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Enhancing Customer Satisfaction in Iron Ore Sample Preparation: Laboratory Capabilities Assessment through Utilizing Overall Equipment Effectiveness (OEE) Case

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Abstract

This paper explores the operational efficacy of an Iron Ore sample preparation laboratory using the Overall Equipment Effectiveness (OEE) model. Addressing the discrepancy between the laboratory's production capacity and the client's expectation of reduced turnaround time, the study investigates the impact of operational inefficiencies on customer satisfaction. Employing a mixed-methods approach, the research combines quantitative data from a time and motion study with qualitative insights from interviews and observations. The findings reveal that by eliminating planned stops, an increased target of six batches per day could be achieved, enhancing the monthly output, and addressing the current backlog. Quality checks embedded in the Laboratory Information Management System (LIMS) ensured 100% process quality with no reworks observed during the study period. The study concludes that optimizing the performance metric across workstations is pivotal to improving productivity and overall operational efficacy, with the potential to reduce sample turnaround time significantly. Recommendations include comprehensive training for personnel, implementation of pre-emptive screen tests, and ergonomic adjustments to the equipment. For future research, the paper suggests comparative studies across diverse laboratory settings, the adoption of experimental designs for empirical validation of improvements, and the use of simulations and qualitative methods to predict outcomes and understand operational challenges comprehensively.

Keywords
Iron Ore Sample Preparation, Overall Equipment Effectiveness (OEE), Operational Efficiency, Customer Satisfaction

1. Introduction
According to Chen, Xu, and Yao (2022), the mining and metallurgy industries have always been essential components of the development of any civilization, even though they are classified as high-risk industries. According to Aguilar (2023), the mining and metals industry plays a significant role in a variety of socioeconomic systems. It is responsible for supplying essential materials for a variety of economic activities, including construction, transportation, and energy production (Aguilar 2023). The mining industry is widely considered to be the most significant source of revenue for a significant number of countries (Iatan 2021; Hussain et al. 2022). This indicates that there is a degree of satisfaction on the part of the customers involved. According to Mittal et al. (2021), businesses that sell their products or services to other businesses (B2B) invest a significant amount of resources to measure the level of satisfaction of their customers, but they do not receive adequate guidance on the implementation of satisfaction programs. Amin (2016) stated that customer satisfaction is the comparison result of customers' perceptions and expectations of services or products. As a result, it is essential to take note of the fact that Yang et al. (2023) reported that Amin (2016) described customer satisfaction accordingly.

Iron ore is the primary raw material from which metallic iron is extracted to produce steel (Holmes et al. 2022), a crucial element in various industries including construction, shipbuilding, motor vehicle manufacturing (Shin and

Ciccantell 2009; Liu et al. 2017), and more (Chen et al. 2019). Proper sample preparation is vital; if the samples are not prepared properly or if there is cross-contamination, the results will be compromised. In the context of mining, the importance of sample preparation is fundamentally linked to the quality and reliability of the outcomes derived from analyzing geological samples, independent of the specific analysis technique used, according to Somarin (2013).

The research delves into the operational processes of an Iron Ore sample preparation laboratory, focusing on the overall resource effectiveness, including the evaluation of all equipment and manpower used per hours available for production time. The laboratory is crucial in the metallurgical industry, receiving approximately 2500 samples monthly and working on 7.5 hours shift, five days per week, with an additional two Saturdays of overtime per month. The current target is to prepare five batches per day, which implies a normal production of 2200 samples per month and 2420 samples per month with two Saturdays of overtime worked. However, this falls short of the 2500 samples expected by the laboratory's clients. The residence time of batches before processing is between 30 to 36 days, making the total turnaround time approximately 52 days on average. The clients have requested a reduction in the turnaround time to at least 30 days, necessitating a 40% performance improvement.

The research employs the Overall Equipment Effectiveness (OEE) model, a globally accepted standard for measuring productivity, to quantify the results (Choi 2018). Ideal or 100% OEE means that only good products have been produced as fast as possible, without stopping times (Performance Storyboard 2018). The study aims to arm the laboratory with valuable information to affect total productivity by changing or improving one of the variables of OEE, such as Availability (A), Performance (P), or Quality (Q).

