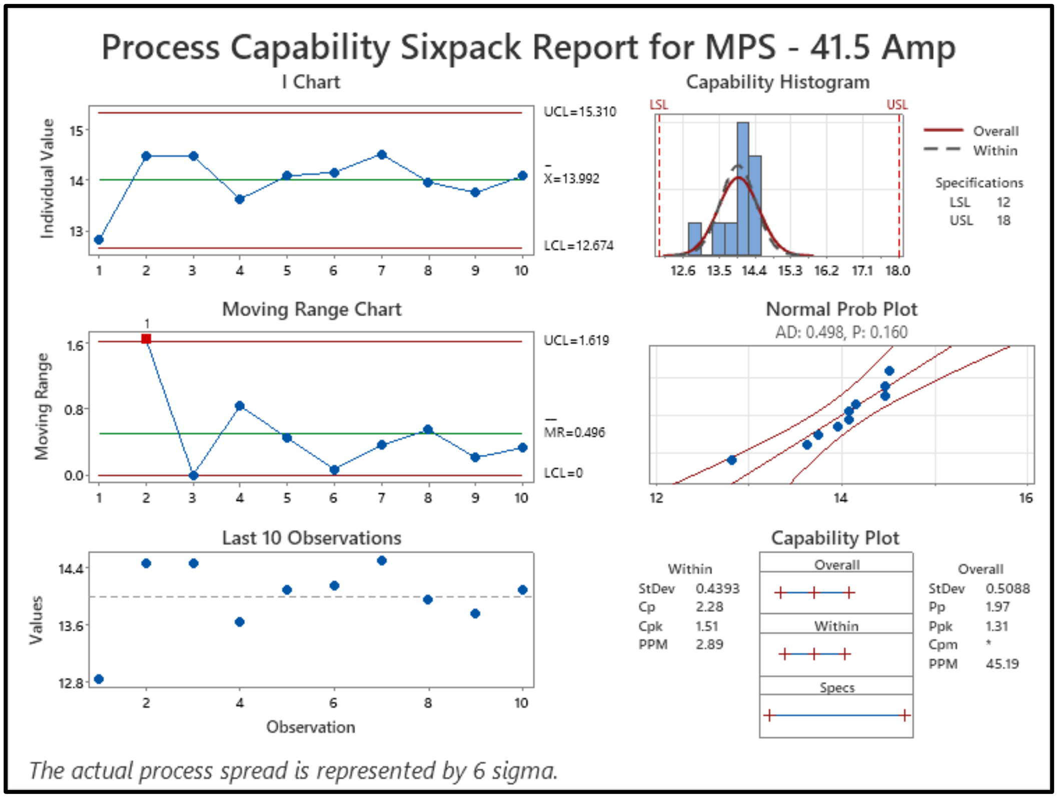


Figure 15: 41.5 Amp Process Capability Sixpack

5.2.1 Shewhart Control Chart for Individual Measurements

In Figure 15, the Shewhart Control Chart for Individual Measurements illustrates a robust statistical control, with all ten observations falling within the calculated control limits. The UCL was determined to be 15.310 microns (µm), and the LCL was calculated as 12.674 µm. The central tendency of the quality samples, represented by the average ($\bar{x}$) at 13.992 µm, aligns well within these control limits, indicating a stable and controlled process. Importantly, no individual quality samples breach the UCL or dip below the LCL, reinforcing the notion of consistent and predictable performance. This adherence to control limits suggests that the data collection process is free from significant biases or systemic errors, enhancing the reliability of the quality measurements. The Shewhart Control Chart not only provides a snapshot of the current stability but also serves as a tool for continuous monitoring, enabling timely identification of any shifts or trends that might affect product quality. This level of control is pivotal for maintaining quality standards and instills confidence in the reliability of the measured data for subsequent analyses and decision-making.

5.2.2 Moving Range Chart

In Figure 5, the Moving Range Chart presents a generally controlled variation, with the calculated control limits defining the expected range of variability. The UCL and LCL were determined to be 1.619 µm and 0 µm, respectively. Notably, the average moving range, measuring 0.496 µm, comfortably resides within these control limits, indicating a consistent and predictable level of variation between successive subgroups. However, a discernible observation stands out, exceeding the UCL at 1.619 µm. Upon closer examination and a thorough investigation, this particular variation was deemed non-assignable or common cause, suggesting that it is not indicative of an inherent flaw in the process but rather a transient and expected fluctuation. The identification and classification of this variation contribute to the understanding that the observed variability is well within the bounds of common cause variability, reinforcing the conclusion that the process is under control. The Moving Range Chart not only serves as a real-time monitor of variation but also aids in the discrimination between common and special causes, offering valuable insights for process improvement and maintenance of consistent quality standards. This level of control fosters confidence in the reliability of the process and underscores the effectiveness of the data collection and measurement systems.

5.2.3 Data Dot Plot

The Data Dot Plot offers a comprehensive visual representation of the dataset, revealing distinctive characteristics beyond what is apparent in traditional control charts. In scrutinizing the plot, the absence of discernible patterns or clusters becomes evident, underscoring a lack of systematic trends or irregularities in the dataset. Notably, Observation 1, while potentially appearing as an outlier, does not breach the LCL in the corresponding Shewhart Control Chart for Individual Measurements. This observation, therefore, can be considered within the acceptable range of variation and is not indicative of a systemic issue. The dot plot's depiction of raw data emphasizes a consistent spread, with data points closely distributed around the center line. This uniformity suggests a stable and controlled process, further corroborating the findings from the control charts. The exception of Observation 1 does not manifest as a pervasive concern, given its isolated nature and lack of influence on the overall distribution. The absence of prominent indicators of troublesome data in the Data Dot Plot reinforces the reliability and robustness of the dataset, contributing to the overall assessment of a well-controlled and predictable process. The dot plot's role in highlighting subtle variations and providing a nuanced view of the data complements the insights derived from control charts, enriching the analytical perspective and facilitating a more comprehensive understanding of the underlying process dynamics.

