ENHANCING BOILER EFFICIENCY: STRATEGIES TO OPTIMIZE AVAILABILITY, PERFORMANCE, AND QUALITY IN THE FOOD AND BEVERAGE INDUSTRY

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ABSTRACT: The industrial manufacturing sector faces the dual challenge of meeting increasing global market demands while ensuring consistent, high-quality outputs, which is particularly critical in the food and beverage industry, where product consistency and quality are non-negotiable. Maintaining the efficiency and effectiveness of production equipment is imperative to address these challenges and is the cornerstone for optimising productivity. This study presents a novel approach by combining the analysis of factors affecting productivity with the application of Overall Equipment Effectiveness (OEE) as a comprehensive metric. OEE evaluates equipment performance through three key dimensions: availability, performance efficiency, and product quality. This study utilises qualitative and quantitative research methods to explore these factors in-depth. Qualitative methods include data collection via worker interviews, questionnaires, and literature reviews supported by theoretical and experiential evidence. Quantitative analysis employs statistical tools and measurable data validated through case studies in selected companies. The findings reveal unique insights: while performance efficiency achieves an exceptional 100% and quality rates are sustained at an impressive 98.12%, equipment availability lags at an average of 52.15%, signalling substantial room for improvement. These results underscore the need for targeted interventions to enhance equipment availability through optimized maintenance schedules, machinery upgrades, and refined operational processes. Additionally, minor quality-related issues can be addressed to improve the quality rate efficiency. This study identifies critical factors impacting productivity in the food and beverage industry. It introduces actionable recommendations for enhancing equipment effectiveness, paving the way for future research and practical advancements in industrial manufacturing.

KEYWORDS: *Availability; Performance; Quality; Root Cause Analysis; Manufacturing Productivity*

1.0 INTRODUCTION

We have been reflecting on how customers constantly seek high-quality products at affordable prices in today's globalized world [1]. Navigating the complexities and uncertainties of ever-expanding global markets and operations presents challenges and opportunities. The dynamic nature of consumer expectations requires constant adaptation, making the management of production lifecycles and manufacturing processes a sophisticated and evolving endeavour. This study introduces a novel perspective by focusing on how advanced methodologies, such as Total Productive Maintenance (TPM) and OEE, can address these challenges, offering actionable insights to harmonize efficiency, quality, and productivity in a competitive global landscape. Normally, a manufacturing company aims to produce products at low production costs and good quality standards [2]. It is a delicate balance, but achieving it is crucial to stay competitive.

One key insight that emerged is the critical role of accurate performance measurement in long-term equipment effectiveness monitoring. Precise and reliable performance metrics highlight areas for improvement and serve as a foundation for driving efficiency and fostering innovation. Businesses can leverage this data to enhance productivity, deliver superior products, and elevate customer satisfaction. This perspective underscores the interconnected challenges and opportunities organisations face in their pursuit of operational excellence, providing a novel approach to aligning precision measurement with strategic goals for sustainable growth.

Zubair et al. [3] stated that the TPM concept provides an evaluation metric for equipment performance. The principles of TPM OEE serve as a versatile tool for quantifying productivity by identifying and addressing equipment-related losses. While rooted in TPM's foundational framework, OEE introduces a flexible and customizable approach, allowing modifications to adapt to specific operational needs. Despite these adaptations, the 'Six Big Losses' core concept remains integral, systematically categorizing equipment inefficiencies. This study highlights the novelty of integrating traditional TPM principles with modernized OEE methodologies to offer a more tailored and effective strategy for optimizing equipment performance and overall productivity.

The productivity standards of equipment should achieve an availability of 90%, a performance rate of 95%, and a quality rate of 99%, which could result in an OEE rate of 85%, the world standard performance [3]. Consequently, this study aims to optimise production productivity by enhancing OEE in the manufacturing industry [4].

The main objective is to ensure that the manufacturing industry optimises its production productivity with OEE enhancement, as stated below:

i. To identify the factors that affect production productivity in the manufacturing industry,
ii. To measure the OEE of equipment in the manufacturing industry,
iii. To propose an action to improve equipment performance in the manufacturing industry.