1.1 Research Aim, Objectives, and Questions

This study's primary objective is to carry out a comprehensive investigation into the operational procedures that are carried out within a laboratory that is dedicated to the preparation of iron ore samples. The purpose of this research is to identify areas of inefficiency, bottlenecks, and areas that require improvement to maximize the utilization of resources, increase productivity, and decrease turnaround times, ultimately leading to an increase in overall customer satisfaction.

The following major research questions, also known as RQs, serve as the focal point of the investigation: (RQ1) What are the operational inefficiencies and bottlenecks that are currently present within the laboratory? What are some strategies that can be implemented to reduce turnaround times and meet the expectations of customers? (RQ2) How can the processes in the laboratory be optimized to improve resource utilization and productivity? (RQ3) What different strategies can be implemented?

Following are the research objectives (ROs) that have been developed based on the research questions that were presented earlier: (RO1) To conduct a comprehensive analysis of the operational procedures of the laboratory in order to identify inefficiencies and bottlenecks; (RO2) To evaluate the utilization of the laboratory's resources and productivity; and (RO3) To develop suggestions for optimizing the processes, improving the utilization of resources, and reducing the turnaround time.

1.2 Significance of the Study

The significance of this study lies in the fact that it provides a comprehensive analysis of the relationship between customer satisfaction, loyalty, product knowledge, and the competitiveness of businesses. It sheds light on how these factors, when combined with an in-depth understanding of the customer, can optimize business operations, reduce production losses, improve product quality, and cut manufacturing costs, all of which have a direct impact on the competitive position that a company holds in the market. This research is especially important for laboratories that want to reduce turnaround times and improve the quality of their results, consequently increasing the level of satisfaction experienced by their customers. On the other hand, its implications are not limited to laboratories; rather, they provide valuable insights for a wide variety of professional organizations. This study provides a road map for businesses to follow to meet the needs of their customers, maintain their market competitiveness, and make smart strategic decisions more effectively. It does this by integrating customer-centric strategies with operational efficiency.

1.3 Scope and Limitations of the Study

Specifically, the scope of the research is limited to the investigation of the operational procedures that take place within a laboratory that prepares samples of iron ore. The purpose of this investigation is to identify areas of operational inefficiency, assess the utilization of resources, and develop recommendations for improvements that are methodical in nature. It is important to note that the scope of this study is limited; it does not include the actual implementation of these recommendations, nor does it engage in an evaluation of the subsequent impact that these recommendations will have on the operational dynamics of the laboratory.

A particular emphasis on a particular laboratory setting is one of the limitations of the study. This is one of the distinguishing characteristics of the study. Given the specificity of the findings, it is inherently difficult to extrapolate them to a wider variety of laboratory environments. Furthermore, the methodological approach that is being utilized in this research is limited to the examination of operational procedures that are already in place. Consequently, the scope to empirically validate the efficacy of the suggested improvements is restricted because of the fact that it does not incorporate experimental methodologies.

2. Literature Review

2.1 Iron Ore Sample Preparation – An Overview

Steel, which is an alloy of carbon and iron, continues to play an important role in the economy of the entire world due to the exceptional qualities that it possesses, including its strength, formability, flexibility, recyclability, and low cost (Bustillo Revuelta 2021). The construction industry, shipbuilding, automobile manufacturing, railway construction, bridge building, heavy industry, machinery manufacturing, and engineering applications are just some of the many industries that make extensive use of it (Bock 2006; Cigolini et al. 2020; Fu and Kaewunruen 2021). Iron ore, which is the primary raw material for the extraction of metallic iron, is an essential component in the manufacturing of steel (Olade 2019).

According to the International Energy Agency (IEA 2020), the significant increase in the production of crude steel over the past twenty years has led to a significant increase in the global output of iron ore (Fan and Friedmann 2021). This is evident from the fact that the production of crude steel has increased significantly. This increase in production is in line with the growing demand from major consumers such as China. The data on China's imports in 2021 provide a striking illustration of this trend. The nation imported the highest dollar value worth of iron ore from leading suppliers, with Australia leading the pack with a total volume of US$105.7 billion (Workman 2021). This represents a 49.2% increase from the year 2020. It was also important to note that Brazil, South Africa, and India were among the other major suppliers. As a group, these 15 countries were responsible for 98.6% of the iron ore that China imported in 2021 (Workman 2021). This reflects China's dominant position as the primary consumer in the global iron ore market (Yermolenko 2023). In addition to highlighting the interconnected nature of global iron ore supply chains and their responsiveness to the demands of the steel production industry, these data not only emphasize the significant role that China plays in the iron ore industry but also highlight the interconnected nature of their supply chains.