5.2.4 Process Capability Histogram

Examining the Process Capability Histogram provides a nuanced perspective on the distribution of data, revealing additional insights into the process capability. The histogram's portrayal of the data spread is crucial for understanding the concentration and dispersion of quality datapoints.

The tight clustering around 14 µm indicates a consistent and centralized distribution, reinforcing the findings from the control charts. However, the observation of some data points skewing towards the LSL suggests a potential proximity to the lower threshold of acceptable quality. Despite this skewing, all data points remain within both the LSL and USL, underscoring the overall compliance of the process with the established quality specifications. The histogram's ability to visually distinguish the data within the control limits and against the specification limits contributes to a comprehensive assessment of process capability. This analysis facilitates a more detailed understanding of how the process performs relative to the defined quality standards, allowing for targeted improvements if necessary. The Process Capability Histogram serves as a valuable tool for quality control, aiding in the identification of any deviations from specifications and providing a visual context for assessing the robustness of the manufacturing process.

5.2.5 Normal Probability Plot

In scrutinizing the Normal Probability Plot, a calculated p-value of 0.160 becomes a pivotal statistic in determining the normality of the dataset. Utilizing hypothesis testing as the foundation for this evaluation, the null hypothesis posits that the data follows a normal distribution, while the alternative hypothesis suggests otherwise. A crucial threshold is established at the conventional significance level of 0.05. In this context, the p-value of 0.160 exceeds this threshold, leading to the conclusion that the null hypothesis fails to be rejected. This result implies that, statistically speaking, there is insufficient evidence to challenge the assumption of normality within the dataset. A p-value greater than 0.05 indicates a reasonable alignment of the data with the characteristics of a normal distribution. This confirmation holds significance for subsequent analyses, as many statistical methods and control chart assumptions rely on the underlying data conforming to a normal distribution. The Normal Probability Plot, by providing a formal test of normality, contributes valuable information to the broader assessment of data reliability, enhancing the credibility of subsequent statistical analyses and interpretations.

5.2.6 Process Capability Plot

Examining the Process Capability Plot allows for a comprehensive evaluation of how well the process can meet business requirements, employing both potential and actual capability measurements. The potential capability measure, calculated at 2.28, surpasses the threshold of 1, signifying a process with minimal spread and tight control. This suggests that the data points are concentrated and consistent, meeting the criteria for effective process capability. Additionally, the actual capability measure, registering at 1.51, exceeds the required value of 1, indicating that the process is not only tightly controlled but also reasonably centered around the target value. This dual confirmation, with both potential and actual capability measures exceeding 1, instills confidence that the process is well-positioned to meet business specifications. The consideration of both spread and centrality metrics ensures a balanced assessment of the process's overall capability.

Furthermore, the parts per million (PPM) metric, quantifying the defect rate, stands at 2.89. This PPM value, falling below 3.4, aligns with a Six Sigma level of quality, underscoring an exceptionally low defect rate. This outcome substantiates the high quality and efficiency of the process, affirming that it operates well within the defined business requirements. The synergy between the capability measures and the PPM metric reinforces the conclusion that the process is not only capable but also excels in producing high-quality output. This favorable result in process capability signifies a robust and reliable manufacturing process, meeting stringent business standards and reflecting a commitment to delivering products with minimal defects.

5.3 43 Separator Amperage / 30 Classifier Blades

The subsequent analysis of quality data was conducted following the examination of the benchmark dataset. This particular dataset encompassed the SM81 amps set at 43, with SM81 equipped with 30 classifier blades. Employing the set of six previously outlined quality graphs and charts, we systematically scrutinized the dataset acquired during this benchmark phase.

