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A Review of Overall Equipment Effectiveness (OEE) as a Theoretical Approach to Production Line Improvement

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ABSTRACT

This study presented a comprehensive review of Overall Equipment Effectiveness as a theoretical and practical framework for production line improvement, with particular emphasis on the bakery, patisserie, and confectionery industry in Saudi Arabia. Rooted in the principles of Total Productive Maintenance, OEE was examined as an integrative performance measure that combined availability, performance, and quality to identify hidden losses and guide improvement priorities. The review showed that, in multi–stock-keeping unit production environments characterized by frequent changeovers, setup and adjustment losses represented a major constraint on equipment availability and effective capacity utilization. Drawing on empirical and conceptual studies, the research demonstrated that OEE was most effective when it was applied as a diagnostic and improvement-oriented tool rather than as a standalone numerical indicator. The analysis further highlighted the interdependence of the three OEE dimensions, indicating that availability losses often propagate into performance inefficiencies and quality defects, particularly in time-sensitive food manufacturing operations. In addition, the study identified limitations related to inconsistent OEE calculation and interpretation, which reduced its comparability and weakened its role as a driver of continuous improvement. Overall, the findings confirmed that OEE provided a robust and holistic framework for uncovering concealed capacity, reducing reliance on overtime.

Keywords: Overall Equipment Effectiveness (OEE); Total Productive Maintenance (TPM); Production Line Improvement; Changeover Time; Availability Losses; Bakery and Confectionery Industry; Manufacturing Performance.

INTRODUCTION

The primary objective is to manufacture small batches with minimal lead times, enabling swift transitions between products, thereby positioning the firm competitively (Hodgea et al., 2011) by reducing changeover time (the duration required to produce the final acceptable unit of the initial lot and the first satisfactory unit of the subsequent lot) (Chen, 2009).

Excelling in your field and surpassing client expectations is crucial for survival in contemporary competitive markets. The competitiveness of the manufacturing sector is dictated by the availability and efficiency of production facilities (Fleischer et al., 2006). Consequently, it is essential to possess a legitimate performance metric that encompasses the fundamental elements of productivity. Overall equipment effectiveness (OEE) is a crucial applied metric for assessing performance in the industrial sector (Wudhikarn, 2016). OEE was initially proposed by Nakajima in 1988 as a component of total productive maintenance (TPM) initiatives. Academics and practitioners continue to focus on OEE today (Braglia et al., 2020).

This research examines the actual levels of Overall Equipment Effectiveness (OEE) utilizing data from a reputable confectionery manufacturer in Saudi Arabia, specifically focusing on two stock-keeping units (SKUs) production lines under real working conditions. It aims to bridge the gap between theory and practice by minimizing changeover time, thereby decreasing direct costs associated with the confectionery plant's production line. The optimal production scenario in the food sector necessitates minimal to no interruptions in both automatic and semi-automatic production lines. A disruption in a manufacturing line due to equipment breakdown will result in decreased productivity and quality issues (Liberopoulos and Tsarouhas, 2002).

Problem Statement

Overall Equipment Effectiveness (OEE) differs across several industries. Consequently, the current study serves as an industrial application in bakery, patisserie, and confectionery, exemplifying a fast-moving consumer good (FMCG). This research will examine the impact of managing one of the six critical losses, specifically setup and adjustments (minimizing changeover time), on availability.

Most industrial organizations swiftly resort to augmenting overtime, adding extra shifts, or expanding the number of production lines when confronted with capacity restrictions as the sole feasible alternative to enhance productivity. Nevertheless, the current study demonstrates that employing OEE as a diagnostic instrument can yield alternative strategies for improving performance through the utilization of existing capacity (Muchiri and Pintelon, 2008). This research examines how OEE can serve as an effective instrument for uncovering hidden capacity without incurring overtime expenses, hence reducing significant capital outlays and enhancing profitability and competitiveness.

Research Questions

This study examines the implications of total equipment efficacy based on its theoretical framework. The subsequent phase involves analyzing overall equipment effectiveness (OEE) metrics and the primary factors that affect the operation of the patisserie production line. This was conducted to illustrate the significance of OEE as a tool for all production measuring activities in the plant for establishing priorities and tracking progress and enhancements. The subsequent research questions are delineated as a framework for the investigation as follows:

1. How does implementing the OEE methodology to reduce changeover time affect availability in the confectionery production line?
2. What is the impact of splitting different SKUs with different process flow over other production lines on OEE results in the confectionery industry?
3. How do the three main pillars of availability, performance, and quality rate interrelate to impact OEE results in the confectionery production line?
4. What independent and moderating variables have the most significant influence on OEE in the confectionery industry, and how can they be leveraged to improve performance?

