International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 03 Mar. 2024, pp: 739-747 www.ijaem.net ISSN: 2395-5252

Enhancing Injection Moulding Productivity through Overall Equipment Effectiveness and Total Preventive Maintenance Approach

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Date of Submission: 15-03-2024 Date of Acceptance: 30-03-2024

ABSTRACT
Injection moulding is a widely used manufacturing process, crucial for the production of various plastic components across industries. Through a comprehensive review of literature and case studies, the significance of Overall Equipment Effectiveness (OEE) and Total Preventive Maintenance (TPM) in minimizing downtime, reducing defects, and enhancing overall equipment performance were highlighted. To maintain competitiveness in today's dynamic market, maximizing productivity is paramount. This article therefore, explores the integration of OEE and TPM as a holistic approach to optimizing productivity in the injection moulding process of a plastic manufacturing company. Consequent upon this, the firm's OEE stood at a mere 29%, which is far below the ideal benchmark of 75%, and further analysis revealed a performance rate of only 36%, with the root cause pinned down at diesel cost, which are used for backup power during electrical outages, which leads to prolonged downtimes. After highlighting the equipment effectiveness considering three critical dimensions of machine availability, machine performance, and product quality, the key determinants influencing productivity were identified in order to quantify the OEE accurately. Furthermore, practical strategies and implementation methodologies were discussed to aid manufacturers to successfully harness the full potential of OEE and TPM for the attainment of optimal productivity in injection moulding operations.

Keywords: total preventive maintenance, overall equipment effectiveness, injection moulding, productivity optimization, manufacturing efficiency, downtime, quality

I. INTRODUCTION

Injection moulding is a pivotal manufacturing process utilized across industries for the production of a myriad of plastic components. It offers numerous advantages such as high production rates, design flexibility, and cost-effectiveness. However, to remain competitive in today's global market, manufacturers must continuously strive for operational excellence by optimizing productivity and efficiency in their injection moulding operations. Okpala, Anozie and Ezeanyim (2018), observed that the contemporary business environment has become considerably complex and challenging, leading to a variety of factors that influence the manufacturing organization's ability to compete effectively. They noted that modern manufacturing approach requires that firms that wish to be successful and also intend to achieve world-class manufacturing, must possess both effective and efficient maintenance strategy.

Overall Equipment Effectiveness (OEE) and Total Preventive Maintenance (TPM) are two key methodologies that have garnered significant attention in manufacturing industries for enhancing operational performance. OEE measures the effectiveness of equipment utilization, while TPM focuses on proactive maintenance strategies to prevent equipment failures and downtime. Integrating these methodologies into the injection moulding process can lead to substantial improvements in productivity, quality, and cost-effectiveness

Bupe, Mwanza and Charles (2015), explained that automation has played a great role in increasing productivity, however, they pointed out that it fails when the equipment are not properly maintained. Like many manufacturing facilities, the injection moulding unit of Company A under review is faced with the inability to meet production targets due to several factors observed to be present within the production unit. These factors, affect production management at every level of production and also reduces the OEE and production optimization. The decrease in efficiency is as a result of high levels of equipment downtime, leading to production losses, and operational inefficiencies. These inefficiencies are largely because of unskilled operators, maintenance personnel, processes, tooling issues, and non-availability of components and materials. To avoid breaks in production and low efficiency, many companies are adopting the idea of the TPM Principle.

TPM is a proactive maintenance approach aimed at maximizing equipment reliability, minimizing breakdowns, and optimizing overall equipment performance. It involves systematic maintenance activities such as regular inspections, lubrication, and calibration to prevent unexpected failures and ensure equipment operates at peak efficiency. While OEE is a metric used to evaluate the efficiency of manufacturing equipment by considering three primary factors: availability, performance, and quality. Availability measures the actual operating time of the equipment compared to the planned production time. Performance evaluates the speed at which the equipment operates relative to its maximum speed under ideal conditions. Quality assesses the percentage of defect-free products produced by the equipment.