During this process, the preparation of the samples is an essential step. An inadequate or improper preparation, as well as the cross-contamination of samples, can significantly compromise the results that are ultimately obtained. The most recent research in the field of iron ore processing has concentrated on the development of new processing techniques to address these challenges. These techniques aim to ensure sample preparation methods that are more reliable and efficient. Several studies have investigated the possibility of enhancing the quality of iron ore lumps and fines through the application of high-temperature reduction treatments (Wan et al. 2021; Prasad et al. 2022; Wei et al. 2022; Legemza et al. 2023). Moreover, there is a particular emphasis placed on the utilization of catalysts derived from iron ore to produce hydrogen and other byproducts (Qian et al. 2020; Aravindan et al. 2023), which is indicative of a shift toward processing methods that are more environmentally friendly and add value (Zhang et al. 2024).

In the realm of mineral processing, particularly concerning iron ore, sample preparation emerges as a critical step to ensure the accuracy and reliability of subsequent analytical processes. The literature emphasizes the significance of automated sample preparation methods. These methods, which include automated crushing and milling, are designed to achieve a consistent, fine particle size, essential for accurate X-ray fluorescence spectrometry (XRFS) analysis of iron ore (Hofmeyr and Valentin 2010). The uniformity in particle size attained through such automated processes is key to ensuring representative samples that accurately reflect the composition of the larger ore body, a factor pivotal for reliable decision-making in mining operations (Hofmeyr & Valentin 2010). Furthermore, Poojari et al. (2023) delves into the various characterization techniques integral to understanding the mineralogical, chemical, and physical properties of iron ore. Techniques such as Scanning Electron Microscopy (SEM) for micro-morphological examinations and X-ray Diffraction (XRD) for chemical investigations are highlighted. The comprehensive analysis involving a combination of these techniques is deemed crucial for a thorough understanding of ore characteristics, which is essential for effective ore processing (Poojari et al. 2023).

To ensure that personnel are not subjected to an excessive amount of pressure, it is essential that methods for improving sample preparation are identified and successfully implemented. It is of the utmost importance to preserve the quality of the craftsmanship, as any compromise in this area can result in unreliable outcomes, which in turn can have an impact on the overall efficiency and sustainability of the steel production process.

2.2 Customer Satisfaction

Customer satisfaction is not limited to merely satisfying the fundamental needs of customers; rather, it encompasses the creation of a positive experience that has the potential to result in long-term success for the business and loyalty from customers. Over the course of several decades, this subject has been investigated and discussed in depth. According to the definition provided by Gajewska et al. (2019), customer satisfaction is a measurement of the degree to which the products or services offered by a company can meet or exceed the expectations of the customer. According to the findings of Maharsi et al. (2021), customer satisfaction is an essential indicator of consumer retention and intentions to make future purchases. Kotler et al. (2019) state that customer satisfaction can be defined as a feeling of happiness or disappointment that arises because of comparing the performance of a product to the expectations that were set for it. This definition is based on the findings of the aforementioned researchers. Additionally, Kotler et al. (2019) state that customer satisfaction is comprised of an evaluation of the products or services that are being provided, which provides a level of satisfaction that is associated with the fulfillment of needs. According to Hasfar et al. (2020), this level of satisfaction can range from meeting to exceeding the expectations of the customer regarding the quality of service provided. In addition, customer satisfaction is an essential component of a company's overall strategy, serving as a fundamental component that can be responsible for the generation of profits and the development of brand ambassadorship (Basari and Shamsudin 2020; Azlan Bin Hamzah and Farid 2020). In addition, Wulandari (2022) highlights the significance of customer satisfaction in the delivery of excellent services, highlighting the central role that it plays in the achievement of business success.