Research Objectives

Given the discussed problem statement, the main objectives of this study are to:

1. The main objective of this research is to improve the performance and Overall Equipment Effectiveness.
2. Contribute to the growing literature on OEE, as there is a relative shortage of case studies concerning this topic in the bakery's patisserie confectionery industry.
3. Using detailed analysis, investigate how reducing changeover time (downtime loss) affects OEE in the bakery's patisserie confectionery industry.
4. Moreover, reaching more concrete results and shedding light on improving the availability, thus, OEE results. Use OEE through action research as a diagnostic tool that would help minimize overtime costs and reach the optimal throughput.

Research Significance

This study enhances both theoretical and practical understanding by framing Overall Equipment Effectiveness (OEE) as a diagnostic and improvement-focused framework, rather than simply a quantitative performance metric, specifically within the bakery patisserie confectionery sector. The research fills a significant gap in the literature by expanding the debate of OEE to a multi-SKU food production environment marked by frequent changeovers and substantial process variability, a scenario that has garnered minimal empirical scrutiny. The study elucidates how prioritizing setup and adjustment losses as a key factor in diminished availability might facilitate the release of hidden capacity without necessitating further capital expenditure. From a managerial standpoint, the results yield pragmatic insights into employing OEE to facilitate changeover management, production planning, and continuous improvement efforts, presenting an alternative to overtime and capacity augmentation as major solutions to productivity issues.

LITERATURE REVIEW

The implementation of lean operations and the adoption of total productive maintenance (TPM) can be credited to Taiichi Ohno, a distinguished industrial engineer and the principal designer of the Toyota Production System (TPS) (Womack et al., 1990). Ohno's groundbreaking initiatives in the 1950s transformed production methodologies, prioritizing waste minimization, increased efficiency, and employee engagement in ongoing enhancement (Liker, 2004). Ohno established the foundation for lean manufacturing by prioritizing principles such as inventory reduction, flow enhancement, and the eradication of non-value-added activities (Womack et al., 1990).

While Ohno is not the progenitor of TPM, his substantial contributions to its advocacy and execution inside the Toyota Production System are undeniable (Nakajima, 1988). In close collaboration with Seiichi Nakajima, Ohno was instrumental in embedding TPM within Toyota's operational framework (Liker, 2004). Seiichi Nakajima, in collaboration with other Toyota executives, enhanced and broadened the TPM technique (Nakajima, 1988).

It is imperative to recognize that lean operations and Total Productive Maintenance (TPM) have developed and achieved global acceptance since their origin. Although Ohno's contributions are crucial in the dissemination of these principles, they have been enhanced via ongoing refinement by various persons and groups over time.

Stakeholders and executives' managers want equipment and production lines to function at full capacity, achieve superior production quality, and maintain optimal operational duration. Nonetheless, this will not be achieved owing to losses in processes and productivity.

The Japan Institute of Plant Maintenance (JIPM) defines Total Productive Maintenance (TPM) as a strategy for enhancing equipment productivity in a manufacturing environment (Parihar et al., 2012). The OEE metrics were obtained from the Japanese manufacturing model.

Overall Equipment Effectiveness (OEE) is a statistic utilized to assess the performance of manufacturing machinery. To mitigate equipment challenges and guarantee ongoing production enhancement, OEE enacts corrective measures to diminish adverse variables affecting output, which are then disseminated to other manufacturing units.

The conceptual foundation of OEE originates from Total Productive Maintenance (TPM), a maintenance approach developed in Japan in the 1970s. The principal aim of TPM is to improve equipment productivity and efficiency, adhering to a concept of "zero defects, zero accidents, and zero breakdowns." The maintenance procedure encompasses all personnel and ongoing enhancement initiatives. OEE was then established as a vital KPI under TPM to assess equipment effectiveness regarding availability, performance, and quality. The three components of OEE—availability, performance, and quality—are based on the six major losses identified in TPM: breakdowns, setup and adjustment, minor stoppages, reduced speed, defects and rework, and startup losses. OEE is predicated on the premise that equipment effectiveness can be enhanced by mitigating the six principal losses through activities such as autonomous maintenance, planned maintenance, and quality enhancement. The assessment of OEE is essential for pinpointing areas requiring enhancement and assessing the efficacy of improvement efforts.

OEE is determined by availability (A), performance efficiency (PE), and quality rate (Q), serving as an analytical instrument to discover substantial losses and establish avenues for enhancement. OEE may serve as an internal standard to measure enhancements, facilitate performance comparisons, and identify underperforming machinery or equipment (Dal et al., 2000).