By analyzing these factors, manufacturers can identify and address underlying issues that impede productivity and performance. OEE provides actionable insights into equipment downtime, speed losses, and quality defects, enabling targeted improvements to enhance overall operational efficiency in injection moulding processes. By addressing the root causes of under-performance, the research aims to elevate not only the efficiency of the injection moulding unit but also the overall competitiveness, as well as the optimization of the firm's profitability.

II. LITERATURE REVIEW

Candra et al. (2017), defined TPM as a tool to maintain equipment efficiency, reduce failures and increase the initiative of workers, and also showcases a new equipment maintenance culture, philosophy and attitude amongst the entire workforce. It is a widely used equipment maintenance plan in the manufacturing industries aimed at the enhancement of equipment life, reduction of production activities' losses, increase in equipment life, as well as ensuring effective equipment utilization. Okpala, Anozie and Mgbemena (2020), explained that TPM strategy is an important improvement process that emphasizes on equipment maintenance approach, as its positive impact has made many organizations to embrace it in order to enhance organizations' responsiveness in satisfying the customers' expected needs.

According to Venkatesh (2007), concluded that the principles of TPM are applied in manufacturing companies to reduce defects, flaws, and accidents in all processes of an enterprise, starting from the top management to the front-line operators; reduce the incidence of defects and equipment maintenance by establishing different teams and activities running as a system. Méndez and Rodríguez (2017), observed that the TPM principles are ever improving as its implementation brings short and long-term improvements to the enterprise, including the OEE.

Mendez and Rodriguez (2017), opined that education and training is a critical aspect of TPM implementation and usage, while Adesta, Prabowo and Agusman (2018), proposed that the aim of TPM is to improve employee morale and experience by bridging the knowledge and skills gap, through technical skill trainings. However, Okpala and Egwuagu (2016), explained that the objective of TPM is to involve the entire workforce in all the levels of a manufacturing company by forming teams and assisting operators to fully maintain their machines and equipment, lay a strong foundation for enhanced production, by drastically reducing defects, and stoppages that may arise due to accidents and machine breakdowns in all functional areas of a plant.

Overall Equipment Effectiveness (OEE)

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The OEE identifies the percentage of manufacturing time that is truly productive in a firm, as many manufacturing lines are only 60% productive, which implies that there is a huge room for improvement. Often regarded as one of the best measurements of TPM, OEE according to Okpala and Anozie (2018), is a technique that is applied for the measurement of major production features which entail performance efficiency, rate of quality and availability, which aims at speed increment, and the reduction of defective products, machines stoppages, and poor quality products by machines, as well as machines and equipment that work below their production capacity. The OEE model is depicted in figure 1.