Numerous studies have been conducted all over the world to investigate the factors that contribute to increased levels of customer satisfaction and loyalty, as well as product knowledge and competitive ability. Customer satisfaction and loyalty are the relationships that are typically the subject of the most research (Fornell et al. 1996; Türkyilmaz and Özkan 2007). According to El-Diraby et al. (2006), over the course of time, these two variables have been supplemented by the factors of business competitiveness. Later, these two factors were supplemented by business competitiveness (El-Diraby et al. 2006), and more recently, comprehensive knowledge (of the customer) (Aghamirian et al. 2015; Suchánek and Králová 2019). In studies that were conducted more recently, Sastra and Baihaqi (2021) highlight the significance of product quality in driving customer satisfaction. In addition, they highlight the nuanced role that relational benefits and service quality play in influencing customer loyalty. According to the findings of another study conducted by Djunaidi et al. (2021), the importance of multiple aspects of the customer experience in driving satisfaction and, as a result, loyalty is demonstrated. This suggests that increases in customer satisfaction are likely to lead to higher levels of loyalty, and vice versa.

Productivity is something that needs to be optimized and improved for businesses to avoid unplanned production losses and get rid of defects. This results in an increase in the product's quality, which, in turn, reduces the costs of manufacturing, assists in meeting the requirements or specifications of the customer, and helps the company maintain its competitive position in the market (Ross 2017). For the laboratory to maintain its competitive edge and ensure its continued existence, the statement that was just presented highlights how essential it is for the laboratory to conduct this study.

2.3 Overall Equipment Effectiveness (OEE) Matrix

Because of both planned and unexpected process losses, it is impossible for the equipment to operate at 100% capacity and at maximum capacity while maintaining a high level of output quality. However, the directors of the company and other interested stakeholders, such as customers, want this to be the case. According to the Japan Institute of Plant Maintenance (JIPM), Total Productive Maintenance (TPM) is a method that aims to enhance the efficiency of machines by utilizing the total equipment effectiveness matrix (Jain et al. 2015).

Performance, availability, and quality are the three components that are utilized in the OEE, which is a method that is utilized to assess the overall effectiveness of equipment in terms of their productivity as described in a 2015 publication by Domingo and Aguado or as Tobe et al. (2017) put it "a procedure that is utilized for the purpose of determining the effectiveness of an equipment by utilizing three different elements of measurement, namely the performance rate, the availability rate, and the quality rate". This details the remedial procedures that need be followed to eliminate the possibility of losses and identifies the probable losses that might occur. Díaz-Reza et al. (2022) cite the following among the benefits of OEE: (1) A reduction in defects, reworks, and scrapping of batches, which ultimately leads to a rise in both productivity and quality; (2) Determines all the processes in which there are bottlenecks, which ultimately results in increased production; (3) Because of fewer reworks, the costs of maintenance and the amount of time machines are offline have dropped, which has led to an increase in the life cycles of machines and (4) Increases the effectiveness of the use of personnel, which in turn leads to increased profits.

It is essential to identify and get rid of waste and loss to achieve higher levels of production. As part of the process of maintaining machinery or equipment, Total Productive Maintenance (TPM) is one method that may be utilized in conjunction with OEE as noted Jin et al. (2016). OEE has been applied in a few research studies (Choi 2018; Herry et al. 2018; Prabowo et al. 2016), and it has been demonstrated to be a significant improvement in terms of productivity. According to Jonsson and Lesshammar (1999), it is an all-encompassing capability measuring method that is directed from the center outward.

2.4 Quantification of results by Overall Equipment Effectiveness (OEE) Matrix

According to Nakajima (1988), OEE is calculated as the ratio of Fully Productive Time (only good counts produced) to Planned Production Time represented by the expression below:

$$\text{OEE} = \frac{(\text{Good Count} \times \text{Ideal Cycle Time})}{\text{Planned Production Time}} \tag{1}$$

The mentioned formula does not provide information about the three main loss related factors, namely: Availability, Performance, and Quality. Thus, the preferred expression as formulated by Tsarouhas (2019a):

$$\text{OEE} = \text{A} \times \text{PE} \times \text{Q} \tag{2}$$

Where:

- A: Availability Rate which accounts for all significant stops like equipment failure/breakdown losses and set-up and adjustment losses or also known as uptime, often referred to as the amount of time that the machine is available to be used (Hazza et al. 2021), and it is expressed as:

$$\text{Availability Rate} = \frac{\text{Run Time}}{\text{Planned Production Time}} \times 100 \tag{3}$$

