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ORIGINAL

Enhancing Operational Performance through Digitalization and Industry 4.0: A Comprehensive Model for Data Reliability and OEE Optimization

Mejora del rendimiento operativo a través de la digitalización y la industria 4.0: Un modelo integral para la fiabilidad de los datos y la optimización de la OEE

Abdelkarim AIT BRIK[1], Ahmed EN-NHAILI[1], Anwar MEDDAOUI[1]

[1]ENSAM Hassan II university, Industrial Engineering. Casablanca, Morocco.

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Editor: Adrián Alejandro Vitón-Castillo

Corresponding author: Anwar MEDDAOUI

ABSTRACT

In today's industrial context, three key elements are guiding the course of small and medium-sized enterprises (SMEs) towards improved productivity, efficient operations, and sustainable growth. The introduction of Industry 4.0 signifies a groundbreaking shift, integrating state-of-the-art technologies into manufacturing processes and propelling industries towards heightened efficiency and competitiveness. This article dealt with the crucial role of productivity measurement in SMEs and examined the impact of data reliability on operational performance assessment. It explored the strategic use of Industry 4.0 tools to enhance data reliability in processes like production, quality, and maintenance. The research focused on designing a comprehensive model for data collection, reliability, and utilization, ultimately aiming to improve Overall Equipment Effectiveness (OEE) within SMEs. By displaying the synergistic integration of Industry 4.0 advancements, the article provided practical insights for SME stakeholders to optimize operational performance. The proposed model contributes to the understanding and implementation of efficient methodologies for data management, fostering sustainable improvements using calculation of OEE within SMEs. The case study conducted in a plastics manufacturing SME that produced components for various industries. These findings can be enhanced and improved through additional case studies to refine the proposed model.

Keywords: Industry 4.0; SMEs; OEE; Industrial Performance; Plastics Industry.

RESUMEN

En el contexto industrial actual, tres elementos clave guían el rumbo de las pequeñas y medianas empresas (PYME) hacia la mejora de la productividad, la eficiencia de las operaciones y el crecimiento sostenible. La introducción de la Industria 4.0 supone un cambio revolucionario que integra las tecnologías más avanzadas en los procesos de fabricación e impulsa a las industrias hacia una mayor eficiencia y competitividad. Este artículo aborda el papel crucial de la medición de la productividad en las PYME y examina el impacto de la fiabilidad de los datos en la evaluación del rendimiento operativo. Exploraba el uso estratégico de las herramientas de la Industria 4.0 para mejorar la fiabilidad de los datos en procesos como la producción, la calidad y el mantenimiento. La investigación se centró en el diseño de un modelo integral para la recopilación, fiabilidad y utilización de datos, con el objetivo último de mejorar la eficacia general de los equipos (OEE) en las pymes. Al mostrar la integración sinérgica de los avances de la Industria 4.0, el artículo ofrece ideas prácticas para que las partes interesadas de las pymes optimicen el rendimiento operativo. El modelo propuesto contribuye a la comprensión y aplicación de metodologías eficientes para la gestión de datos, fomentando mejoras sostenibles mediante el cálculo de la OEE en las PYME. El estudio de caso se llevó a cabo en una PYME fabricante de plásticos que producía componentes para diversas industrias. Estas conclusiones pueden ampliarse y mejorarse mediante otros estudios de casos para perfeccionar el modelo propuesto.

Palabras clave: Industria 4.0; PYME; OEE; Rendimiento Industrial; Industria del Plástico.

INTRODUCTION

Industry 4.0 represents a revolutionary shift, integrating advanced technologies into manufacturing and enhancing efficiency and competitiveness. This fourth Industrial Revolution transforms strategies, organizations, business models, supply chains, and stakeholder relationships, creating new opportunities that need to be managed for positive impacts on business and society. Concurrently, Overall Equipment Effectiveness (OEE) becomes essential for optimizing machinery performance. Industry 4.0 emphasizes data transparency and clarity, while modern management methods like Lean focus on minimizing waste and ensuring value-added transparency. However, implementing these changes is particularly challenging for small and medium-sized enterprises (SMEs) in manufacturing, as they often exhibit low management maturity.(1)