1.1 Understanding Performance Measures

Companies compete to gain control of the global market and gain profit [5]. A manufacturing company uses raw materials to efficiently produce an end product of the best quality in a cost-effective, safe, and environmentally friendly manner. Companies should implement the standard procedures, training, empowerment, and communication that improve the companies [6]. Jain et al. [7] agreed that formulated productivity is the input and output coefficient ratio that changes over time. Due to high demand, the global marketplace has observed growing pressure amongst customers and competitors in the manufacturing sector [8].

The performance measurement compares different types of organization performance in the same field, departments, project teams, and individual assessment [8]. The performance of a firm or company is based on the financial statement [10]. Having control over the lead time of a manufacturing process would certainly create positive outcomes that contribute to a successful business establishment [11].

The novelty of understanding performance measures lies in its practical, data-driven approach to applying established methodologies like OEE while addressing the challenges of global market demands and incorporating modern tools and technologies. This perspective bridges the gap between theoretical frameworks and their real-world applicability in enhancing manufacturing productivity.

1.2 A Tool to Measure Performance

The performance of a manufacturing process requires a proper evaluation matrix to provide evidence that a process is done with optimal input and maximum output. The overall production cost could be attributed to the production losses, known as the hidden cost [2]. OEE is a tool that measures the productivity of individual equipment in the factory, which is done in a quantitative matrix form to assess the TPM concept [3]. The main goal of an OEE is to achieve an ideal equipment performance. The Japanese have developed an innovative concept called TPM, a maintenance program to increase production efficiency, employee morale and job satisfaction. The goal is to achieve a smooth production line without interruption [3]. The major goals of TPM are zero breakdowns, waste, and downtime. The eight pillars are used as a standard practice of TPM implementation to achieve these goals.

1.3 The Six Big Losses

Each type of loss found during the manufacturing process can be categorized according to the occurrence frequency [12] and defined as follows:

i. Equipment failure and breakdown losses,
ii. Adjustment time loss during production,
iii. Idling and minor stoppages,
iv. Reduced machine speed,

v. Yield reduction,

vi. Quality defects that require rework.

Firstly, the availability element is based on total stoppage time, accumulated from unscheduled downtime, process set-up time, changeovers, and other unplanned downtime [13]. The availability % is calculated using Equation 1.

$$\text{Availability\%} = \frac{\text{Actual Operating Time (mins)}}{\text{Planned Operating Time (mins)}} \times 100\% \quad (1)$$

Next, the actual speed to ideal speed ratio must be known to calculate the performance rate. Glock and Grosse [14] claimed that the performance rate calculation is based on the deviation of the production rate from its planned rate. Therefore, the Performance % is obtained using Equation 2.

$$\text{Performance \%} = (\text{Net Operate Rate} \times \text{Operate Speed Rate}) \times 100\% \quad (2)$$

Finally, the quality rate is measured by indicating the proportion of defective quantity with the total production volume [15]. The Quality % is calculated using Equation 3:

$$\text{Quality\%} = \frac{(\text{Total No. Produced - No. of Scrapped})}{\text{Total No. Produced}} \times 100\% \quad (3)$$

The OEE value can be calculated after obtaining all element values that measure the losses categorized from the Six Big Losses. OEE requires a detailed and accurate measurement of the Six Big Losses parameters. The OEE rate determines the different standards and state of productivity reduction using Equation 4:

$$\text{OEE \%} = \text{Availability\%} \times \text{Performance\%} \times \text{Quality\%} \quad (4)$$

The OEE measurement determines the equipment's effectiveness. The OEE results have a value range indicating whether the effectiveness is in poor, average, good, or world-class standards. Prasetyo and Veroya [14] stated that the value of OEE elements, such as availability, performance rate, and quality, should be more than 90%, 95%, and 99%, respectively [14].

In this study, the significant area that warrants further investigation is the practical implementation and application of OEE. While numerous previous studies have explored the theoretical aspects and benefits of OEE, there is a lack of in-depth exploration of the real-world challenges

and nuances encountered during the implementation process [16].
This study contributes a novel perspective to manufacturing efficiency by integrating traditional TPM principles with modernized methodologies for calculating and applying OEE. This holistic approach contributes to the ongoing discourse on enhancing manufacturing productivity, offering practical guidance for achieving operational excellence in a competitive and dynamic environment.