- Run Time is simply Planned Production Time less Stop Time, where Stop Time is defined as all-time where the manufacturing process was intended to be running but was not due to Unplanned Stops (e.g., Breakdowns, incidents) or Planned Stops (e.g. meetings) (Murugesan et al. 2018).

$$\text{Run Time} = \text{Planned Production Time} - \text{Stop Time} \tag{4}$$

- P: Performance - Performance Efficiency can be affected by minor stoppage losses, reduced speed losses and idling, anything that affects the process to run at less than the maximum possible capacity or speed (Jonsson and Lesshammar 1999; Tsarouhas 2019b).

$$\text{Performance} = \frac{\text{Ideal Cycle Time} \times \text{Total Count}}{\text{Run Time}} \tag{5}$$

- Q: Quality - Quality Rate accounts for rework, rejection, and start-up losses. OEE Quality is like First Pass Yield, in that it defines Good Parts as parts that successfully pass through the manufacturing process the first time without needing any rework or without defect (Singh et al. 2018):

$$\text{Quality} = \frac{\text{Good Count}}{\text{Total Count}} \tag{6}$$

The world class OEE is 85% which means 99% Quality, 95% Performance and 90% Availability (Singh et al. 2018; Hazza et al. 2021).

3. Research Methods

3.1 Research Approach

Yin (2018) explains that a mixed methods research approach provides the researcher with the opportunity to evaluate all aspects of the subject matter, which allows for the achievement of detailed results as well as the formation of an objective evaluation and recommendation regarding the research, hence it was the method chosen by the researchers. As a quantitative research methodology, a descriptive method approach was taken using a questionnaire. Participants were given the opportunity to select an answer that applied to them more personally. In addition, observations and interviews were used to collect qualitative data, which was then used to provide a clear explanation of the quantitative data obtained from the surveys and to strengthen the findings.

3.2 Data Collection

According to Taylor (2018), the data collection process must be objective (i.e., free of bias) and accurate. As a result, the method that was utilized in the data collection process is the most important factor to consider when calculating the OEE percentage value. Because of the mixed method that was used for data collection during this project, the quantitative data was collected using the survey. Subsequently, qualitative data was collected through the observation of processes during normal production while timing all of the tasks that were involved.

The study had 17 employees and a sample size of 15, including 14 technicians and a supervisor who manages processes, evaluates results, and manages manpower. To eliminate bias and identify outliers, the sample size includes at least three technicians who are interviewed, observed, and timed for each workstation. One outlier will be considered, but if all three data sets are unrelatable, the study will be considered inconclusive until conclusive results are obtained through repeated data collection. A three-week (15-day) period was allocated for each workstation to ensure interaction with at least three technicians due to weekly rotation. The areas of work were observations were conducted were (1) sample reception, (2) crushing, (3) coarse splitting, (4) milling, and (5) micro splitting as detailed in Figure 1.