Our article aims to deepen our understanding of the central role played by productivity measurement within small and medium-sized enterprises (SMEs). We strive to comprehensively breaking down the impact of data reliability on the accurate assessment of operational performance within these entrepreneurial structures. A prominent aspect of this research involves exploring how the innovative tools offered by Industry 4.0 can be judiciously utilized to enhance the reliability of data stemming from various processes such as production, quality, and maintenance. In this context, we delve into the design and implementation of a comprehensive model for data collection, data reliability, and data utilization. The ultimate goal of this model is to establish a robust methodology for improving Overall Equipment Effectiveness (OEE) within SMEs. We aim to demonstrate how Industry 4.0 advancements can be synergistically integrated into these processes to ensure increased data quality and reliability. By exploring these innovative avenues, we aspire to provide SME stakeholders with practical insights and informed recommendations on how to best leverage Industry 4.0 technologies to optimize their operational performance. In summary, our approach is geared towards making tangible contributions to the understanding and successful implementation of efficient methodologies for data collection, reliability, and utilization, thereby contributing to the sustainable improvement of OEE within SMEs.

Literature review

Industry 4.0 Dynamics

Industry 4.0 sets the stage for a comprehensive societal and technological transformation, reshaping the global landscape significantly. Information is seamlessly integrated into the components, allowing for tasks such as ordering missing parts and configuring individual production parameters. Concurrently, clients are continuously informed about the latest production status. As the plant commences operations, a wealth of additional data is generated. Precise output and real-time performance data of the products can be collected, analyzed, and fed back into the development process. In this context, Industry 4.0 technologies play a pivotal role in advancing and optimizing both new technologies and processes.

In Industry 4.0, business management relies, to some extent, on monitoring and analyzing collected data. Key components of smart manufacturing include processes, human/machine interactions, and the transition from paper to digital data. The primary objective is to establish a digital interaction mechanism for human-to-human, human-to-object, and object-to-object communication throughout the entire production process.(2)

Other researchers present a model application tailored for small and medium-sized enterprises (SMEs), providing a comprehensive overview of existing Industry 4.0 concepts. Concurrently, Müller suggests associating business model implications with Industry 4.0, utilizing the Business Model Canvas as a reference. Elements such as key resources and value propositions are identified as the most significantly influenced components of the business model, while channels are noted as being less affected.(3) Rauch et al. model supports SMEs in formulating an individual strategy for the successful implementation of Industry 4.0.(4)

In today's manufacturing landscape, production companies face a crucial mandate for both operational excellence and flexibility in their manufacturing and assembly operations. This imperative arises from the ongoing shift from mass production to mass customization.(5) The evaluation of industrial system effectiveness, encompassing processes and machinery, has a well-established history and remains a central focus in recent research.(6) Considerable attention has also been devoted to exploring the flexibility of manufacturing equipment and its interconnectedness in achieving overall manufacturing flexibility. Current research is dedicated to clarifying concepts, operationalization, measurement frameworks, and related aspects.(7)

Challenges and Opportunities

The discourse surrounding "Industry 4.0" and the broader digitization process revolves around internal discussions concerning the technological challenges and opportunities presented by recent advancements. There is also significant consideration given to the direct and indirect impacts on employment, encompassing both quantitative and qualitative aspects, as well as on labor conditions. In recent years, two distinct narratives have surfaced. From a firm-level perspective and grounded in managerial discussions, the narrative of "emerging opportunities" suggests that digitalization offers new possibilities for companies. This perspective envisions firms becoming more agile and intelligent, reducing inefficiencies, fostering collaborative working systems, and optimizing inter-organizational relations within what is termed 'industrial ecosystems'.(8) As emphasized by Cirillo et al., an opposing perspective arises from a reading that underscores the risks associated with the widespread digitalization and interconnection of processes.(9) These risks include the reinforcement of decision-making power without the centralization of production,(10) the resurgence of neo-Taylorization in work processes through the introduction of micromanagement practices and new forms of proceduralization characterized by extensive surveillance systems,(11 12) and the unequal distribution of power and information .(13)