In Seiichi Nakajima's book 'TPM Tenkai' (1982, Japan Institute of Plant Maintenance JIPM, Tokyo), Overall Equipment Effectiveness (OEE) was presented as a fundamental element of Total Productive Maintenance (TPM), a strategy for enhancing machine efficiency in various production settings. By the conclusion of the 1980s, the concept and practice of TPM had gained greater recognition globally. Nakajima has stated that OEE is an essential statistic for measuring the advancement of TPM and assessing actual performance.

OEE is a quantitative indicator and a Key Performance Indicator (KPI) that identifies and quantifies losses in critical elements of a manufacturing process, namely availability, performance, and quality. OEE is highly beneficial for producing new products using existing resources and minimally modified work methods. Overall Equipment Effectiveness (OEE) was introduced by Nakajima (1988) to measure the efficacy of the suggested managerial maintenance strategies. This indication was distinctive as the OEE metric subtracted preventive maintenance intervals from the Total Effective Equipment Productivity (TEEP) metric. The substantial demands of preventive maintenance inevitably reduce the availability of production equipment; therefore, preventive maintenance should be factored into maintenance downtime. The computation of OEE offers a comparative assessment of equipment efficacy as organizations endeavor to attain a consistent performance level, as reflected by a stable OEE. The primary benefit lies in examining OEE elements and utilizing them as a foundation for root cause analysis to eradicate the sources of suboptimal performance (Dal et al., 2000).

The primary value of OEE lies in its emphasis on improvement drivers and its straightforward yet dynamic nature; thus, the essential objective of OEE is not to establish an optimal metric but to provide a simple computation that guides decision-makers on where to allocate resources for improvement (Jonsson and Lesshammar, 1999). The authors Jonsson & Lesshammar (Jonsson and Lesshammar, 1999) initiate the research study by addressing the significance of performance monitoring in manufacturing and the diverse methods established for this objective, including Total Quality Management (TQM). They subsequently provide OEE as a metric particularly appropriate for application in manufacturing environments.

The essence of the work by Jonsson and Lesshammar (Jonsson and Lesshammar, 1999) is a case study wherein the authors utilize Overall Equipment Effectiveness (OEE) to assess the performance of a packaging line at a prominent Swedish food enterprise. They provide comprehensive statistics on the line's performance, including OEE scores, and examine the variables that influenced the variances in performance. They also propose a strategic plan to enhance the line's performance, aiming to elevate OEE. The authors determined that OEE is a potent and efficient instrument for assessing and enhancing manufacturing performance. They propose that OEE can be utilized alongside other performance metrics to comprehensively comprehend a manufacturing operation. They also indicate that OEE can identify areas for enhancement, resulting in a more targeted and efficient improvement process. Jonsson and Lesshammar (Jonsson and Lesshammar, 1999) present a commendable methodology for utilizing OEE as an indicator with other performance metrics.

OEE was proposed by Nakajima in 1988, but its definition has since evolved into a key performance metric throughout the years, as noted by Muthiah et al. in 2006. Muthiah et al. (Muthiah and Samuel, 2006) presented an overview of the importance of measuring and improving productivity in manufacturing, along with the approaches developed for this purpose, including Total Quality Management (TQM), Just-in-Time (JIT), and Six Sigma. The authors subsequently provide a thorough literature review of the topic, analyzing the several approaches, models, and tools suggested for assessing and improving productivity in manufacturing processes. The research is constrained as the paper predominantly emphasizes conventional industrial processes, neglecting contemporary technology and methodologies, like Industry 4.0 and productivity evaluation. The evaluation primarily focused on methodology, models, and tools for assessing productivity, with diminished attention to strategies for enhancement and execution.

Fleischer et al. (Fleischer et al., 2006) assert that maintaining competitiveness in manufacturing enterprises relies on the availability and efficiency of production facilities. Conversely, Huang et al. (Huang et al., 2003) asserted that the efficacy of the OEE tool as a crucial quantitative instrument for assessing productivity was confined to individual equipment. Jeong and Phillips (Jeong and Phillips, 2001) identified that factors contributing to OEE losses, including preventative maintenance, holidays, and off-shifts, were considered inappropriate for the capital-intensive organization as originally outlined by Nakajima (Nakajima, 1988). OEE aims to identify losses, defined as resource-consuming operations that yield no value; these losses are classified into three categories: Availability, Performance, and Quality losses Nakajima, (Nakajima, 1988) as quoted in (Muchiri and Pintelon, 2008).

OEE is utilized within the performance measurement systems of many corporations. OEE is defined as a metric of overall equipment performance, indicating the extent to which the equipment fulfills its intended function (Williamson, 2006); hence, OEE serves as a measure of effectiveness.