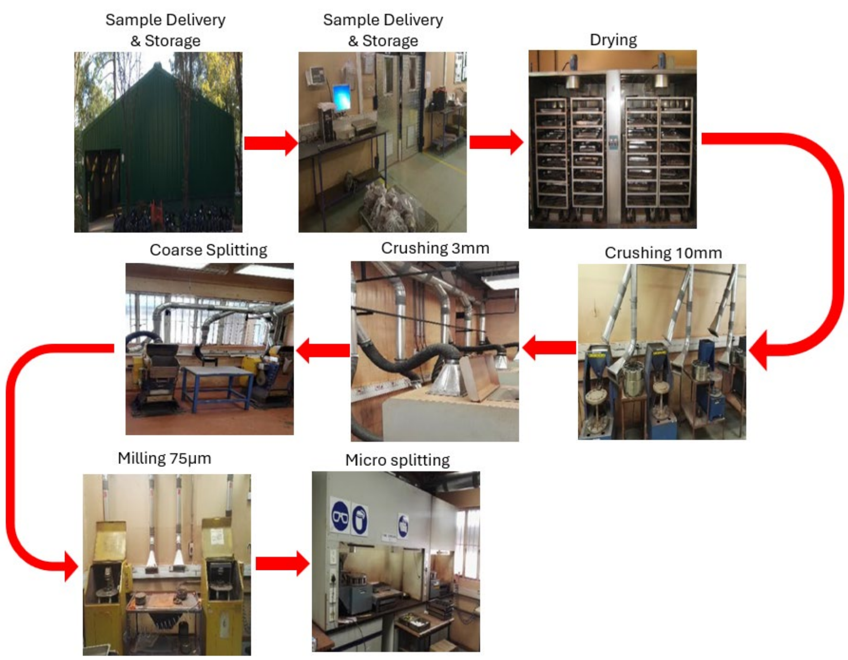

Figure 1. Work Areas

For quantitative data, an interview-style questionnaire was used to measure elements on a Likert scale. Five anchor points (1= strongly disagree, 2= disagree, 3= neutral/uncertain, 4= agree, 5= strongly agree) were used to assess manpower perceptions (Sekeran et al., 2013; Sullivan and Artino, 2013) with regards to the questions below in Table 1.

While for qualitative data, in-situ data was collected through observations using all senses: hearing, touching, seeing, and smelling. The researcher can gather perceptions, memories, and feelings of employees, as well as observe culture, relationships, time management, communication styles, and backlog areas (Paradis et al. 2016). Combining a standardized questionnaire and interviews allowed researchers and responsible staff to discuss potential improvements and obstacles that may not be apparent due to limited time and experience.

Table 2. Questionnaire

Questions	Description
Q-1.	Well-trained for my job.
Q-2.	I can handle all tasks.
Q-3.	The SOP is simple to follow
Q-4.	I can easily achieve the current target.
Q-5.	With current resources, I can exceed the current target.
Q-6.	It feels overwhelming to meet the current target.
Q-7.	Improved resources can increase production beyond the current target.

3.3 Data Analysis

Data from questionnaires, timed time, and motion study were in a Microsoft Excel spreadsheet. OEE calculations were based on quantitative measurements from all machines used over time. Machine downtimes were recorded using a computer and operator assistance, as recommended by Ahmad et al. (2015). Data from questionnaires and interviews was analyzed using a descriptive approach, dividing responses by age and experience level. Data analysis was presented using frequency tables and plots in a clear and easy-to-understand format. Using a Cause-Effect diagram and five (5) whys root cause analysis tools, we identified the root cause of OEE losses on machines, processes, manpower, methods, and materials, and developed corrective actions and recommendations.

3.4 Validity and Reliability

Data validity and reliability are crucial in any study. Validity improves employee communication, especially when responding to production process deviations, according to Graban and Toussaint (2018). This concept refers to how well measured scores represent the intended variable. Connell et al. (2018) define three types of validity: face validity, where experienced people apply their knowledge to the study; content validity, which concerns the measure's simplicity and clarity; and criterion validity, which is established by statistically significant relationships between a measurement and a criterion. This project assessed criterion validity using Pearson correlation.

The data was collected using a concise, non-biased, direct closed-ended questionnaire. Participants could remain anonymous, encouraging honest responses without fear of victimization. Each questionnaire required one correct answer.

According to Surucu and Maslakci (2020), reliability is a measure's consistency over time, across items, or across researchers. Olayinka and Abideen (2023) describe these consistency types. This study used test-retest reliability to compare data from a group at two times. Reliability is usually assessed using a scatterplot and Pearson's r, which should exceed 0.8.

4. Results and Discussion

4.1 Questionnaire Results

The study included 15 participants of various ages and experience levels and detailed their task distribution within a workflow. The sample ranged in age from 7% under 20 to 13% over 50, with 33% in the 31–40 age group as shown in Figure 2. The range of experience, as depicted in Figure 3, was less than a year to over 15 years, with 40% falling within the 6 to 10 years category, indicating this was the most common level.