Industry 4.0: Data Transformation Challenges

The emergence of Industry 4.0 and its consequential changes in process management significantly impact the interpretation and utilization of digital data. The principles of Industry 4.0 are inherently grounded in ensuring transparency and clarity of data throughout the entire process. Additionally, contemporary management methodologies, such as Lean principles, contribute to the imperative of transforming the value creation process. This transformation involves minimizing losses in non-value-added operations and enhancing the transparency of operations that contribute value. Implementing these changes, in line with 21st-century trends, presents a specific challenge for small and medium-sized enterprises (SMEs) in the manufacturing sector. This challenge is exacerbated by the relatively low level of managerial maturity exhibited by SMEs in this domain.(14)

The adoption of innovative technologies presents a challenge for small and medium-sized enterprises (SMEs), given their inherent weakness in handling complex procedures. This challenge is particularly evident in the context of Industry 4.0, where business management relies to some extent on the monitoring and analysis of collected data. Smart manufacturing, a vital aspect of Industry 4.0, includes elements such as processes, human/machine interactions, and the transition from paper to digital data. The primary objective is to establish a comprehensive digital interaction mechanism covering human-to-human, human-to-object, and object-to-object communication throughout the entire production process.(15)

METHOD

A general methodology figure 1 that will be utilized for developing a model enhancing Operational Performance by focusing on accurate data collection, integration of digital tools, and fostering an environment on continuous improvement.

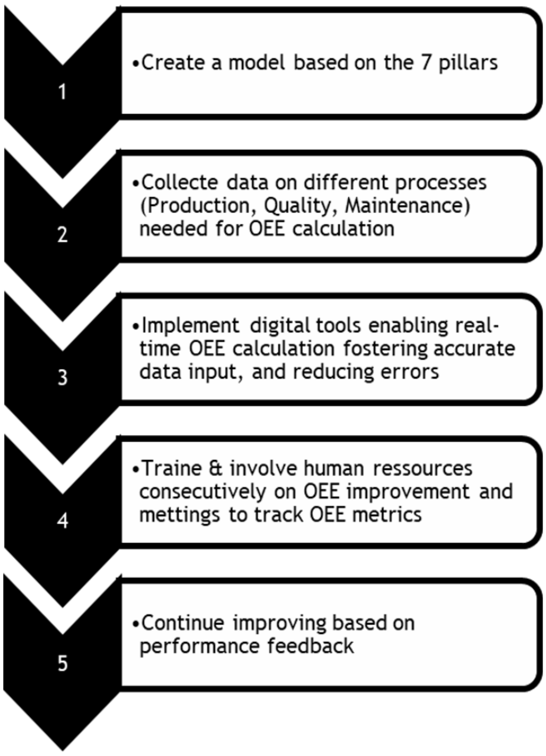

Figure 1. Followed methodology

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The purpose of the model

This study proposes an innovative approach to integrate Industry 4.0 technologies with robust data reliability management practices, aiming to elevate productivity in Small and Medium-sized Enterprises (SMEs), with a specific focus on the plastics industry. The research explores the synergies between smart manufacturing processes and advanced data management strategies, emphasizing the pivotal role of reliable data in optimizing operations and fostering sustainable growth.