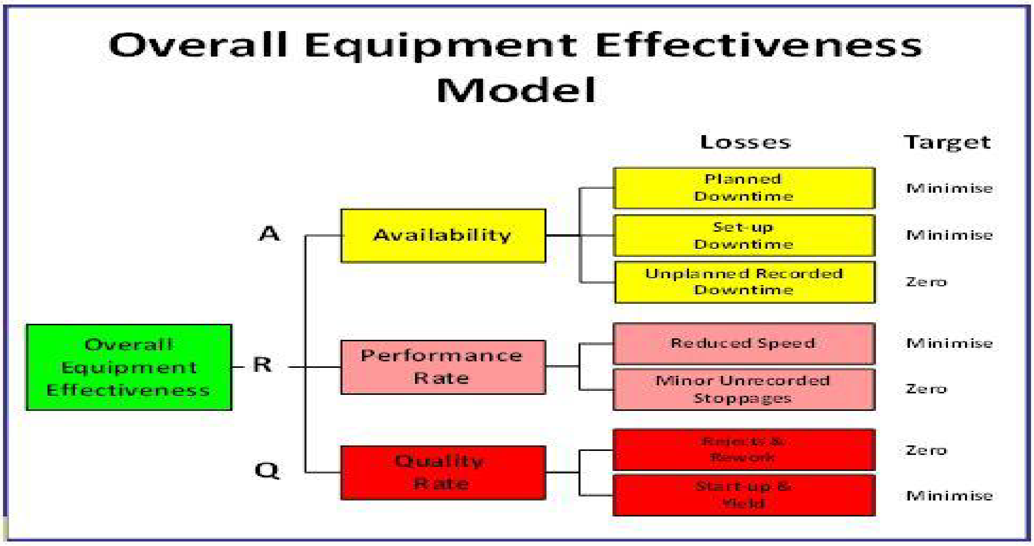

Figure 1: The OEE model

Wudhikarn (2016), noted that rather than efficiency alone, the OEE measures a machine's effectiveness comprehensively and intuitively reveals the production problems arising thereof. It is a key performance metric that measures the actual output of equipment, relative to its maximum potential output. Interestingly, during manufacturing activities, several losses occur from start to finish, thereby dwindling the overall productivity and affecting equipment performance.

These losses include breakdowns, setup and adjustment, idling and minor stoppages, speed losses, defect, rework and startup losses. This study therefore, seeks to improve equipment performance, by dealing with these losses or reducing them to the barest minimum. Rullán-Bidot (2006), explained that TPM takes full advantage of equipment's success and yield, reducing equipment breakdowns, decreasing idling and minor stops, lowering quality defects, packaging labor and costs, shrinking inventory, cropping accidents, and enabling employee participation.

TPM Pillars

Improving OEE with the application of TPM approach for the Company A's injection moulding unit, the study delved into the application TPM and its alignment with the eight pillars of TPM. These pillars provide a structured framework for enhancing OEE through various strategies and practices.

Eight Pillars of TPM

i. Autonomous Maintenance: This pillar emphasizes empowering operators to take responsibility for equipment maintenance. It involves training operators in routine tasks, record-

keeping of machine changes, and engaging maintenance teams for evaluations and repairs.
ii. Maintenance Improvement: This pillar involves developing a comprehensive maintenance plan to prevent breakdowns and reduce downtime. It includes tasks such as periodic inspections, preventive maintenance, and machine overhauls.
iii. Quality Maintenance: This focuses on ensuring that equipment consistently produces quality products, as well as detecting and addressing quality issues promptly.
iv. Training and Education: this focuses on providing continuous training and education to employees to enhance their skills and knowledge in operating and maintaining equipment effectively.
v. Early Equipment Management: This pillar aims to identify and address equipment-related problems proactively through data analysis and preventive measures.
vi. Focused Improvement: A systematic approach to identifying, analyzing, and eliminating production process losses, thereby ultimately improving OEE and also reducing costs.
vii. Safety, Health, and Environment: Developing a comprehensive program for employee safety, health, and environmental protection, and minimizing the impact of operations on the environment.
viii. Office Administration: Applying TPM principles to administrative functions such as finance, human resources, and marketing to identify and eliminate inefficiencies, optimize efficiency, and also reduce costs.

In the context of injection moulding, TPM emphasizes the importance of routine maintenance tasks, predictive maintenance techniques, and employee involvement in equipment care. By implementing these principles, manufacturers can reduce unplanned downtime, extend equipment lifespan, and improve product quality, thereby enhancing productivity and profitability.

Case Studies and Practical Applications

Several case studies demonstrate the effectiveness of integrating OEE and TPM in injection moulding processes. For instance, a plastics manufacturing company implemented OEE tracking and TPM practices, resulting in a 20% reduction in downtime, a 15% increase in production output, and a significant improvement in product quality. Another case study involved a collaborative effort between maintenance personnel and production teams to conduct regular equipment inspections, implement preventive maintenance routines, and optimize machine settings based on OEE data analysis. This resulted in a notable reduction in defects, enhanced equipment reliability, and improved overall productivity.

Okpala, Anozie and Mgbemena (2020), noted that the implementation of TPM in organizations as performance improvement tool has various benefits and challenges, as effective application of TPM program focuses on addressing these challenges, thus resulting in optimized equipment performance in the company. They concluded that TPM concepts and philosophy can be effectively implemented to realize fundamental improvements in the manufacturing performance in any pharmaceutical firm or any other company, thereby leading organizations successfully in the highly competitive drug market.