2.0 METHODOLOGY

2.1 Step of processes

A new flowchart is constructed to design a guideline that shows each phase or task in the study (Figure 1). This approach simplifies the required techniques and methods applied in each phase. Case studies have emerged as a valuable research methodology in various academic disciplines, offering researchers a unique opportunity to delve into complex phenomena and generate in-depth insights. A case study based on operation activities was used to complete this study.
The problem is divided into three segments. Firstly, the initial problem is identifying the factors that affect production productivity in the manufacturing industry, followed by the measurement method to determine the equipment's effectiveness, and finally, the action required to improve its effectiveness.

2.2 Data Collection

The spreadsheet is one of the most useful and simplest programs to store information, summarise, formulate, and calculate data. Data collected from the selected factory was computerized and summarised using OEE formulas for the calculation process. The following template was created using the OEE formula spreadsheet. This template consists of data such as shift duration, break time, rejected pieces, total production, etc., to ensure there was no error during the calculations for availability, performance, quality, and OEE rate.

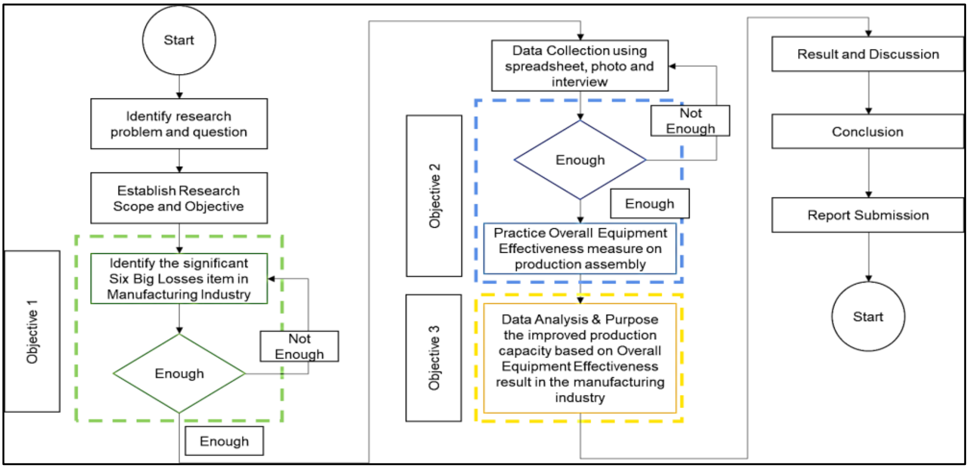

Figure 1: Detailed Process Flow of Research Methodology

2.3 Data Analysis

Data analysis is the second part of data collection, during which the gathered and arranged data is interpreted and calculated to achieve the second objective.

2.3.2 Utilization of Problem-Solving Tools

The fishbone diagram was used in the analysis to identify the problem the selected equipment faced. A fishbone diagram, also known as a cause-and-effect diagram or Ishikawa diagram, is a visual tool to identify and organize potential causes of a problem or issue. The Why-Why Analysis is an analytical method designed in a table or any form arranged in a sequence that allows us to determine the core cause of a problem. Based on the fishbone analysis, the initial problem identified becomes the main problem for the Why-Why analysis.

The novelty of this study lies in its structured and systematic approach to addressing manufacturing productivity challenges through a combination of methodologies and tools, such as developing a guideline flowchart, integration of case studies, customized data collection template, and problem-solving tools applied in a Small and Medium Enterprises (SME). This methodological combination contributes a novel perspective to enhancing manufacturing productivity by leveraging structured analysis, advanced problem-solving tools, and real-world data.

3.0 RESULT AND DISCUSSION

3.1 Data Collection

Data collection is important because it addresses the problem statement to achieve the stated objective. The soya bean manufacturing process uses a boiler machine (vertical one-through type steam boiler). This boiler was purchased in the same year the company was opened in 2006, and was inspected in 2009. It is a vertical boiler, unlike the horizontal boiler commonly used for steam-powered machines. The maximum working pressure it could distribute is 142 psi, and the maximum allowable temperature is about 183oCelsius. Figure 2 shows the template used to calculate the OEE rate of the F&B company for one month. The results for that period (Availability 52.15%, Performance 100%, Quality 98.12%, and OEE 51.17%) was compared with the World Class OEE rate (Availability 90%, Performance 95%, Quality 99.9%, and OEE 85%).