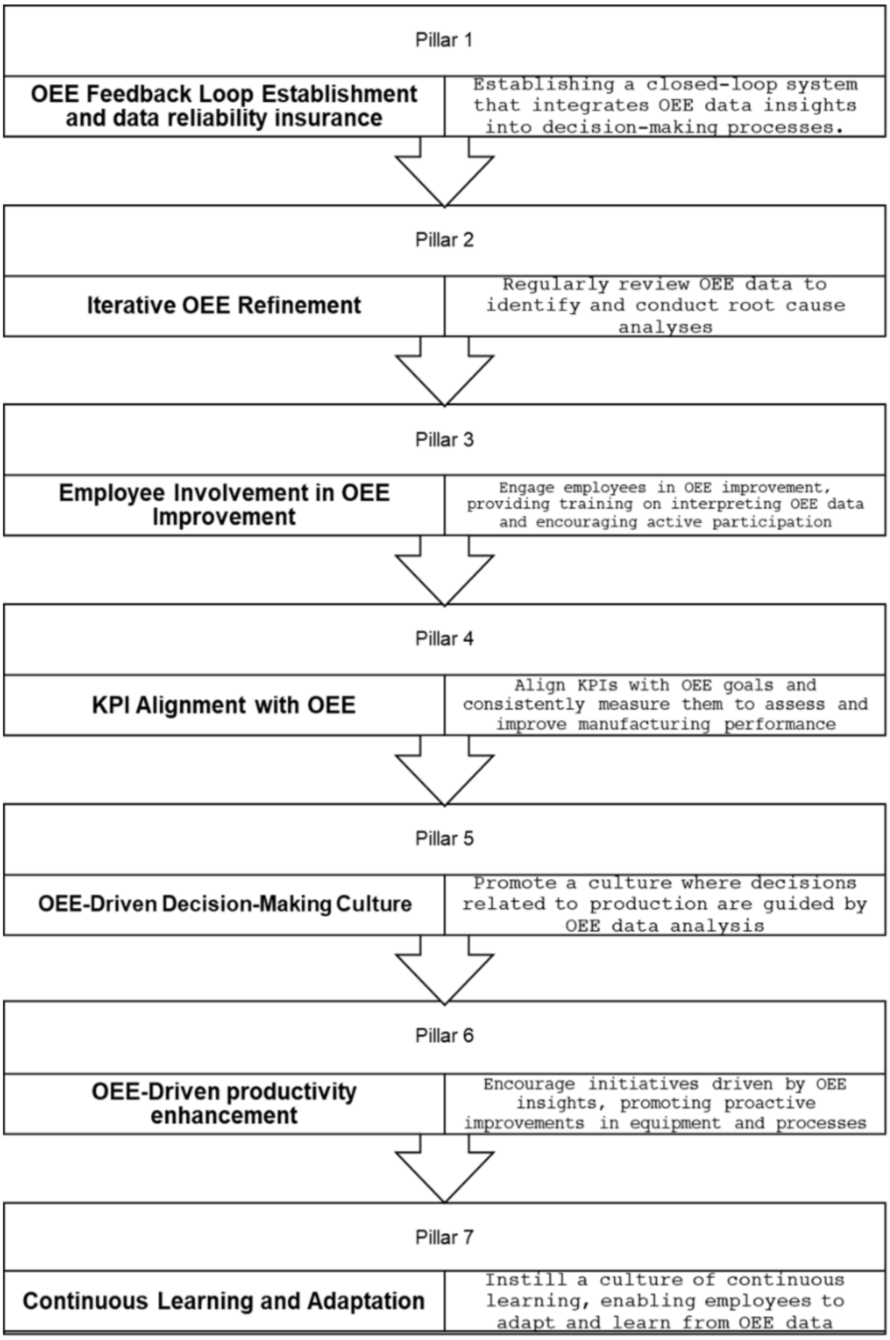

Figure 2. The proposed model of productivity enhancement through OEE

The proposed model is based on 7 pillars:

1. Feedback Loop Establishment: Establishing a closed-loop system that actively incorporates data insights into the decision-making process. Designing a feedback mechanism where real-time data from production processes informs decision-makers about current performance, enabling prompt adjustments and improvements.
2. Iterative Process Refinement: Cultivating a culture of continuous improvement by using data feedback to iteratively refine manufacturing processes.
3. Employee Involvement in Improvement: Fostering a culture where employees at all levels actively contribute insights and suggestions for process improvement.

4. Key Performance Indicator (KPI) Alignment: Ensuring that KPIs align with the overarching business goals and are regularly updated based on data insights.
5. Real-time Monitoring and decision-making: Infrastructure: Implementing tools for real-time monitoring of production processes and generating automated reports.
6. Data-Driven Innovation: Encouraging innovation initiatives that emerge from data insights, promoting a proactive approach to product and process enhancements.
7. Continuous Learning and Adaptation: Installing a culture of continuous learning, where employees are encouraged to adapt and learn from both successes and challenges identified through data.

The proposed model for operational performance using OEE

The model introduced in this section serves as a global framework. It will be used for its application in the context of productivity optimization with the OEE indicator. The sub-model proposed in the figure 2 represents a specific integration productivity enhancement.