III. RESEARCH METHODOLOGY

The comprehensive methodology employed to investigate productivity enhancement through OEE and TPM in a plastic manufacturing firm included the mixed-method approach of incorporating both quantitative and qualitative research methodologies, in order to gain a holistic understanding of the factors influencing productivity. This involved the research mechanisms of data computing, Exploratory Data Analysis (EDA), OEE analysis, and Root Cause Analysis (Why-Why Analysis), while the quantitative research methodology allowed for the quantification of critical variables related to productivity improvement and OEE.

Data Computing/Presentation

EDA was applied for the analysis of the data collected from the production department of Company A under review. It led to the identification of interesting patterns or trends within the data, thereby providing valuable insights for further investigation. The extracted data from the administered questionnaire is shown in table 1.

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Table1: Data extracted from questionnaire and observations

Total available time/shift length	8:30am-6pm = 10hrs:30mins 6pm- 8am =14hrs Total of 24hrs
Schedule operating time	22hrs
Breaks	1hr per shift = 2hr
Downtime	2hrs each shift = 4hrs
Idle cycle time	60 sec per piece
Operating time	20hrs
Effective operating time	17hrs
Total piece produced	350,000 for the duration of 4 months
Total Defects produced	1,765 for the duration of 4 months
Defects produced (in percentage) In November, December, January and February	0.56%, 0.5%, 0.56% and 0.59% respectively.
No of active machines	12

OEE Analysis

The core emphasis of this research, was centered on the OEE approach which involved a thorough assessment of equipment efficiency and performance within the plastic manufacturing firm. Key metrics namely; equipment availability, performance rate, and quality of production output were measured and analyzed. The monthly OEE for the months of November, December and January were analyzed.

Analysis and calculations for the individual months on: Availability, Performance, and Quality.

Calculations for the Month of November

Availability

Availability rate =
Planned production =
Where, shifts = 24hrs,
Breaks = 2hrs
Planned production time =
Thus,
Operating time = planned production time − downtime
Planned production time = 22hrs
Downtime = 4hrs
Operating time =
Thus, =
Operating time = 1080mins
Availability =
Availability = 81.81% 82%

Performance

Performance =
Actual run rate = total piece produced in operating time
Total piece produced per day = total piece produced per month number of days worked
92,000 pieces in 22 days = 4182 pieces produced per day
Operating time= 1080
Actual run rate =
Ideal run rate =
Ideal production run rate = 1 piece per 60 seconds
Number of machines = 12
Ideal run rate =
Performance =

Therefore, performance for month of November = 32%

Quality

Quality =
Total piece produced on the month of November = 92,000
Defects = 0.56 % of total piece produced on the month of November
Defects =
Quality =
Percentage of good quality pieces produce =
Thus, quality for the month of November = 99%

Calculations for the Month of December

The adoption of similar calculations performed for the month of November gave the following results for the month of December:
Availability = 81.81% 82%;
Performance = 49%; and
Quality = 99.5%

Calculations for the Month of January

The adoption of similar calculations performed for the month of November gave the following results for the month of January:
Availability = 81.81% 82%
Performance = 27%
Quality = 99%

The calculated monthly analysis which entail availability, performance and quality is depicted in table 2.

Table 2: Monthly availability, performance and quality

	November	**December**	**January**	**Average**	**Percentage average**
Availability	0.8181	0. 8181	0.8181	0.8181	82%
Performance	0.3225	0.4924	0.2717	0.3622	36%
Quality	0.9944	0.995	0.9943	0.9945	99%

The relationship between the quantity of manufactured products and the performance rate is shown in table 3 and figure 2.

Table 3: Relationship between quantity produced and performance rate

	November	**December**	**January**
Quantity produced	9200	13400	81000
Performance rate	0.32	0.49	0.27