The low OEE is primarily due to low availability and slightly lower quality rates. Conducting a root cause analysis can help identify specific issues causing downtime and defects. Then, implementing a continuous improvement program, such as TPM, can systematically address these issues and drive improvements in all OEE components. Finally, regularly comparing performance against world-class standards can help set realistic targets and measure progress [16].

Production Data						
Shift Length	277.5	Hours =	16650	Minutes		
Short Breaks	1	Breaks @	450	Minutes Each =	450	Minutes Total
Meal Break	1	Breaks @	1800	Minutes Each =	1,800	Minutes Total
Down Time	6890	Minutes				
Ideal Run Rate	9.33	PPM (Pieces Per Minute)				
Total Pieces	116,461	Pieces				
Reject Pieces	2,189	Pieces				
Support Variable	**Calculation**				**Result**	
Planned Production Time	Shift Length - Breaks				14,400	Minutes
Operating Time	Planned Production Time - Down Time				7,510	Minutes
Good Pieces	Total Pieces - Reject Pieces				114,272	Pieces
OEE Factor	**Calculation**				**My OEE%**	
Availability	Operating Time / Planned Production Time				**52.15%**	
Performance	(Total Pieces / Operation Time) / Ideal Run Rate				**100.00%**	
Quality	Good Pieces / Total Pieces				**98.12%**	
Overall OEE	Availability x Performance x Quality				**51.17%**	

OEE Factor	World Class	My OEE%
Availability	90.00%	**52.15%**
Performance	95.00%	**100.00%**
Quality	99.90%	**98.12%**
Overall OEE	85.00%	**51.17%**

Figure 2: OEE's results rate of the F&B Company

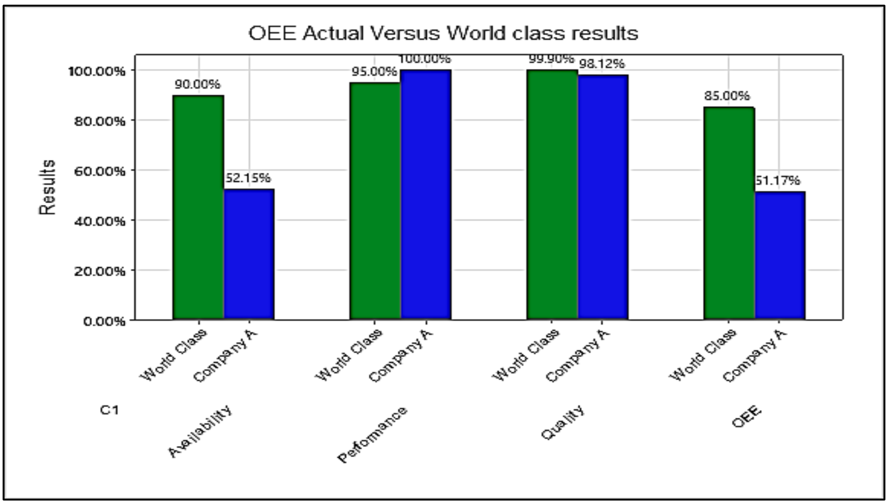

Figure 3: The graph for OEE actual versus world-class results

3.2 Data Analysis

3.2.1 Fishbone Diagram

A cause-and-effect diagram, also known as a Fishbone Diagram or Ishikawa Diagram, is a visual tool to systematically analyse the potential causes of a specific problem or effect. It was used to identify the primary contributing factors, as depicted in Figure 4. This diagram is a fundamental tool in analysing the problems the selected equipment encounters. By examining availability, performance, and quality rates, we can pinpoint the areas affecting the OEE, and based on this outcome, we propose the improvement towards achieving a lean Six Sigma approach campaign in many manufacturing industries. Consequently, the main factors contributing to defects are illustrated in the fishbone diagram. This diagram is instrumental in identifying the initial stages of the issues impacting the equipment's effectiveness. This study determined the root causes using the 4M framework: Man, Machine, Method, and Material.