Afefy (Afefy, 2013) examined the execution of Total Productive Maintenance (TPM) and the assessment of Overall Equipment Effectiveness (OEE) in a manufacturing facility. The author commences with an outline of Total Productive Maintenance (TPM) and Overall Equipment Effectiveness (OEE), elucidating their significance in manufacturing processes and emphasizing the advantages of their implementation. The text next delineates the application of Total Productive Maintenance (TPM) and Overall Equipment Effectiveness (OEE) within a case study of the Salt Company (Emisal) production facility.

Conversely, Parihar, Jain, and Bajpai (Parihar et al., 2012) elucidated the computation of Overall Equipment Effectiveness (OEE) for an assembly process by a mathematical formula and presented a theoretical example of its application in a practical context. The authors present a summary of OEE and its significance in manufacturing processes. The authors thereafter introduce their methodology for estimating Overall Equipment Effectiveness (OEE), encompassing a mathematical formula and a detailed, sequential elucidation of its use. They also present an example demonstrating how their method may compute OEE for an assembly process in a practical context. The authors' sole drawback is their exclusive focus on computing OEE for assembly operations. The essay emphasizes that the proposed method quantifies the productivity of a manufacturing process. The authors ought to have examined the merits or drawbacks of their strategy in relation to alternative approaches for calculating OEE or other performance metrics. The example presented in the article is constrained and requires elucidation regarding the practical use or outcomes of the method in a real-world context. The research is constrained. Further investigation is required to comprehensively assess the merits and drawbacks of the proposed method in relation to alternative approaches for measuring OEE and other performance metrics. Additionally, a comprehensive real-life case study, including relevant data and outcomes, along with an analysis of the long-term ramifications and sustainability of the OEE program, would be beneficial.

Reyes et al. (Reyes et al., 2010) presented the background of OEE and examined its limitations. The document additionally illustrates the conceptual and mathematical evolution of ORE measurement and the corresponding calculation methods. Empirical and simulation-based analyses and applications of ORE are conducted via two case studies for validation purposes. The ORE approach's incorporation of process cost variations, material cost variations, and material efficiency renders its overall effectiveness measure more attainable and relevant than the old OEE metric.

Braglia et al. (Braglia et al., 2020) presents an alternative perspective on the significance of labor productivity measurement in manufacturing, specifically for assessing the performance of a packaging line within a manufacturing firm, and the diverse metrics established for this objective, including Overall Equipment Effectiveness (OEE) and Labor Utilization. The authors assert that the updated OLE metric is a robust and efficient instrument for assessing labor productivity in manufacturing processes. They propose that the OLE can be utilized alongside additional performance metrics to achieve a comprehensive picture of a manufacturing operation. They also indicate that OLE can be utilized to pinpoint areas for enhancement, resulting in a more targeted and effective improvement approach.

Muchiri and Pintelon (Muchiri and Pintelon, 2008) determined in their study that Overall Equipment Effectiveness (OEE) is a prevalent and recognized indicator for assessing and enhancing industrial equipment performance. They emphasize the benefits of OEE, including its capacity to deliver an extensive overview of equipment performance, its user-friendliness, and the accessibility of OEE data gathering software. The discussion also addressed the limitations of OEE, including the challenges in standardizing OEE data for equipment running under varying conditions and the possibility that OEE data may not encompass all elements influencing productivity. A notable quality of the research is its thorough examination of the literature on OEE; the authors effectively described and categorized the diverse definitions, techniques, and implementations of the OEE measure. They offer valuable insights into the practical application of OEE for measuring and enhancing equipment performance in manufacturing operations. Nonetheless, certain shortcomings of the study warrant attention. A disadvantage is that the study mostly emphasizes historic equipment, neglecting modern and contemporary tools utilized in the sector. The authors fail to elucidate how OEE data might facilitate improvement efforts; it would be advantageous if they presented examples of its application in decision-making and enhancement initiatives.

Tsarouhas (Tsarouhas, 2018) conducted a case study on the croissant production line, utilizing the OEE metric to assess performance and pinpoint areas for enhancement. The author presents comprehensive data indicating that OEE is a potent and efficient instrument for assessing and enhancing manufacturing equipment performance, resulting in improved overall performance of the croissant production line. The author posits that OEE may be utilized with additional performance measures and underscores the significance of operator engagement in executing enhancements. The case study offers significant insights and pragmatic uses of OEE in a practical context. Nonetheless, the study has drawbacks that warrant attention, as it solely comprises a single case study, potentially lacking generalizability to various manufacturing contexts.