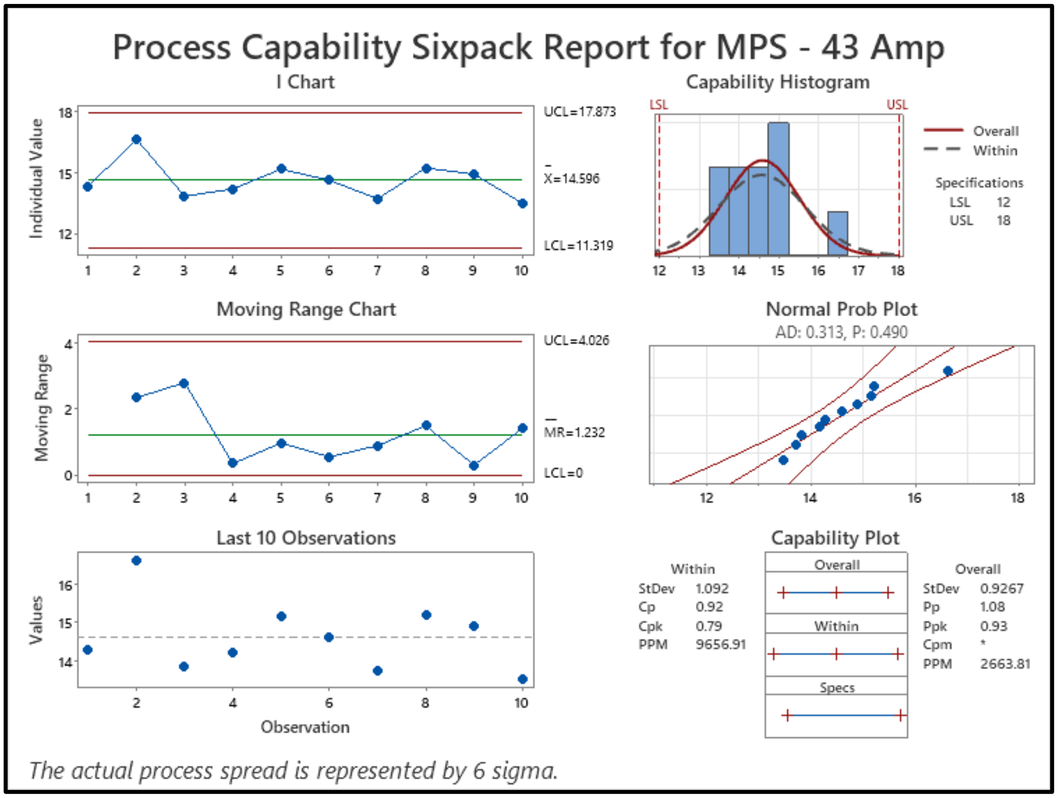


Figure 16: 43 Amp Process Capability Sixpack

5.3.1 Shewhart Control Chart for Individual Measurements

In Figure 16, the Shewhart Control Chart for Individual Measurements showcases a dataset in robust statistical control, where all ten observations remain within the calculated control limits. The UCL was established at 17.873 µm, with the LCL computed as 11.319 µm. The central tendency of the quality samples at 14.596 µm aligns well within these control limits, signifying a stable and controlled process. Crucially, none of the individual quality samples exceed the UCL or fall below the LCL, underscoring the consistency and predictability of performance. This adherence to control limits implies an unbiased and systemically error-free data collection process, bolstering the reliability of the quality measurements. The Shewhart Control Chart not only offers a snapshot of the current stability but also serves as an instrument for continuous monitoring, facilitating prompt identification of any shifts or trends that may impact product quality. This level of control is imperative for upholding quality standards, instilling confidence in the reliability of measured data for subsequent analyses and decision-making.

In contrast to the findings in the 41.5 Amp Shewhart Control Chart for Individual Measurements, the UCL and LCL exhibited a greater distance from the center line. Specifically, the UCL increased from 15.310 µm to 17.873 µm, marking a 16.74% deviation farther from the center line. Similarly, the LCL transitioned from 12.674 µm to 11.319 µm, representing a 10.69% shift farther from the center line. Additionally, the average quality result saw an increase from 13.992 µm to 14.596 µm, reflecting a 4.32% augmentation in the average mean particle size. These alterations were anticipated when elevating the amps on SM81, as such adjustments influence the throughput of the entire process, leading to corresponding shifts in the average mean particle size.

5.3.2 Moving Range Chart

In Figure 6, the Moving Range Chart provides a comprehensive view of controlled variation, where calculated control limits delineate the anticipated range of variability. The UCL and LCL were established at 4.026 µm and 0 µm, respectively. Notably, the average moving range, measuring 1.232 µm, comfortably resides within these control limits, indicating a consistent and predictable level of variation between successive subgroups. All observed values fall well within the control limits, with no instances of out-of-control quality samples. Beyond serving as a real-time monitor of variation, the Moving Range Chart aids in distinguishing between common and special causes, offering valuable insights for process enhancement and the maintenance of consistent quality standards. This degree of control instills confidence in the reliability of the process and underscores the efficacy of data collection and measurement systems.

In contrast to the findings in the 41.5 Amp Moving Range Chart, notable differences emerge, particularly in the distance of the UCL from the center line. The UCL increased from 1.619 µm to 4.026 µm, marking a substantial 148.67% deviation farther from the center line. In contrast, the LCL remained constant at 0 µm. Additionally, the average moving range metric escalated from 0.496 µm to 1.232 µm, reflecting a significant 148.39% increase. These adjustments align with expectations when elevating the amps on SM81, as such modifications influence the throughput of the entire process, resulting in an amplified variation in the quality results.

5.3.3 Data Dot Plot

The Data Dot Plot serves as a comprehensive visual tool, offering insights into the dataset that extend beyond the capabilities of traditional control charts. Upon careful examination of the plot, the apparent absence of discernible patterns or clusters becomes evident, signaling a lack of systematic trends or irregularities within the dataset. Emphasizing raw data, the dot plot illustrates a consistent spread, with data points uniformly distributed around the center line. This uniformity suggests a stable and controlled process, aligning with and reinforcing the conclusions drawn from the control charts. The conspicuous absence of noteworthy indicators of problematic data in the Data Dot Plot bolsters the reliability and robustness of the dataset, contributing to the overarching evaluation of a well-controlled and predictable process. The dot plot's role in highlighting subtle variations and providing a nuanced perspective complements the insights derived from control charts, enhancing the analytical depth, and fostering a more comprehensive understanding of the inherent dynamics of the underlying process.

5.3.4 Process Capability Histogram

Examining the Process Capability Histogram provides a nuanced perspective on data distribution, offering additional insights into process capability. The histogram's depiction of data spread is vital for grasping the concentration and dispersion of quality datapoints. The clustered data is spread within the Upper Specification Limit (USL) and Lower Specification Limit (LSL), maintaining a central tendency around 14 µm, albeit not as tightly packed as observed in the 41.5 amp findings. This reaffirms the conclusions drawn from the control charts.

Despite the expanded data spread, certain data points continue to skew towards the LSL, indicating a potential proximity to the lower threshold of acceptable quality. However, it's noteworthy that all data points remain within both the LSL and USL, highlighting the overall compliance of the process with established quality specifications. The histogram's visual ability to discern data within control and specification limits contributes to a comprehensive evaluation of process capability. This analysis enhances the understanding of how the process aligns with defined quality standards, facilitating targeted improvements if needed. The Process Capability Histogram stands as a valuable tool for quality control, aiding in the identification of deviations from specifications and providing a visual framework for assessing the manufacturing process's robustness.