CASE STUDY

In this case study, we examine a Small and Medium-sized Enterprise (SME) operating in the plastic industry, grappling with significant challenges in industrial performance primarily linked to organizational deficiencies. The current state of the production system reflects suboptimal performance, prompting the need for the proposed model to address these issues. The application focuses on restructuring organizational workflows (data collecting and analysis), implementing effective strategies to enhance operational performance, and optimizing resource allocation. Drawing insights from contemporary management methodologies, especially OEE and Total Productive Manufacturing and Industry 4.0 techniques, we aim to enhance value creation, streamline processes, and minimize non-value-added operations.

Data collection and decision-making process

The data filled in the manufacturing sheet SH1 by the production teams includes finished product references, their quantity and some machine parameters. The quality department records on the daily form (SH3) the number of non-conforming products, as well as parameters such as the weight and size of these products. The finished product storage warehouse, on its part, records the quantity of finished products and the product exits from the warehouse (sheet SH3). Figure 3 illustrates the flow of data collection in the process.

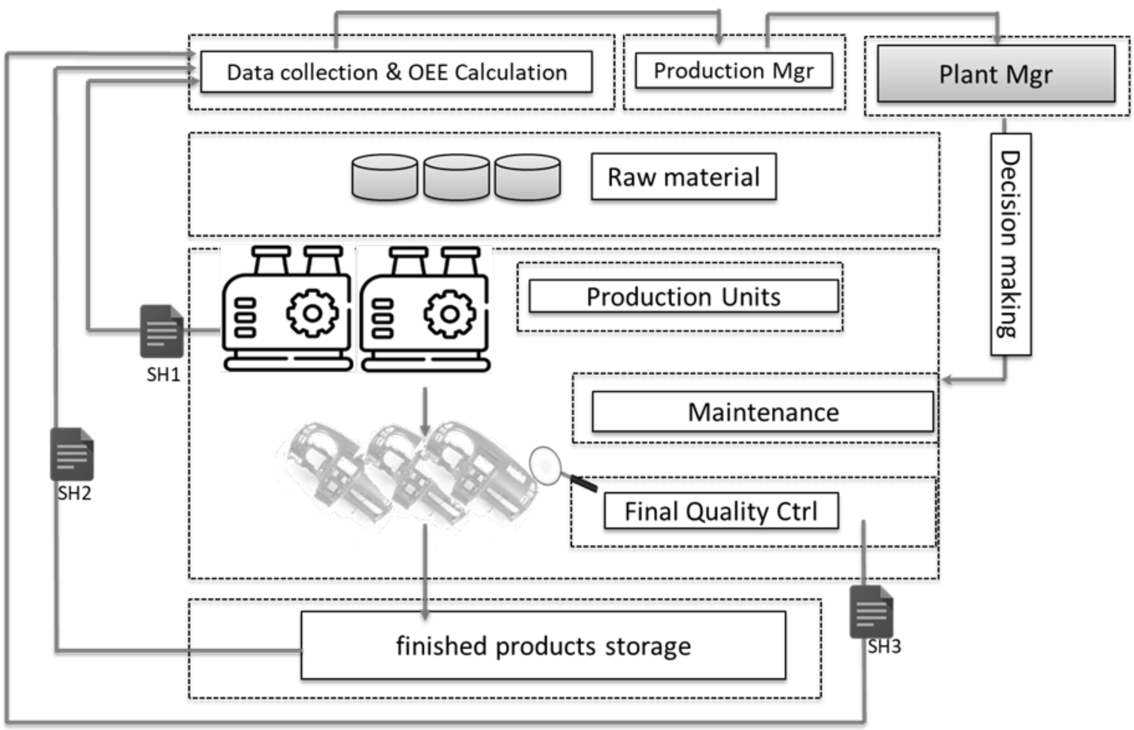

Figure 3. Initial data collection process, calculation of OEE and decision-making

In order to demonstrate the impact of poor organization on productivity outcomes, we will measure the OEE ratio for the four months preceding the implementation of the model. Below, Figure 4 illustrates the trend of OEE and its low value recorded despite the efforts of the production system.