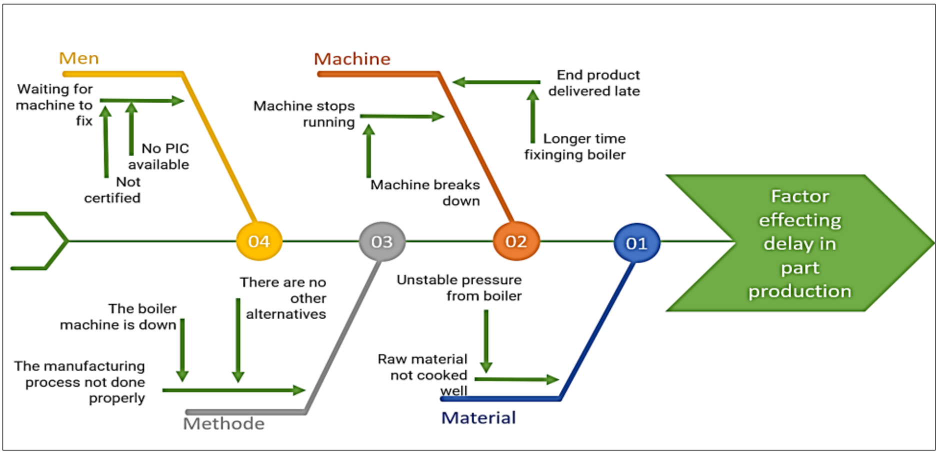

Figure 4: The Fishbone diagram for the identifying factors affecting delay in part production

Based on the interview with an experienced person-in-charge (PIC), Material is not a factor that significantly impacts the whole process. Therefore, it is not the focus of this study. Figure 5 shows the elimination of this factor from the traditional 4Ms (Man, Method, Machine, Material). The analysis focuses on the other three factors (Man, Method, and Machine). After excluding Material, we focused on man (People), i.e., factors related to human resources, skills, or behaviours. Method (Processes) involves factors related to procedures, workflows, or practices. Machine (Equipment) are factors related to tools, technology, or maintenance. We focused on the primary factors driving the problem through brainstorming sessions or using tools like the 5 Whys to dig deeper. We eliminated any irrelevant or redundant causes.

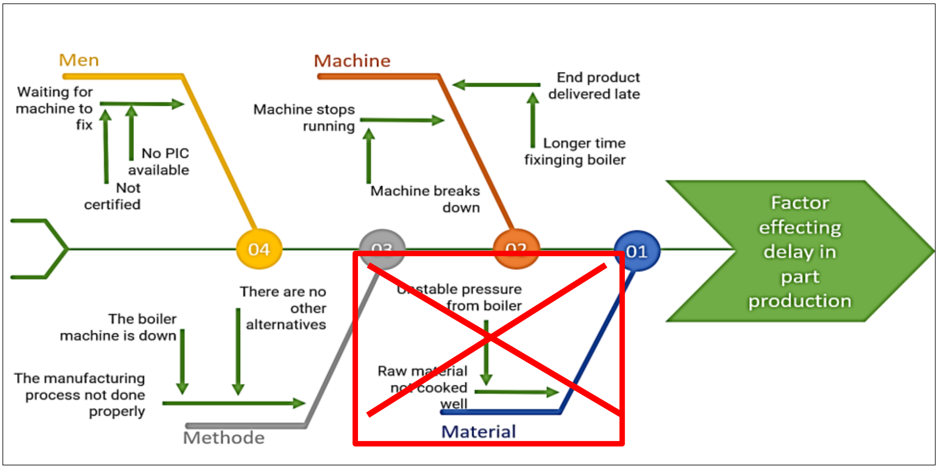

Figure 5: The Fishbone diagram eliminating material factor

3.2.2 Why-Why Analysis

The Why-Why Analysis was used to determine the root cause of the problem, as shown in Table 1. The investigation explored suggestions for future improvement in making precision parts.