5.3.5 Normal Probability Plot

Upon meticulous examination of the Normal Probability Plot, a calculated p-value of 0.490 emerges as a pivotal statistic in assessing the normality of the dataset. Grounded in hypothesis testing, the null hypothesis asserts that the data adheres to a normal distribution, while the alternative hypothesis posits otherwise. A critical threshold is established at the conventional significance level of 0.05. In this context, the computed p-value of 0.490 surpasses this threshold, leading to the conclusion that the null hypothesis fails to be rejected. Statistically speaking, this outcome suggests insufficient evidence to challenge the assumption of normality within the dataset. The p-value exceeding 0.05 indicates a reasonable conformity of the data with the characteristics of a normal distribution. As described before, this validation assumes particular importance for subsequent analyses, given that various statistical methods and control chart assumptions rely on the underlying data conforming to a normal distribution. The Normal Probability Plot, by conducting a formal test of normality, provides valuable insights for the comprehensive assessment of data reliability. This, in turn, enhances the credibility of subsequent statistical analyses and interpretations, underscoring the importance of confirming the normality assumption in facilitating robust and accurate engineering evaluations.

5.3.6 Process Capability Plot

Analyzing the Process Capability Plot provides a comprehensive assessment of the process's ability to meet business requirements, employing both potential and actual capability measurements. The potential capability measure, calculated at 0.92, marginally below the threshold of 1, indicates a process with some spread and loose control. This suggests that data points are more dispersed, barely missing the criteria for effective process capability. Additionally, the actual capability measure, registering at 0.79, again falls short of the required value of 1, indicating that the process is not well-centered around the target value. The convergence of both potential and actual capability measures below 1 raises questions about the process's readiness to meet business specifications. The consideration of both spread and centrality metrics ensures a balanced assessment of the process's overall capability.

Furthermore, the Parts Per Million (PPM) metric, quantifying the defect rate, stands at 9,657. This PPM value, falling below 66,807, aligns with a Three Sigma level of quality, underscoring a reasonably low defect rate. This outcome substantiates the high quality and efficiency of the process, affirming its adherence to defined business requirements. The interplay between the capability measures and the PPM metric reinforces the conclusion that the process is somewhat capable but does meet standards in producing high-quality output.

In comparison to the results found in the 41.5 Amp Process Capability Plot, both potential capability and actual capability moved from above the threshold of 1 to below it. The potential capability decreased from 2.28 to 0.92, representing a 67.38% decrease, while the actual capability decreased from 1.51 to 0.79, representing a 47.68% decrease. Additionally, the estimated PPM result decreased from a Six Sigma level of quality to a Three Sigma level. While these results indicate negative progress, these changes were expected when increasing the amps on SM81 because such changes influence the throughput of the entire process, leading to fluctuations in the mean particle size averages. These outcomes are anticipated to reverse with the implementation of new classifier blades into SM81.

Chapter 6: Economic Analysis

6.1 Economic Context, Revenue, & Cost Savings

Following the completion of data collection for the project, a comprehensive economic analysis was undertaken to ascertain the financial implications of the procedural modifications. It is worth reiterating that Imerys' operational portfolio encompasses a wide array of products; however, this study primarily centers its focus on those products that emanate downstream from the production units TM81 and TM82. Specifically, TM81's production process culminates in the generation of CS-11, while TM82 yields more products downstream, which are Calwhite and Gamaco.

Prior to the commencement of this project, it is noteworthy that TM81 was incapable of producing sufficient feedstock to sustain the production of CS-11 downstream, necessitating supplementation from TM82. Consequently, TM82 also experienced inadequacies in its Calwhite output to meet its internal demand, which subsequently prompted the implementation of an interplant transportation system at Imerys. This system entailed the engagement of a third-party trucking company to transport surplus products from Imerys's inventory and rejects to a designated facility for reprocessing and reformation into Calwhite.

6.1.1 TM81 Potential Revenue

The enhanced production output of TM81 has ushered in a substantial augmentation in potential revenue. Comparative analysis based on benchmark data reveals that TM81, under ideal conditions, previously yielded 3.84 TPH, equivalent to approximately 641 tons per week (TPW), accounting for scheduled downtime, and assuming the absence of any unscheduled interruptions. At an average sales price of $152 per ton for Calwhite, the extant weekly revenue generated by TM81's Calwhite production stands at approximately $97,450, which extrapolates to an annual revenue of approximately $5,067,412.

Currently, TM81's productivity has seen a remarkable boost, resulting in a current production rate of 5.28 TPH, marking a major improvement of 32%. This notable improvement translates into an additional 242 TPW. Consequently, the potential revenue gains stemming from TM81's production upsurge amount to an additional weekly revenue of approximately $36,790, with a potential annual revenue increase of up to approximately $1,913,084. It is, however, imperative to underscore that the realization of these potential financial benefits is contingent upon the downstream processes maintaining pace with TM81's heightened production, as well as the concurrent demand for CS-11 bulk truck loading.

6.1.2 TM82 Cost Savings

After the successful implementation of the project's modifications, TM82 ceased its role in supplementing TM81's production, thereby enabling TM82 to meet the burgeoning demand for Calwhite autonomously. Thus, TM82 is now able to meet the feed demand of the Calwhite silo. Consequently, the need for the interplant truck system, previously employed to transport excess product or rejects for Calwhite reprocessing is currently not needed. Before the project's intervention, an average of 2-3 trucks per week were dispatched for this purpose, incurring an approximate cost of $300-400 per truck. This equated to a weekly expenditure reduction of approximately $875, resulting in an annual savings of approximately $45,500. Furthermore, the preservation of excess products on-site, rather than initiating the labor-intensive process of reworking already fabricated products, has yielded additional, albeit challenging to precisely quantify, cost savings. Although specific figures related to the avoidance of product rework are elusive, it is evident that this practice has contributed to overall cost reduction as well.