Furthermore, the author must elucidate the methodology employed for calculating the OEE scores and the data collection process, as this may hinder readers' ability to duplicate or expand upon the study. The paper offers a significant contribution to the area by giving a case study on the implementation of OEE in a bakery manufacturing operation and its efficacy in enhancing the overall performance of the production line. The offered case study is pragmatic and beneficial for anyone seeking to utilize OEE to enhance equipment performance. Nonetheless, additional case studies across various businesses or facilities could enhance the validity and generalizability of the results.

OEE Calculation and Constituents

In response to industry demands, some authors have made minor modifications to the original OEE formula, while others have proposed new formulas. While OEE implementations have been tailored to meet industry requirements, several authors have made minor alterations to the original formula, and others have introduced novel formulations (Ng Corrales et al., 2020); OEE is determined by availability, performance, and quality as defined by Nakajima (1988): OEE = Availability (A) × Performance (P) × Quality (Q) × %

Availability: The ratio of the actual production time of a machine to the total time it is capable of producing components. This figure encompasses breakdowns, setups, and adjustments. The availability calculation deducts the actual production time, inclusive of setup, from the projected production time. The computation will encompass the time wasted attributable to machine malfunctions, insufficient input materials, and/or operator absence as a series of occurrences. Consequently, the ratio of actual time utilized to available time produces a percentage that contributes to the overall OEE calculation.

The duration a machine or process is operational during designated production hours, excluding both planned and unforeseen downtime. Where:
Operating time = Loading time – Downtime

Performance: Performance, in theory, is defined as the ratio of the machine's actual run rate to its optimal run rate, expressed as a percentage. The machine maker frequently specifies the unit's optimal operational rate. However, the appropriate run rate can be influenced by the machine's condition, temperature, and the type of product being processed. Purists contend that one should continue to reference the declared run rate, whilst others may assert that the characteristics of the product involved could need a reduction in performance.

The percentage of total components produced by the machine relative to its production rate in a different context indicates the efficiency of the machine during operation

Quality

Quality is the ultimate determinant in the whole OEE computation. This represents the ratio of high-quality products to the total number of products. It is the proportion of quality parts relative to the total components produced by a machine, representing the ratio of functional to defective components made by that machine.

Interpretation of OEE Values

Nakajima (Nakajima, 1988) posits that the optimal world-class value of Overall Equipment Effectiveness (OEE) is anticipated to be 85.0%, contingent upon an availability of 90.0%, a performance rate of 95.0%, and a quality rate of 99.9%. Various methodologies have been employed to elucidate optimal OEE levels; for instance, Kotze (Kotze, 1993) proposed a benchmark of OEE above 50%, whereas Ericsson (Ericsson, 1997) indicated that OEE values may range from 30% to 80% as referenced by Tsarouhas (Tsarouhas, 2018). Ljungberg (Ljungberg, 1998) indicated that the OEE value ranges from 60% to 75% in the sampled situations. The precise data source Ljungberg (Ljungberg, 1998) indicated a mean percentage of 55%. According to Domingo & Aguado (Domingo and Aguado, 2015), OEE levels range from 60% to 70% as acceptable, from 70% to 85% as good, and above 85% as excellent. They also indicated that values below 60% are deemed unsatisfactory due to the sustainability of the method (Domingo and Aguado, 2015). Bicheno (Bicheno, 2004) has indicated that a range of 85%-92% is regarded as world-class in non-process sectors.

Nakajima's (Nakajima, 1988) division of losses into six principal categories in the elimination process addresses just certain variables that diminish capacity utilization, including planned downtime, material shortages, and staff deficiencies, among others. Downtime losses, both planned and unexpected, as a function of Availability: It includes the two most significant losses detailed below and is utilized to assess the true worth of a machine's availability within its industry.

1. Failure of Equipment: Breakdown losses are defined as time and quantity losses caused by equipment failure, breakdown, or product faults.
2. Setup and Adjustment: These are the losses incurred when the production of one item is swapped to another or a variety of items or when equipment is fine-tuned.

Speed losses that affect Performance

Speed losses are necessary to calculate a machine's genuine performance value. While machine downtime, it cannot be measured.

1. Idling and minor stoppage: These losses occur when production is briefly paused because of a malfunction or while a machine is idle. For instance, this often leads to tiny, reparable stoppages, frequently resulting in serious capacity loss.
2. Reduced speed: These losses relate to the gap between the equipment's theoretical and actual working speeds

Quality losses that affect the Quality Percentage

Losses in quality impact the final product's quality. This results in significant economic losses for a factory due to the waste of resources and the expense of recycling. They originate from;
Defect in process/rework: These are losses due to faulty production equipment.
Reduced yield: These are yield losses that occur between machine startup and stabilization.