Overview of OEE Calculation based on bellow variables:

OEE = Availability × Performance × Quality

$$\text{Availability} = \frac{\text{Run Time}}{\text{Planned Production Time}}$$

$$\text{Performance} = \frac{\text{Ideal Cycle Time} \times \text{Total Units}}{\text{Run Time}}$$

$$\text{Quality} = \frac{\text{Total good unit}}{\text{Total units}}$$

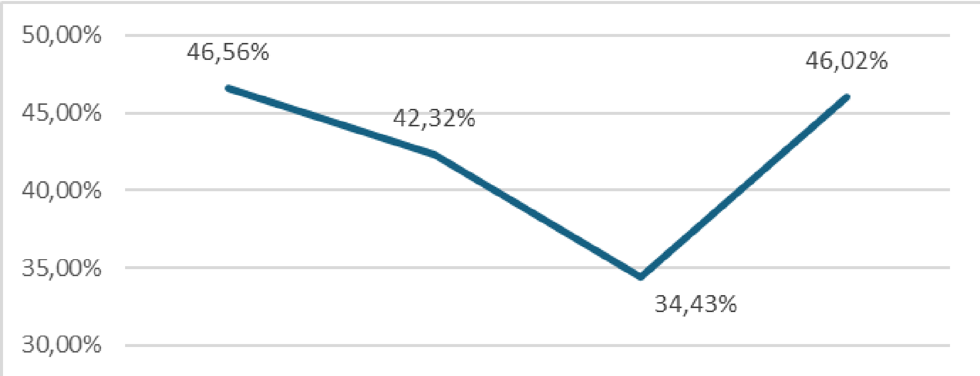

Figure 4. Evolution of OEE before implementing theproposed model

Data Reliability, OEE Calculation, and Their Impact on Decision-Making

Incomplete data, whether resulting from incomplete collection or insufficient input, poses a significant challenge in the context of analysis and decision-making. The accuracy of manually collected data is often prone to human errors, compromising the reliability of the information. Furthermore, the presence of multiple sources of data to calculate the same indicators can lead to inconsistencies and discrepancies in the results.

The absence of a reliable database also represents a significant obstacle.

A robust infrastructure is essential to ensure the consistency and integrity of data, and its absence can result in gaps in the overall understanding of available information. Additionally, dependence on claims and the urgent need for data verification add a dimension of time pressure, further compromising the quality and truthfulness of the gathered information. Thus, managing and improving data quality become crucial aspects to ensure a solid foundation for any analysis or decision-making process.

Implementation of the proposed model

After studying the problem in the production lines and to enhance operational efficiency, several strategic initiatives has been proposed. First, the transition from traditional data entry on sheets to the utilization of calculation tablets and digital files is recommended . This shift aims to streamline processes and eliminate manual data entry errors. Additionally, the calculation of Overall Equipment Effectiveness (OEE) is suggested on a shift-wise basis, as opposed to the conventional monthly assessment. This real-time approach provides more accurate insights into production efficiency and enables prompt corrective actions.

Furthermore, a comprehensive training program on OEE calculation is proposed, emphasizing its direct impact on productivity. This program will not only educate employees but also equip them with the knowledge needed to implement effective improvement strategies. Creating sub-indicators for availability, performance, and quality specific to each department ensures a targeted approach to addressing key operational aspects. Integrating frontline staff—operators, maintenance technicians, and quality agents—into weekly OEE tracking and action implementation meetings fosters collaboration and collective responsibility. To encourage a culture of continuous improvement, the establishment of idea boxes and incentive programs is suggested, encouraging operators and collaborators to contribute innovative ideas for productivity enhancement. Lastly, implementing semi-annual productivity review sessions, involving external training and discussions with industry experts, creates a forum for ongoing learning and strategic planning outside the day-to-day operational environment. Table 1 resumes all those established actions.

After several meetings with the plant director and fieldwork sessions, it was decided to implement actions following pillar 1 and 2, based on the established model using OEE, a strategy involving data collection by operators from each department. The analysis and verification of this data will be carried out by process managers (quality, maintenance manager, etc.). Only urgent actions will be initiated, if necessary. The Overall Equipment Effectiveness (OEE) calculation is performed by the calculation department, and a weekly action plan is established during a brief meeting. A more comprehensive action plan is formulated monthly and semi-annually in the presence of the plant director (see table 1).