6.2 Economic Costs

6.2.1 SM81 Classifier Blade Cost

A significant component of the project's expenses pertained to Imerys' investment in the acquisition and installation of new classifier blades for SM81. The procurement of these blades involved the purchase of 72 units at a unit cost of $72 each, amounting to a total expenditure of $5,184. Subsequently, the installation of these blades necessitated the employment of two associates, each dedicating eight hours to the task, at an hourly rate of $57.25. This resulted in a one-time installation labor cost of $916. In addition to the procurement and installation costs, the final requisite for ensuring the functional integration of the classifier blades into SM81 involved a balancing procedure, incurring a flat-rate charge of $3,750. In summation, the comprehensive expenditure associated with the purchase, installation, and balancing of the classifier blades within SM81 aggregates to a grand total of $9,850.

6.2.2 TM81 Media Ball Cost

A significant cost associated with this project pertained to the installation of new media balls in TM81, along with the removal of the old media balls. While the specific cost of purchasing the new media is currently undetermined (TBD), the labor cost for this task is well-defined. To execute the replacement of media balls in TM81, approximately four associates were engaged, each contributing 16 hours of work at an hourly rate of $57.25, which accumulates to a labor cost of $3,664. Moreover, there is an additional flat-rate cost of $4,500 allocated for the disposal of the old media balls. In aggregate, the total expense for the installation of new media balls stands at $8,164 (including the labor cost), and the undetermined cost of the new media balls (TBD).

6.3 Breakeven Analysis

Based on the previous cost and revenue estimates, several breakeven analyses can be conducted to assess the project's financial viability under different scenarios and assumptions.

6.3.1 Conservative Estimate

In the conservative estimate, we are excluding potential revenue and the cost associated with the installation of new media balls. The one-time cost for the classifier blade installation was $9,850. However, it's essential to consider the cost savings resulting from TM82's current discontinuation of the interplant truck system, which amounts to an estimated $875 per week or $125 per day. Given this information, it would take approximately 79 days to recover the project costs, and beyond that point, the project would yield pure financial gains. This demonstrates the project's ability to deliver positive financial outcomes in a relatively short timeframe, even in the conservative estimate.

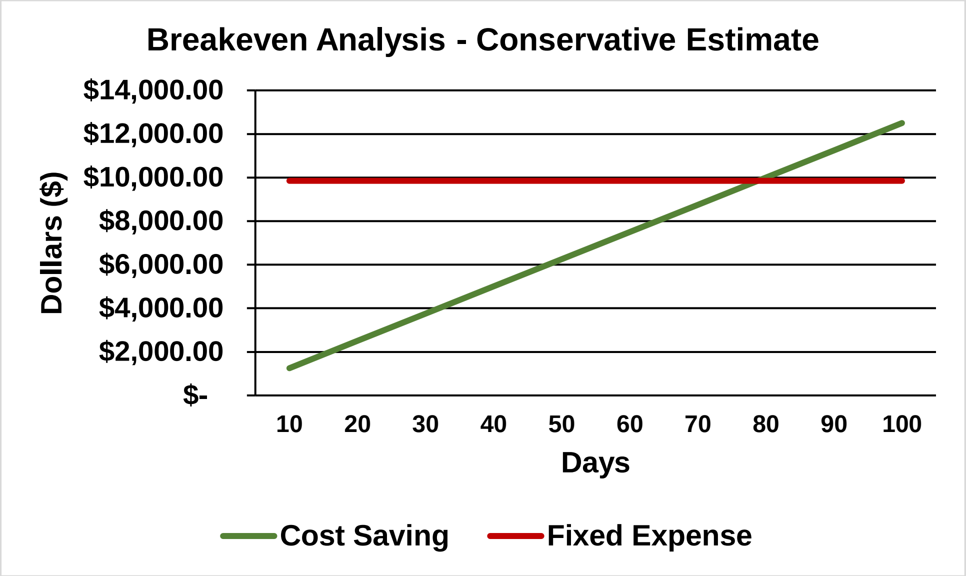


Figure 17: Breakeven Analysis

Chapter 7: Environmental Analysis

When looking at the results of this project, it is important to encompass impacts outside of Imerys. This section undertakes an environmental consideration of the project with respect to power usage. Documentation from a previous study at Imerys reports that the power drawn by TM81 and SM81 is 94.2 kW over an 8-hour shift (2014). This results in 11.775 kW/hr used by the TM81. In a report based on data from 2022, the U.S Energy Information Administration announced that energy production in America results in 0.86 lbs CO_2 per kilowatt hour (n.d.). The following calculations show the impact of changing the SM81 amperage.

7.1 Calculations for 41.5 Amps

Converting to watts/ton:

$$Watts\ used\ per\ ton = \frac{Power\ per\ hour}{tons\ per\ hour} = \frac{11.775 kW/hr}{3.84\ ton/hr} = 3.07\ kW/ton$$

Converting into pounds of carbon dioxide produced per ton marble processed:

$$Pounds\ CO_2\ produced\ per\ ton = \frac{Power}{ton} * \frac{Pounds\ CO_2}{Power} = \frac{3.07 kWhr}{ton} * \frac{0.86\ lbsCO_2}{kWhr}$$
$$= 2.64 lbsCO_2/ton$$

7.2 Calculations for 43 Amps

Converting to watts/ton:

$$Watts\ used\ per\ ton = \frac{Power\ per\ hour}{tons\ per\ hour} = \frac{11.775 kW/hr}{5.28\ ton/hr} = 2.23\ kW/ton$$

Converting into pounds of carbon dioxide produced per ton marble processed:

$$Pounds\ CO_2\ produced\ per\ ton = \frac{Power}{ton} * \frac{Pounds\ CO_2}{Power} = \frac{2.23\ kWhr}{ton} * \frac{0.86 lbsCO_2}{kWhr}$$
$$= 2.003\ lbsCO_2/ton$$

7.3 Comparison of Results

Through changes to SM81, the marble production rate has increased but the watts used stayed the same. This results in an improvement of watts consumed per ton of marble processed for the TM81 system. Before the amperage change, we estimated 2.64 lbs of CO_2 per ton of marble processed. After changing the amperage to 43, we estimate the CO_2 emissions were reduced to 2 lbs of CO_2 per ton of marble. This is a 24% reduction in carbon dioxide emissions per ton of marble processed by TM81 and SM81