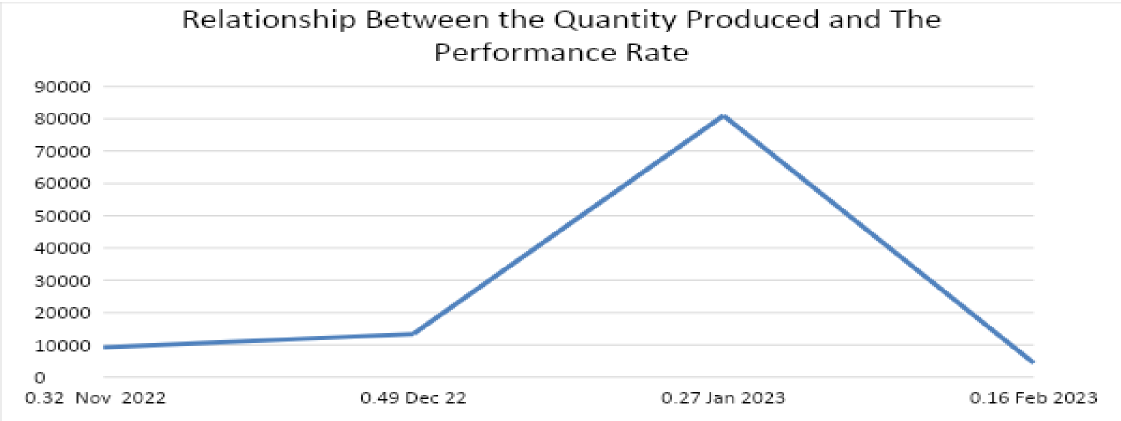

Figure 2: Graph of quantity produced against performance rate

OEE Analysis

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To pinpoint the underlying reasons for performance bottlenecks and productivity challenges, a Root Cause Analysis (RCA) approach, often referred to as Why-Why Analysis, was applied. The method involved systematically asking "why" questions to identify the root causes of identified production related issues. As shown in table 4, RCA was applied to identify the fundamental factors impacting productivity within the manufacturing firm.

Table 4: Root Cause Analysis

	Why	Due to:
Why – 1	Why is there a low performance level?	Stoppages during production hours.
Why – 2	Why are the stoppages during production hours high?	Long duration of downtime during the production hours.
Why – 3	Why is there downtime during production hours?	Power outage during production hours.
Why - 4	Why is there no backup plant in the injection moulding unit?	The backup plants are not in use.
Why - 5	Why are the backup plants not in use?	The cost of diesel to power the backup plant is expensive.

The Root cause: the addition of the cost of diesel to the overall production cost would greatly affect the standard operating cost of manufacturing in the firm.

This mixed-methodology approach of integrating quantitative and qualitative research methods was supported by a structured research mechanism, data computing, EDA, OEE analysis, as well as Root Cause Analysis. These methodological components collectively facilitated a comprehensive exploration of productivity improvement through TPM in the manufacturing company. The research process was also designed to yield data-driven insights and actionable recommendations towards the enhancement of manufacturing efficiency and addressing the identified challenges effectively.

IV. RESULTS AND DISCUSSIONS

The comprehensive TPM and OEE analysis conducted in this research has yielded valuable insights into the production processes, performance, and root causes within the manufacturing firm being understudied. The following key findings and their implications were made:

OEE Analysis

Low OEE Performance: The OEE analysis revealed that the performance of the injection moulding unit was notably low at only 29%. This low OEE score indicates that the injection moulding unit is experiencing significant downtime and operational inefficiencies that are hindering its overall optimal performance.

Availability and Quality

Despite the low OEE, Availability and Quality which are two critical components exhibited strong performance levels, as Availability recorded 82%, which suggests that the unit is consistently available for production, while Quality with a score of 99% is exceptional. Thereby indicating that the unit consistently produces high-quality products.

Root Cause Analysis

Diesel Cost Impact: The Root Cause Analysis identified the cost of diesel to the production expenses as a critical factor that adversely affect the OEE performance. This additional cost has a detrimental effect on the standard operating cost of the injection moulding unit, thereby leading to increased production expenses and reduced overall efficiency.

In the light of these findings, it is imperative that the plastic manufacturing firm takes proactive measures to address the root cause of low productivity and inefficiencies within the production processes. Strategies aimed at optimizing machine utilization, reducing downtime, and mitigating the impact of diesel costs on production expenses should be explored. Additionally, aligning production planning with seasonal demand patterns can lead to more effective resource allocation and improved overall equipment effectiveness.

Monthly Analysis

Availability remains consistently high across all months, indicating ample available production time, while quality levels remained consistently high as well, reflecting improved production. Performance levels were significantly low across the months reviewed due to extended downtime and ideal production rates.