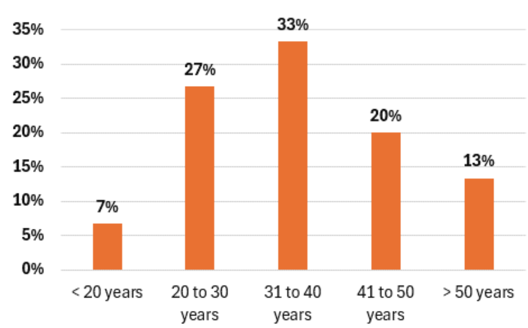

Figure 2. Age of Participants

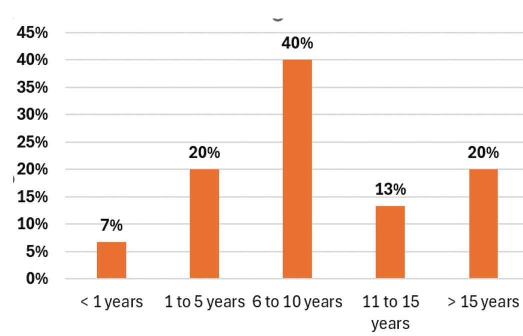

Figure 3. Age of Participants

Figure 4 shows study participants' percentages in five work areas. Sample Reception is the least represented area, with 13% of 14 participants, or 2 people. Crushing and coarse splitting each have 20% of participants, or 3 per area. Milling, the largest segment, employs 27% of participants, or 4 people. Micro Splitting accounts for 20% of the sample, or 3 participants.

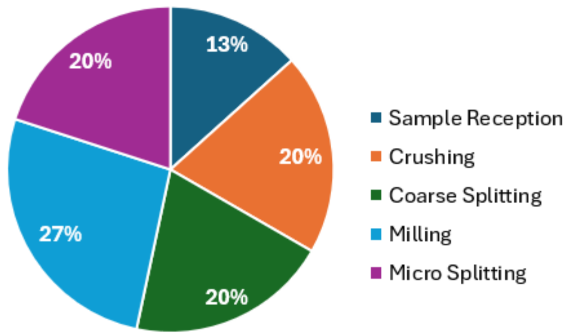

Figure 4. Participants per Work Area

Table 2. Questionnaire Response – Means and Standard Deviations

Questions	Description	Mean	Std. Dev.
Q-1.	Well-trained for my job.	4,33	1,0541
Q-2.	I can handle all tasks.	4,40	1,0876
Q-3.	The SOP is simple to follow	4,80	0,8485
Q-4.	I can easily achieve the current target.	2,73	0,7424
Q-5.	With current resources, I can exceed the current target.	1,40	0,9320
Q-6.	It feels overwhelming to meet the current target.	3,40	1,2917
Q-7.	Improved resources can increase production beyond the current target.	4,13	1,2920

Table 2 reflects the perceptions of the 15 employees sampled in the study, which includes 14 technicians and a supervisor, about their work, training, and resources. The questionnaire used a five-point Likert scale for assessment, with higher scores indicating stronger agreement with the statements provided.

Employees feel well-prepared for their roles, as indicated by the high means for questions Q-1 (4.33), Q-2 (4.40), and Q-3 (4.80), which suggest that they believe they are well-trained, can handle all tasks, and find the Standard Operating Procedures (SOPs) easy to follow. The relatively low standard deviations for Q-1 (1.0541), Q-2 (1.0876), and especially Q-3 (0.8485) imply a consensus among the technicians and the supervisor on these points.

However, the lower mean scores for Q-4 (2.73) and Q-5 (1.40), along with the modest standard deviations (0.7424 and 0.9320, respectively), indicate that employees feel less confident about achieving and exceeding the current targets with the resources provided. This is further supported by the mean score for Q-6 (3.40), which suggests a neutral to slight agreement that meeting the current target feels overwhelming and is reinforced by the highest standard deviation in the set (1.2917), indicating more variability in responses.

The relatively high mean score for Q-7 (4.13) with a corresponding high standard deviation (1.2920) reveals a belief among employees that improved resources could enhance production capability, although opinions vary to a greater extent on this matter.

5.2 Results from Observations

The time and motion study presented in the results delineates a meticulous observation and analysis of the sample preparation process, drawing on a detailed examination of each step from sample reception to micro splitting. The study finds that with current planned stops removed, there is an 86 to 90.45% availability for production per month as shown on Table 3.