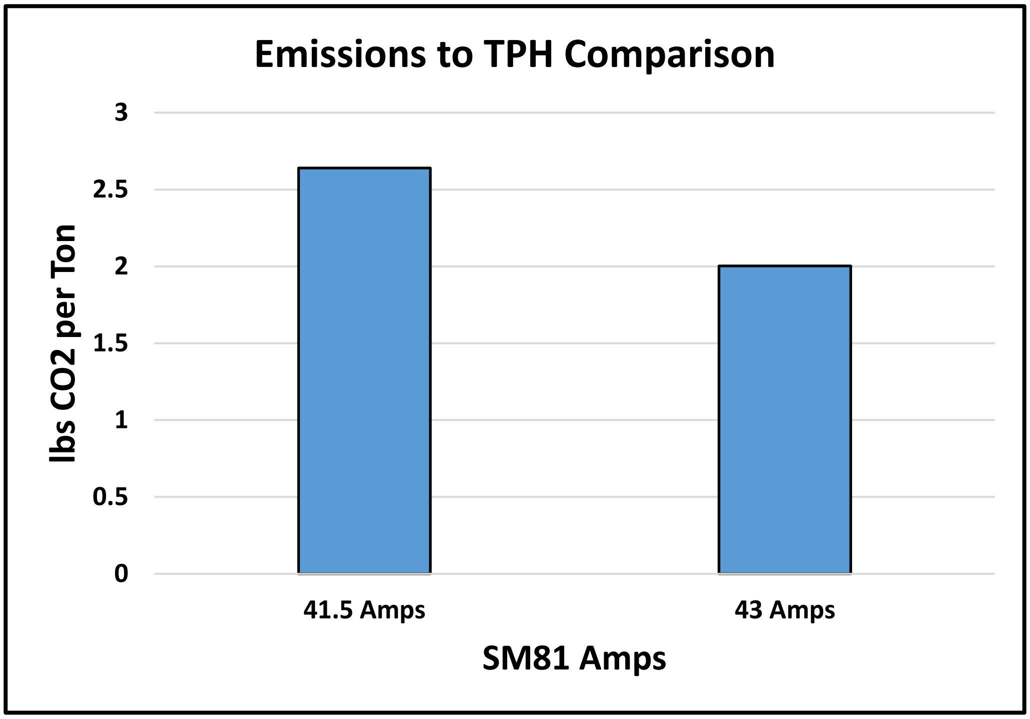


Figure 18: Environmental Analysis Results

Chapter 8: Conclusions

The project set out to increase production, keep the quality within the specifications, and consistently make product for Plant 3. Production increased from 3.84 TPH to 5.28 TPH (37.5% increase) by increasing the SM81 amps from 41.5 to 43. The silo at Plant 3 also reached capacity quicker since the feed was more consistent. TM82 can focus on making feed for Calwhite or Gamaco now instead of assisting TM81 since the circuit is making and sending enough product to Plant 3 on its own. The interplant truck system is currently not having to be used to supplement TM82's production since TM82 is making enough feed now for Calwhite or Gamaco. This is saving around $875 a week, leading to a breakeven point of about 79 days. Changing the amps on SM81 also had environmental benefits where SM81 is making more product per ton now at 43 amps compared to 41.5. Since TM81 has a constant power draw with increased production, this change resulted in a 24% reduction in pounds of CO_2 emissions per ton. A new Classifier blade set was installed to help improve the quality and keep the product within specifications. New grinding media is being ordered to help increase grinding efficiency in TM81. DC88 is in the beginning stages of being reconnected to help reuse waste, lower cleanup costs and limit downtime on maintenance. Overall, the goals of the project have been achieved with three process improvement initiatives currently being implemented from the recommendations of our group.

Table 5: Results and Goals Comparison

Goal Description	Benchmark	Goal Metric	Actual	Achieved?
Increase hourly throughput of Tube Mill 81 (TM81)	~3.84 tons/hour	4 tons/hour	~5.28 tons/hour	✓
Maintain quality and consistency of product	~13.99 microns	12-18 microns	~14.60 microns	✓
Breakeven Point	N/A	< 3 years	~79 days	✓

Table 5 shows a comparison of the initial state, goals, and results in relation to the goals of the project. All three goals were achieved and surpassed at the end of this project.

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Appendix A: Term Definitions

Term	**Definition**
Attrition Mill	Reduces particle size of harder materials and uses an inner and outer disc to mill the material down.
Classifier	The blades help create airflow to separate the fine and coarse materials.
Colorizer	Analyzes the color of the product.
CS-11	A product at Plant 3 that uses Tube Mill 81's product.
DC88	Dust Collector 88
Flow Rate	How many tons per hour are being made.
Media	Balls that are cylinders or circular in inches that help grind up marble into a fine product .
Particle Color	The color of product from 0 to 100 with 100 being brightest.
Particle Density	The mass density of the product.
Particle Size	The size of the particle from microns to inches.
Ro-Tap	Uses meshes to filter the product to see different particle sizes.
Separator	Separates the coarse and fine materials apart. The fines move on and coarse is sent back into the process.
Silo	Holds the finished product or feed.
SM81	Separator 81
SM82	Separator 82
TM81	Tube Mill 81
TM82	Tube Mill 82
Tube Mill	Uses media balls to grind the marble down into a fine product. This is better for softer materials.