Table 1. Applied actions in the plant using the proposed model

Pillar		Applied actions
Pillar 1	OEE Feedback Loop Establishment and data reliability insurance	Assign calculation tablets and digital files and eliminate data entry on sheets. Introduce a shift-wise calculation of OEE
Pillar 2	Iterative OEE Refinement	Review the OEE tracking on a daily and weekly basis instead of reviewing it monthly
Pillar 3	Employee Involvement in OEE Improvement	Make a training program on OEE calculation, its impact on productivity, and the actions to implement for improvement
Pillar 4	KPI Alignment with OEE	Creation of sub-indicators for availability, performance, and quality, respectively, for the maintenance department, quality department, and production department.
Pillar 5	OEE-Driven Decision-Making Culture	Integrate operators, maintenance technicians, and quality agents into the weekly OEE tracking and action implementation meetings (quick meetings)
Pillar 6	OEE-Driven productivity enhancement	Establish idea boxes and incentives to encourage operators and collaborators to propose new ideas for improving productivity
Pillar 7	Continuous Learning and Adaptation	Implement a semi-annual productivity review session involving a training and discussion cycle outside the company, within training program with experts

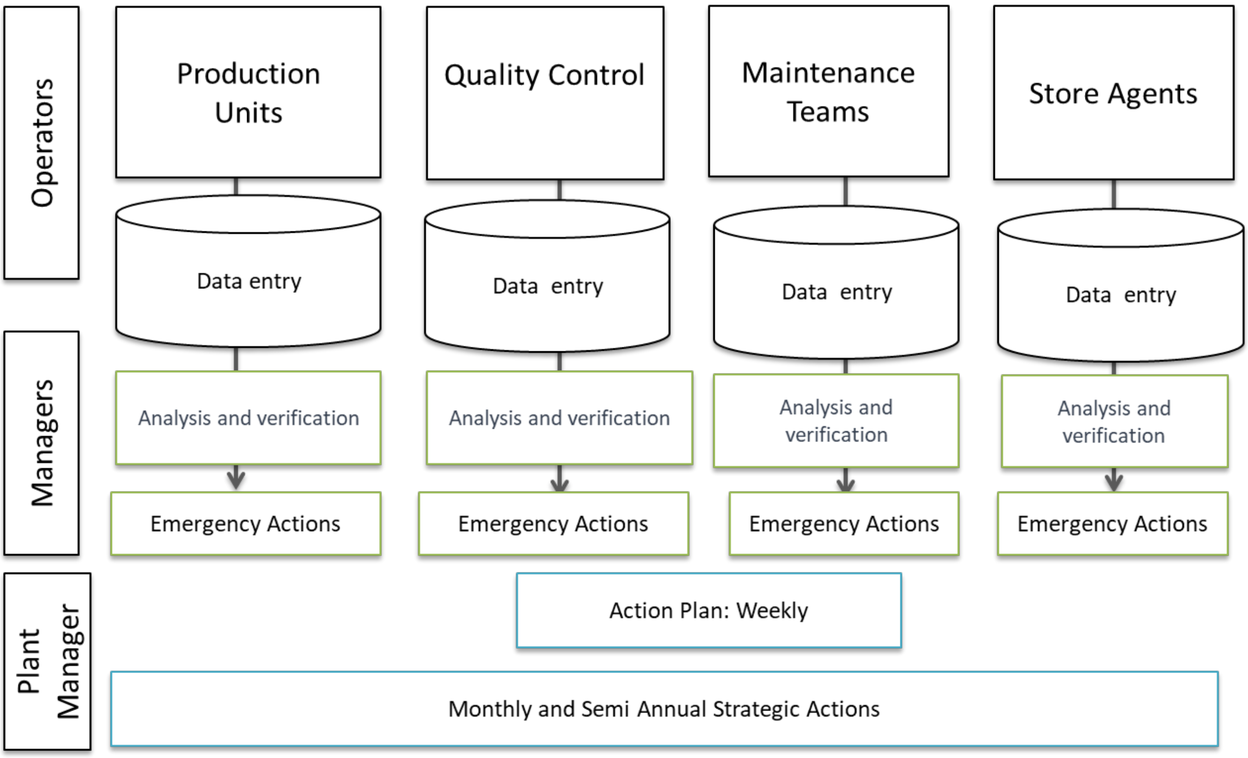

Figure 5. Organization of operational teams following pillars 1 and 2

The pillar 4, it has been introduced 11 KPI (see table 2), such as the number of conforming products and the product weight relative to the target, assess adherence to established standards. Performance indicators, including MTBF, MTTF, availability, and