Table 3. Planned Production time, Runtime and Availability

Day	Run Time (minutes), For 3 weeks in a month	Stop time (minutes)	Availability (%)	Run Time (minutes), For 1 week in a month	Stop time (minutes)	Availability (%)
Monday	405	45	**90.00**	405	45	**90.00**
Tuesday	385	65	**85.56**	345	105	**76.67**
Wednesday	405	45	**90.00**	405	45	**90.00**
Thursday	345	105	**76.67**	345	105	**76.67**
Friday	405	45	**90.00**	405	45	**90.00**
Saturday	405	45	**90.00**	405	45	**90.00**
Total for Mon to Fri	1945	305	**86.44**	1905	345	**84.67**
Total for Monday to Saturday	2350	350	**87.04**	2310	390	**85.56**
Total Monthly data for Mon to Fri	7740	1260	**86.00**			
Total Monthly Data for Mon to Saturday	8955	1440	**90.45**			
Planned production Time/day	450					
Planned production Time/week Mon to Fri	2250					
Planned production Time/week Mon to Sat	2700					
Planned production Time/month Mon to Fri	9000					
Planned production Time/month Mon to Sat	9900					

Notes:

- Run Time = Planned Production Time − Stop Time
- $\text{Availability} = \frac{\text{Run Time}}{\text{Planned Production Time}}$
- For Monthly data, Mon to Sat includes only 2 Saturdays worked overtime

In the study, meticulous time and motion analyses were conducted across various workstations, revealing insights into operational efficiencies and potential areas for improvement.

- **Sample Receipt and Drying**: Data indicated an average processing time of nearly 2 minutes per sample. The calculated average batch time closely matched the observed time, suggesting consistency in operations. The sample receiving area's Overall Equipment Effectiveness (OEE) stood at 65.9%, with the remaining time identified as potential for process optimization.
- **Crushing**: The crushing process, involving jaw and Boyd crushers, showed variations in time efficiency. While jaw crushers averaged 25 minutes per batch, Boyd crushers took almost double that time. Utilizing all available crushers could significantly enhance productivity.
- **Coarse Sample Splitting**: The splitting process took an average of 8 minutes per sample from start to end. The daily output fluctuated depending on the day of the week, with potential to increase the batch production and improve the OEE.
- **Sample Milling**: Milling required approximately 18 minutes per sample, including pot cleaning and bagging. The possibility of producing up to six batches per day per technician was explored, which would increase monthly output and improve the overall OEE by 14%.
- **Pulped Sample Micro Splitting**: Initially, micro splitting presented as a bottleneck, with observations indicating that the targeted batch production was not being met. However, further analysis suggested that with optimal time management, improvements in performance and OEE could be achieved.
- **Entire Process Time Average**: The comprehensive process from receipt to the completion of a packed pulp sample took an average of 38 minutes, with the first sample necessitating approximately 63 minutes due to additional preparation and quality control steps.

6. Conclusion and Recommendations

Production availability ranges from 76% to 90% daily, averaging 84% to 86% from Monday to Friday and increasing slightly on Saturdays. Monthly, availability stands at 86% for regular weeks and 90.5% with two Saturdays of overtime. Consistently achieving the 100% quality target, the study suggests that minimizing production stoppages could further enhance productive hours, a factor for management to consider. Varying performance across workstations suggests that increasing daily batch targets to six could significantly exceed monthly production expectations and expedite backlog clearance, potentially reducing the turnaround time from 52 to 44 days and improving operational efficacy.

Management should use a holistic approach to improve resource utilization, productivity, and workplace safety. To strengthen operational foundations, auxiliary staff receive in-depth sample reception and storage training. To avoid batch reprocessing and comply with Standard Operating Procedures, proactive screening tests should be performed after crushing and milling. These tests align equipment use with quality control standards and LIMS documentation. Ergonomics should be incorporated into technician training to reduce workplace injuries. Increasing worker safety by improving PPE handling, cleaning, and replacement instruction is also recommended.

Furthermore, milling pot washing stations can be made more ergonomic by adjusting the basin height or installing adjustable units to accommodate the average technician. Post-processing sample sequential integrity improves productivity and prevents sample mix-ups, which can cause operational redundancies. For optimal micro-slitting performance, staff should be strategically assigned. Observational data suggests that reallocating resources to allow each technician to manage three batches may increase milling and crushing throughput.

A pilot test should be done before any operational changes to ensure that theoretical improvements are practical. Shared observations between supervisors and technicians can help identify and fix operational bottlenecks. These suggestions optimize resource deployment, improve production workflow, and create a safer, more efficient workplace.

To improve generalizability, future research should compare experiments in different labs. Using experimental designs will help validate operational improvements. Qualitative methods may reveal subjective operational challenges, while simulations may predict change outcomes. These methods will assess laboratory efficiency improvements' applicability.

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