Appendix B: Contact Information

Team Member	Email	Phone #
Dalton Beasley	daltonb.beasley@gmail.com	770-309-5992
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Tristan McMichael	tamcmichael@gmail.com	770-546-2349
Ryan Waltman	ryanlwaltman@gmail.com	404-931-0208

Appendix C: Roles and Responsibilities

Team Member	Role	Responsibilities
Dalton Beasley	Project Manager	1.1, 1.4, 1.8, 1.9, 4.1, 4.5, 4.7, Appendix A, Communications with Imerys
Dyson Beasley	Quality Engineer	1.5, 1.6, 4.1, 4.6, 4.7, Appendix E
Tristan McMichael	Process Engineer	1.2, 1.4, 7.1, 7.2, 7.3, Appendix D
Ryan Waltman	Data & Financial Analyst	1.3, 1.7, 2, 3.1, 3.3, 5.1, 5.2, 5.3, 6.1, 6.2, 6.3, Appendix B, Appendix C, PowerPoint Presentation Formatting, Video Production, Communications with Professor

Appendix D: Quality Results

Tables 2 and 3 show the results from the quality testing of the initial datasets from 41.5 amps and 43 amps. The sample valve refers to the specific location the sample was taken from. In for both amperages, the samples were taken from along the product line. Each sample has a corresponding date and time attached to it. The feeder airlock % describes how much feed was flowing into TM81 at the time the sample was taken. Tube mill amps shows the amperage of the separator at the time of the sample. Mean particle size (MPS) reflects the average size of particles in a given sample in microns. This is directly tied to one of the quality metrics this project aims to improve. Mesh 325 represents the percent of material in a sample is above 45 microns. Color is the average brightness of a sample. Classifier blades describes the number of blades currently operating in the classifier.

Table 6: Raw Quality Data 41.5 Amps

Sample Valve	**Date**	**Time**	**Feeder Airlock %**	**Tube Mill Amps**	**MPS**	**Mesh 325**	**Color**	**Classifier Blades**
PG 81	8/25/2023	11:00	35%	41.5	7.2	16.2	92.3	30
PG 81	9/1/2023	11:29	35%	41.5	11.5	36.8	91.7	30
PG 97	9/18/2023	6:00 AM	35%	41.5	14.47	20.3		30
PG 98	9/18/2023	8:00 AM	35%	41.5	14.47	19.5	91.9	30
PG 99	9/18/2023	10:00 AM	35%	41.5	23.06	32.9		30
PG 81	9/20/2023	7:30 AM	35%	41.5	13.63	20		30
PG 82	9/20/2023	8:00 AM	35%	41.5	14.08	21.6	91.8	30
PG 83	9/20/2023	8:30 AM	35%	41.5	14.15	21.7	92	30
PG 84	9/20/2023	9:00 AM	35%	41.5	14.51	21.8		30
PG 85	9/20/2023	9:30 AM	35%	41.5	13.96	21.4		30
PG 87	9/20/2023	11:00 AM	35%	41.5	13.75	22.1		30
PG 88	9/20/2023	12:00 PM	35%	41.5	14.08	21.5	91.8	30

Table 7: Raw Quality Data 45 Amps

Sample Valve	**Date**	**Time**	**Feeder Airlock %**	**Tube Mill Amps**	**MPS**	**Mesh 325**	**Color**	**Classifier Blades**
PG 86	9/20/2023	10:00 AM	35%	43	14.28	23		30
PG 89	9/20/2023	12:30 PM	35%	43	16.62	22.6		30

PG 90	9/20/2023	1:00 PM	35%	43	13.83	22		30
PG 91	9/19/2023	8:00 AM	35%	43	14.18	21.3		30
PG 92	9/19/2023	10:00 AM	35%	43	15.15	21.6		30
PG 93	9/19/2023	12:00 PM	35%	43	27.98	35.4	91.5	30
PG 94	9/19/2023	4:00 PM	35%	43	13.71	20		30
PG 95	9/19/2023	8:00 PM	35%	43	34.25	39.5		30
PG 96	9/19/2023	12:00 AM	35%	43	26.43	34.9		30
PG 100	9/18/2023	12:00 PM	35%	43	43.5	45.1		30
PG 100	9/18/2023	6:00 PM	35%	43	13.49	21	92.1	30

Appendix E: Site Visit Notes

The following site visit summaries describe what has been learned, what data has been gathered, and the overall progress of the project by date.

Date: 9/01/23

Team in attendance: Dalton Beasley, Dyson Beasley, Tristan McMichael, and Ryan Waltman.

Imerys representatives: Chad Luther, Jeff Updike, Justin Bousfield, and Wilbel Brewer.

Overview: We set up a media and classifier blade inspection for 9/07/23. A rate check will be performed before Thursday to get a baseline on production now. 10 samples will be gathered before Thursday. After the inspection and samples, Tube Mill 81 amps will be increased from 41.5 amps to 43-44 amps. We will then in the following week gather 10 more samples and do another rate check. We will then compare the results with the baseline.

Date: 9/07/23

Team in attendance: Dalton Beasley, Dyson Beasley, Ryan Waltman.

Imerys representatives: Jeff Updike, Justin Bousfield, Chad Luther

Overview: We performed the media and classifier blade inspection on Tube Mill 81. The classifier blade inspection was done first, with 6 of the 36 blades found to be missing. This means 16.67% of the blades were missing. We found that adding the 6 missing classifier blades back into Separator 81 would increase the consistent quality of the product, while lowering the tons per hour by a certain amount. Our team will test to find out the quantitative quality improvement and the change in output once the classifier blades are installed. We then did the media inspection in Tube Mill 81. First, we measured the height to see if the media size had shrunk. Originally 48 inches of media was in the mill, but we measured 42 inches during our inspection. This means 6 inches of media had been lost since 2019. We then gathered a sample of 198 media balls into a 5-gallon bucket and measured their size. We found:

Table 8: Media Sample Data

Media Ball Size	# of Media Balls	% Make-up
0.50”	4	2.02%
0.75”	35	17.7%
1”	86	43.4%
1.25”	73	36.9%

Finally, we got some data on some of our past samples. We found that the quality was at 7.2 Microns and 11.5 Microns. This is under the specification of our 12-18 Micron range.