This is shown in the figure (2.2)

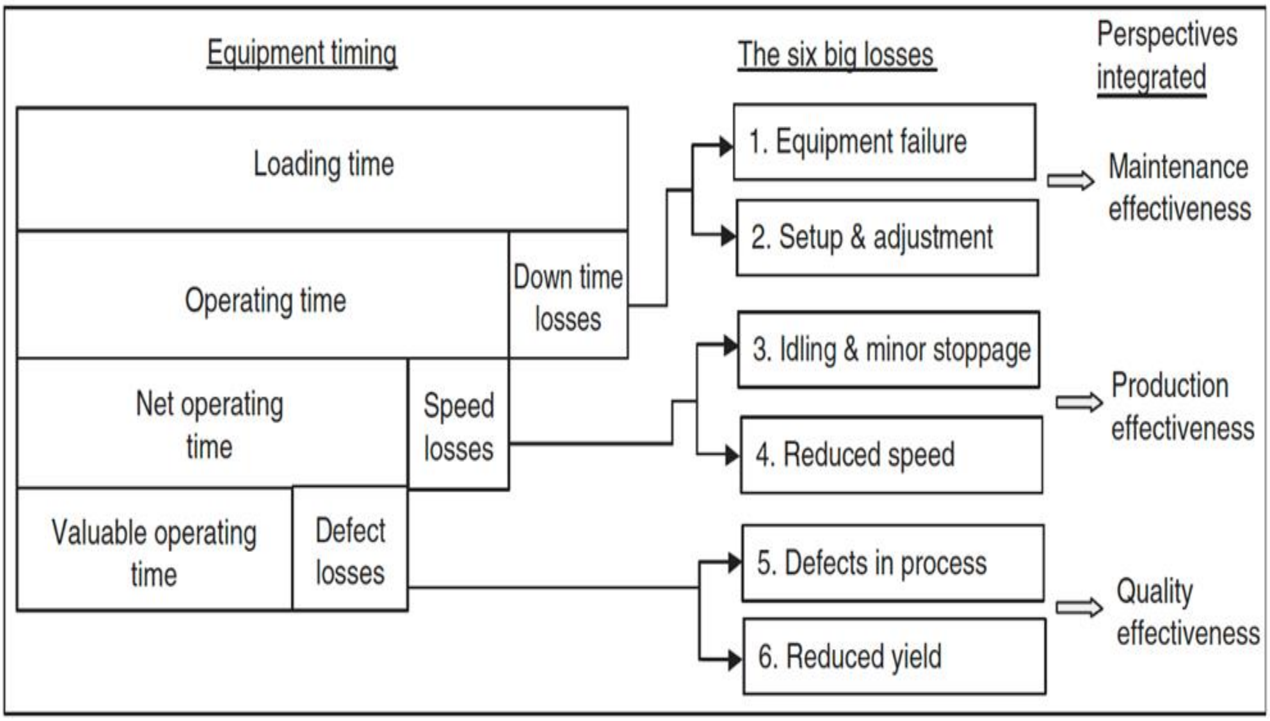

Fig (2.2) OEE measurement tool and the perspectives of performance integrated into the tool (Muchiri and Pintelon, 2008).

As shown in Figure (2.2), OEE is an integrative measurement tool that encompasses maintenance effectiveness, production efficiency, and quality efficiency.

Despite the global standardization of the OEE definition, many companies must still interpret the aspects that comprise this definition. These variations present a problem in utilizing OEE as a catalyst for progress (Andersson and Bellgran, 2011).

Previous empirical research demonstrated discrepancies between planned and unplanned time calculations and the established ideal time, which complicates site comparisons. The structured and accurate implementation, along with standardized calculations of OEE, is crucial for serving as an effective catalyst for enhancements aimed at attaining process stability (Andersson and Bellgran, 2011).

DISCUSSION

The examined literature unequivocally demonstrates that Overall Equipment Effectiveness (OEE) has evolved from a maintenance-centric metric within the Total Productive Maintenance (TPM) paradigm to a holistic managerial strategy for assessing and enhancing production efficacy. Nakajima's (Nakajima, 1988) seminal work established OEE as a systematic approach to reveal concealed losses within production systems by integrating availability, performance, and quality metrics. Subsequent research has consistently validated this conceptual framework, highlighting that OEE's principal advantage is its capacity to convert intricate operational inefficiencies into comprehensible improvement priorities, rather than yielding a definitive measure of productivity (Dal et al., (Dal et al., 2000); Muchiri & Pintelon, (Muchiri and Pintelon, 2008)).