The boiler machine was too old; some parts must be replaced. The inner tubes of the boiler caused a leak inside the boiler. The 4M method identified the root cause of the delay: the boiler was not functioning and there was no alternative. The final aspect was (Man): the workers could not fix the problem (leakage in the boiler) because they were not certified to repair it. Once the root causes were identified, we could propose actionable solutions.

3.3 Improvement Proposal

Based on the Why-Why Analysis, the leaking inner tubes in the boiler caused an imbalanced pressure distribution to the cooking and detoxification machines. This problem can be overcome by introducing a new method to optimise the boiler efficiency, i.e., using Advanced

Monitoring Systems (implementing Internet of Things (IoT)) devices. The devices continuously monitor the boiler performance metrics (e.g., temperature, pressure, and fuel consumption) in real time and use sensors and data analytics to predict maintenance needs, thus reducing downtime and improving availability. Moreover, Artificial Intelligence and Machine Learning can be used to analyse historical data, optimise boiler operations for maximum efficiency, and develop predictive maintenance frameworks that can foresee potential failures and suggest proactive measures.

Table 1: Why-Why Analysis for finding the root cause of delay in part production

Factor	Problem	Why 1	Why2	Why 3	Why 4	Why 5	Root Cause
Machine	The boiler runs slower and stops	The boiler breaks down	There is leakage inside the boiler walls	The tube that flows the water at high pressure	The wall tubes are unable to support the high pressure caused by the boiler	The boiler is outdated	The boiler is too old to perform the task
Method	The process of cooking and detoxification of the soya is not done properly	The pressure supply from the boiler to the cooker and detoxifier is not reached	The boiler breaks down	The inner tubes of the boiler leaking	The boiler is not able to support high-pressure	There is no other method to continue the cooking and detoxification process	There is no alternative method to continue the cooking and detoxification process
		The cooking and detoxifying process of soya is not stable	The soya cooked and detoxified for a longer time	The pressure is not stable when the boiler is down	-	-	The boiler is not functioning
Man	The boiler breaks down	The workers stop working	There is no PIC (person in charge) to handle the boiler	The workers are not certified for this job	The workers wait until contractors fix the problem	-	The workers are not provided with training or certified for boiler handling

The second suggestion is developing sophisticated control algorithms that dynamically adjust boiler operations based on real-time performance data and external factors like fuel quality and load demand. Furthermore, automated fuel feeding and ash removal systems can be implemented to maintain optimal operating conditions.

Lastly, comprehensive standard operation procedures and best practices should be developed, and proper training should be provided for the industry to adopt these new technologies and frameworks to address human issues. Introducing these new methods and technologies can significantly optimise boiler efficiency, offering practical solutions with substantial academic and industrial impact.

4.0 CONCLUSION

Our findings show that OEE is a versatile technique that can be applied across various industries to drive improvement, ensure sustainability, and optimize processes. This research has demonstrated that implementing OEE in F&B manufacturing significantly enhances production productivity. The OEE evaluation is pivotal in optimizing productivity and quality within industrial environments. The OEE metric offers a comprehensive framework for assessing production equipment performance, incorporating aspects of availability, efficiency, and quality outputs.

This study aims to identify factors affecting production productivity. It was achieved through data collection from various journals, pinpointing the main industry causes. We utilized tools like the Fishbone Diagram and Why-Why Analysis to determine the root causes. Next, we focused on the second objective, i.e., evaluating equipment effectiveness.

Finally, we compared the OEE values to World Class Standards to ascertain whether the machinery was operating optimally. The final objective is to propose an improvement based on the identified root cause and the Eight Pillars of TPM, which eliminates unnecessary tasks and losses from the production process, ensuring an optimized production. The OEE increases and differentiates production efficiency from the current process flow. This adjustment in the project will be communicated to the organization to resolve this problem.

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AUTHOR CONTRIBUTIONS

A. H. Abdul Rasib and R. Raju: Conceptualization, Methodology, Writing- Original Draft Preparation; R. Raju: Data Collection and Data Analysis, Validation; R.Abdullah, H. Hanizam, M. I. Ramli, R. Yunos: Validation, and H. Mansoor: Writing-Reviewing and Editing.

CONFLICTS OF INTEREST

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its submission, and declare no conflict of interest on the manuscript.

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