Date: 9/13/23

Team in attendance: Dalton Beasley, Dyson Beasley, Tristan McMichael, and Ryan Waltman.

Imerys representatives: Morgan Pendley, Wilbel Brewer, Justin Bousfield, Chad Luther

Overview: We set up a meeting with several managers and workers for September 20th to go over our findings and ask any questions we have. We will also bring up our solutions and see if they would accept some or all of them. We called up several media ball companies to find out what the optimal ratio, size, and amount of media balls in Tube Mill 81. We also found out that the starting particle size is 2500 Microns and as low as 10 Microns for when the product enters the Tube Mill. We then wrote up a document with our findings and our questions for the upcoming meeting.

Date: 9/20/23
Team in attendance: Dalton Beasley, Dyson Beasley, Tristan McMichael, and Ryan Waltman.
Imerys representatives: Jeff Updike, Wilbel Brewer, Jeffery Williams, and Morgan Pendley.
Overview: We held a meeting with managers and workers. First, we talked about the increases in the Separator Amps. We decided to increase the amps by 2 until the quality is below specifications. Before we increase the amps, we will collect 10 quality samples to make sure the quality is still within specifications. Next, we talked about the media. Imerys has decided to pay for the media replacement. We will find out the optimal ratio, size, and amount of media balls for Tube Mill 81 and then get a quote for purchasing them. Then, we talked about classifying blades. Imerys had already ordered 72 classifying blades for Tube Mill 81 and 82 on June 5.28th and that they should be here soon. The 6 missing blades will be added into Separator 81 once we receive the blades. This should give us a consistent quality. We also talked about increasing the airlock speed to increase our tons per hour, but it was not recommended to due to the possibility of choking the separator.

Dust Collector 88 was then talked about to see if we could reconnect it to Tube Mill 81 to remove any waste in the process. We received documents on DC88 and are planning with maintenance to see if it's possible to reconnect it. Jeffery Williams also brought up that we may need to increase our amps on the Blow Line. We will look into this to see if this will help with our tons per hour increasing. We discussed adding some slide gates into Tube Mill 81 in order to redirect the product if there isn't enough. We were told that this was possible, but that it wouldn't lead to an increase in TPH, but just a steadier rate. We then discussed a possible inspection in Bin 81 to see if there is any product caking on the walls to see if there is a blockage. We will do a Bin 81 inspection soon. For sampling, we decided on 10 samples per amp increase to make sure quality is in specifications. Finally, we discussed labor costs and project costs in order to start planning a ROI.

Date: 10/12/23
Team in attendance: Dalton Beasley, Dyson Beasley, and Ryan Waltman.
Imerys representatives: Jeff Updike and Daniel Wright.
Overview: The feed bin was cleaned out for Tube Mill 81 since it is a flat bottom bin that is prone to having the feed clog the bin and get caked on the walls of the bin. Cleaning the bin would allow the feed to go through easier and could help increase production by allowing more feed to go through. The feeder for Tube Mill 81 was also inspected and cleaned since it could have been clogged with feed too, this could help with getting more feed out also. We also will be discussing Dust Collector 88 to figure out a way to get it back online. This would help increase air quality, reuse waste in the process, and save money on contractors cleaning Tube Mill 81 and 82's area. The Classifier blades will be installed soon once they come in the next week or two. This will help increase the quality of the product.

Date: 10/19/23
Team in attendance: Dalton Beasley, Dyson Beasley, and Ryan Waltman
Imerys representatives: Jeff Updike and Daniel Wright
Overview: Inspected Separator 81 and Separator 82 for mechanical issues since of some recent quality issues. Separator 81 still has the 6 missing blades, has a small gash in lining, and the

product and reject side was not clogged as we thought. The small gash in the lining is too small to affect the quality or production but it will be monitored. Separator 82 is out of the scope of our project, but it was inspected at the same time. Separator 82 had a missing shelf on the bottom and a couple missing blades. After talking with Daniel and Jeff about the inspection, we came to the conclusion that the recent quality issues were operator error and not mechanical. The operators were overloading and underloading the mill so they will be reminded about the correct set points for the mill to run at.

Date: 10/20/23
Team in attendance: Dalton Beasley
Imerys representatives: Jeff Williams
Overview: Jeff and I attended a meeting with IKD to discuss a possible inspection and quote for linings. We went over what we were looking for in an inspection. IKD said they are willing to do an inspection, but they focus on the outside of the mill, the pipes, the dryers, and everything else in the process. They don't typically look on the inside of the mill. As of now, we agreed to get a quote for inspecting Tube Mill 81 and Tube Mill 82 on the outside to look for cracks, leaks, or anything else wrong with the Tube Mill process.

Date: 11/3/23
Team in attendance: Dalton Beasley, Dyson Beasley, and Ryan Waltman
Imerys representatives: Jeff Updike, Morgan Pendley, Wilbel Brewer, Jeff Williams
Overview: We met with management to show them the results of the project so far. Our team showed them our quality and production results for increasing the Tube Mill amps as well as the economic and environmental results we calculated. We then planned to install the missing fan blades in Separator 81 as they were arriving next week. Before leaving, our team also looked at more quality results for 43 amps.

Date: 11/15/23
Team in attendance: Dalton Beasley, Dyson Beasley, Tristan McMichael, and Ryan Waltman
Imerys representatives: Jeff Updike, Chad Luther
Overview: Separator 81's classifying blades were installed during this visit. We watched the installation of the six missing blades, along with the balancing of them. After this, Tube Mill 81 reset its amps to 41.5 to see a baseline after the installation of the new blades. A quality sample was taken to see how the quality was impacted by the addition of the six blades. We tested the sample at the quality lab and received a sample of 12.23 microns. This is still within specifications, and received the expected result that the microns would be smaller in comparison to the results with 6 missing blades due to the added blades rejecting more of the coarser material.