A predominant theme in the literature is that OEE is most efficacious when utilized as an improvement-oriented framework rather than merely a numerical performance indicator. Jonsson and Lesshammar (Jonsson and Lesshammar, 1999) illustrated this through their empirical study in a food manufacturing setting, where OEE was employed to pinpoint primary sources of loss and inform specific corrective measures. Their findings robustly endorse the theoretical framework of the current study, which regards OEE as a diagnostic tool for comprehending production behavior. This viewpoint is especially pertinent in the bakery, patisserie, and confectionery sectors, where constant product modifications, process unpredictability, and time-sensitive operations render numerical efficiency metrics insufficient for managerial understanding.

The examination of setup and adjustment losses in the analyzed studies underscores their significant impact on availability outcomes. Nakajima (Nakajima, 1988) identified setup and adjustment as one of the six principal losses, a classification that continues to be pertinent in contemporary multi-SKU manufacturing contexts. Muchiri and Pintelon (Muchiri and Pintelon, 2008) underscored that setup-related losses frequently surpass availability losses, especially in businesses marked by product diversity and frequent changeovers. This study substantiates the conclusion that extended and non-standardized changeovers constitute a significant limitation on effective capacity utilization, prompting organizations to depend disproportionately on overtime and extra shifts rather than resolving underlying issues within current operations.

A significant observation derived from the literature is the interrelation of the three OEE aspects. Dal et al. (Dal et al., 2000) contended that reductions in availability seldom occur in isolation, as they frequently lead to declines in performance and quality. This systemic interplay is most apparent in food processing, where prolonged downtime shortens production schedules and heightens the demand to operate at accelerated speeds. Consequently, diminished speed losses, minor interruptions, and startup quality deficiencies occur with more frequency. This study reinforces the integrated perspective by demonstrating that availability losses associated with changeover time indirectly compromise performance stability and quality consistency, affirming that OEE should be understood holistically rather than through discrete measures.

The literature elucidates the impact of SKU diversity and process flow intricacy on OEE results. Jonsson and Lesshammar (Jonsson and Lesshammar, 1999) observed that performance degradation frequently arises when production lines must manage items with markedly distinct processing demands. This conclusion is corroborated by the current study, which demonstrates that allocating varied SKUs to the same production line amplifies operational uncertainty, extends setup operations, and undermines equipment performance. In this environment, OEE functions as both a measurement instrument and a strategic framework for production planning and line balance decisions.

Notwithstanding its advantages, numerous research have rigorously analyzed the shortcomings of conventional OEE applications. Huang et al. (Huang et al., 2003) and Jeong and Phillips (Jeong and Phillips, 2001) challenged the appropriateness of OEE in specific capital-intensive contexts, contending that elements such as scheduled maintenance, off-shift periods, and organizational limitations are not consistently represented. Reyes et al. (Reyes et al., 2010) expanded this critique by introducing Overall Resource Effectiveness (ORE), positing that Overall Equipment Effectiveness (OEE) may overly simplify productivity evaluation by overlooking material and cost efficiency. Although these critiques underscore legitimate constraints, Muchiri and Pintelon (Muchiri and Pintelon, 2008) determined that OEE continues to be a highly pragmatic and efficacious paradigm, provided its scope and assumptions are comprehensively understood and it is consistently implemented within a specified operational environment.

A persistent problem in the literature pertains to the absence of standardization in the calculation and interpretation of OEE. Andersson and Bellgran (Andersson and Bellgran, 2011) highlighted that discrepancies in the definitions of planned versus unplanned downtime, optimal cycle periods, and loss classification considerably undermine OEE's effectiveness as a catalyst for development. This discrepancy restricts comparability among production lines and organizations, thus undermining managerial faith in OEE outcomes. This study supports the critique and emphasizes the necessity of establishing consistent definitions and rigorous implementation techniques to ensure that OEE truly represents operational realities.

The analyzed case studies offer compelling proof of the value of OEE in food manufacturing settings. Tsarouhas (Tsarouhas, 2018) illustrated that the implementation of OEE in a croissant production line resulted in quantifiable enhancements in performance and emphasized the significance of operator engagement in maintaining improvement efforts. Afefy (Afefy, 2013) demonstrated that the integration of TPM and OEE can improve equipment efficacy, while the study did not comprehensively examine long-term sustainability. The findings collectively substantiate the conclusion of the current study that OEE-driven enhancement is most effective when bolstered by corporate involvement and a culture of continuous improvement.

From the synthesis of literature and the conceptual findings of this study, numerous recommendations may be formulated. Entities within the bakery and confectionery sector must emphasize the minimization of setup and adjustment losses by implementing standardized changeover protocols, improving operator training, and fostering clearer coordination between production and maintenance operations. Instead of defaulting to overtime and capacity growth, managers should utilize OEE as a diagnostic tool to identify concealed capacity and inform improvement goals. Furthermore, production planning decisions must account for SKU compatibility and process flow similarity to reduce unpredictability and enhance equipment performance stability.