The month of December outperformed other months under review, due to seasonal demand and reduced machine idle time. The ideal run rate was also high for the month of December because of the number of active machines. However, the actual run rate was low due to various other underlying factors.

OEE Result

From the OEE analysis, availability is consistently high at 82%, quality maintained a stellar 99%, but performance lags significantly at 36%. This discrepancy explains the low OEE) of 29%. Achieving a good OEE level is critical, and typically around 75%. However, this will be based on specific needs, capacity, and constraints.

RCA of Low Performance

The root cause analysis indicates that the primary reason for poor performance is the addition of diesel costs to power the backup plant. The backup plant was intended to support the injection moulding unit, utilizing available resources. However, the injection moulding unit prefers low performance to maintain minimal standard operating costs.

Integration of OEE and TPM in Injection Moulding

The integration of OEE and TPM offers a synergistic approach to optimizing productivity in injection moulding operations. By leveraging the insights provided by OEE metrics, manufacturers can identify areas for improvement and prioritize maintenance activities based on criticality and impact on overall equipment performance. Furthermore, TPM practices complement OEE initiatives by ensuring equipment reliability and minimizing disruptions due to breakdowns or maintenance-related issues. Proactive maintenance schedules, equipment condition monitoring, and continuous improvement initiatives are integral components of this integrated approach.

Applying TPM to Company A's injection moulding unit will enhance overall equipment effectiveness by addressing the identified performance gaps, reducing downtime, improving quality, and empowering employees. By aligning with the eight pillars of TPM, the manufacturing facility can work towards achieving higher levels of efficiency, productivity, and market competitiveness to enable it to remain relevant in the manufacturing system.

Conversely, the comprehensive analysis presented in this research underscores the importance of data-driven decision-making and the need for continuous improvement in manufacturing operations. By rapidly addressing identified challenges and implementing targeted solutions to eliminate or minimize the challenges in the manufacturing firm can enhance its productivity, meet production targets, and ultimately achieve higher levels of profitability and competitiveness in the market. Further research and actions are recommended to delve further into these identified constraints and develop strategies for sustainable process improvement.

V. CONCLUSION

The objectives of this research were to assess the OEE as an optional approach to productivity improvement, identify productivity-affecting factors, and propose strategies for enhancing overall equipment effectiveness within the context of the injection moulding unit of the company under review. The findings gave critical insights into the firm's performance(s). The analysis revealed that the injection moulding unit consistently falls short of its daily production targets despite operating round the clock with 24-hour shifts. While achieving commendable availability at 82% and maintaining a high-quality standard at 99%, the company faces a significant challenge with performance, standing at a mere 36%.

Consequently, the OEE remains alarmingly low at 29%. This highlights a substantial gap in OEE compared to the ideal threshold of 75%. This leaves an ample room for improvement by the operators at the shop floor as well as the entire organizational management. A root cause analysis underscores the primary factor contributing to this poor performance: the cost of diesel required to power the plant.

In summary, this project has successfully achieved its goals of identifying key productivity affecting factors, highlighting the low performance rate of 36% as a critical issue, and introducing TPM as a potential solution to enhancing the overall equipment effectiveness of the injection moulding unit. The project also highlights the critical knowledge that every instance of machine or operator idle time translates to productivity losses. Among the various performed analysis, the OEE analysis emerges as the most comprehensive as it encompasses equipment availability, performance efficiency, and quality metrics. It serves as a valuable tool for identifying improvement areas and promotion of a culture of continuous improvement.

The integration of OEE and TPM represents a holistic approach to optimizing productivity in injection moulding processes. By systematically assessing equipment performance, minimizing downtime, and implementing proactive maintenance strategies, manufacturers can achieve significant improvements in operational efficiency, product quality, and profitability. To realize the full potential of OEE and TPM integration, manufacturers must foster a culture of continuous improvement, employee empowerment, and cross-functional collaboration. By embracing these principles and leveraging advanced technologies for data analytics and predictive maintenance, manufacturers can stay ahead in today's competitive market landscape, while driving sustainable growth and innovation in injection moulding operations.

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