Moreover, uniform interpretation and implementation of OEE are crucial for optimizing its efficacy. Organizations must define availability, performance, and quality losses explicitly and ensure that OEE data serves as a foundation for root cause analysis rather than solely as a reporting measure. Enhancing operator engagement in OEE-based projects can help bolster the sustainability of improvements, as shown by Tsarouhas (Tsarouhas, 2018).

In conclusion, this discourse affirms that OEE continues to be a formidable and pertinent framework for enhancing production lines when used as a comprehensive, improvement-focused instrument. Despite its limits, OEE's capacity to amalgamate maintenance effectiveness, production efficiency, and quality performance into a unified analytical framework renders it especially advantageous in intricate, multi-SKU manufacturing settings, such as the bakery, patisserie, and confectionery sectors. The results underscore the significance of contextual interpretation, uniform implementation, and ongoing enhancement in achieving the complete potential of OEE.

FINDINGS

The examination and integration of the analyzed literature disclose numerous significant discoveries about the utilization of Overall Equipment Effectiveness (OEE) as a theoretical framework for enhancing production lines in the bakery patisserie confectionery sector. The principal discovery is that setup and adjustment losses, especially those associated with temporal changes, constitute a key constraint on equipment availability in multi-SKU production settings. In accordance with Nakajima (Nakajima, 1988) and Muchiri and Pintelon (Muchiri and Pintelon, 2008), frequent and non-standardized changeovers markedly diminish effective operating time and obscure considerable latent capacity inside current production lines.

A significant discovery is that losses in availability do not happen in isolation; rather, they permeate across the entire production system, adversely impacting performance efficiency and quality stability. Extended downtime frequently leads to condensed production timelines and heightened operational stress, resulting in increased speed losses, small interruptions, and flaws in startup quality. The interconnectedness of availability, performance, and quality substantiates the integrated nature of OEE highlighted by Dal et al. (Dal et al., 2000) and strengthens the assertion that OEE aspects should be understood holistically rather than in isolation.

The results reveal that SKU diversity and process flow complexity significantly affect OEE outcomes. Allocating items with varying processing demands to a single production line heightens operational variability, prolongs setup times, and undermines equipment performance. This remark corresponds with Jonsson and Lesshammar (Jonsson and Lesshammar, 1999), who contended that OEE should facilitate production planning and line assignment decisions rather than function exclusively as a reporting statistic.

The review emphasizes that OEE is most effective when utilized as a diagnostic and improvement-focused framework rather than merely a quantitative key performance indicator. Research regularly demonstrates that businesses attain superior performance enhancement when Overall Equipment Effectiveness (OEE) is employed to pinpoint significant losses and direct focused corrective measures, rather than relying on absolute efficiency benchmarks (Muchiri and Pintelon, 2008, Andersson and Bellgran, 2011). The varying interpretation and calculation of OEE among organizations constitute a substantial restriction, diminishing its comparability and undermining its effectiveness as a catalyst for continual improvement.

Recommendations

Drawing on the principal findings and the examined literature, numerous practical and managerial advice are suggested for businesses within the bakery, patisserie, and confectionery sectors. Initially, companies ought to emphasize the systematic minimization of setup and adjustment losses by standardizing changeover protocols and explicitly delineating operator duties throughout product transitions. Minimizing changeover time significantly improves availability and facilitates superior exploitation of current production capacity without necessitating further capital expenditure.

Secondly, OEE should be established as a continuous improvement framework rather than only regarded as a performance reporting instrument. Managers are urged to utilize OEE results as inputs for root cause analysis and improvement planning, ensuring that recognized losses lead to implementable operational modifications. This method corresponds with the initial purpose of OEE within the TPM concept and augments its practical significance.

Third, production planning decisions must integrate SKU compatibility and process flow similarity to reduce variability and operational instability. When possible, allocating items with markedly distinct processing requirements to separate or more appropriate production lines can diminish setup complexity and enhance overall equipment efficacy.

Moreover, businesses must implement consistent definitions and calculation methodologies for availability, performance, and quality losses to guarantee the consistency and dependability of OEE data. Explicit interpretation criteria enhance managerial confidence in OEE outcomes and augment its efficacy as a decision-support instrument.

Ultimately, increased focus must be directed towards operator engagement and interdisciplinary cooperation between production and maintenance teams. Involving operators in loss detection and enhancement projects fosters ownership, sustainability, and the enduring efficacy of OEE-based solutions, as evidenced by Tsarouhas (Tsarouhas, 2018).

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