changeover time, provide insights into equipment reliability and operational efficiency. Human performance metrics, like machine rate per operator and corrective maintenance time, evaluate the effectiveness of workforce contributions to overall operational excellence.

Table 2. Sub indicators introduced in the pillar 4

KPI:	
Quality	
Number Conforming Product	Nb Units
Product weight / Target	%
% Waste	(Tn)
Number of Non-Conforming Product	(ppm)
Performance:	
MTBF (Mean Time Between Failure)	(Hour)
MTTF (Mean Time To Failure)	(Hour)
Availability	(%)
Change Over Time	(Hour)
Human Performance	
Machine Rate / operator	(Units/Hour)
Time of Corrective Maintenance / Maintenance Agent	(Hour)
PPM/ operator	(ppm)

RESULTS

Through the model proposed by our research team and the actions deployed in the field, along with the commitment of both management and operators, it was possible to make this proposed model feasible in the workshop. Significant improvements were achieved in the productivity of the studied production lines. It is important to note that these improvements are not temporary but sustainable, as we addressed the root causes within the organization by addressing issues related to data collection, analysis, and Overall Equipment Effectiveness (OEE) calculation. The OEE has been improved by several percentages since the information was gathered quickly and efficiently. Figure 6 shows the discussed improvement.

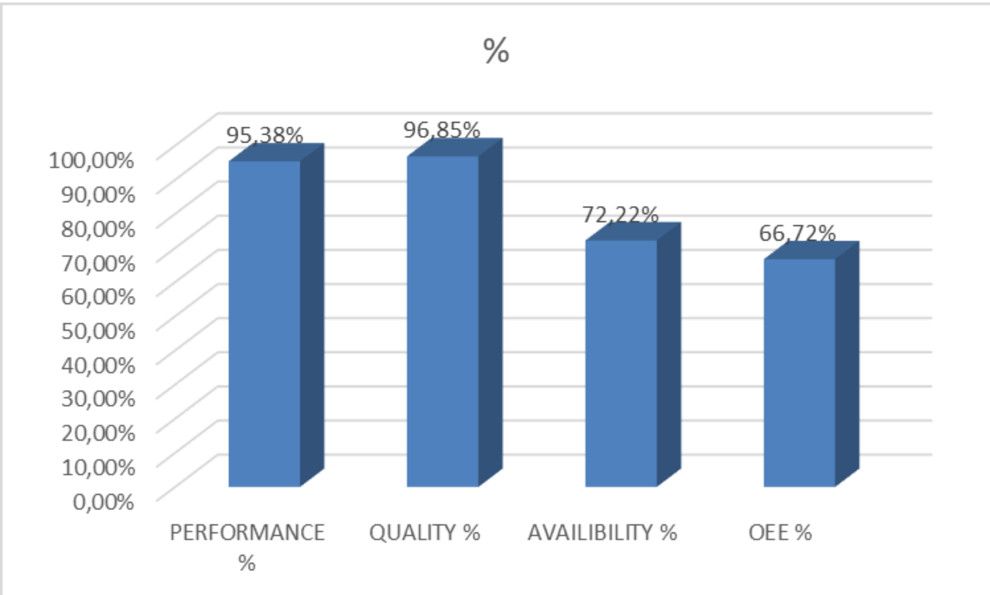

Figure 6. OEE evolution after implementation of the development model

The company's profits have increased, prompting decision-makers to consider further leveraging Industry 4.0 tools in automating performance tracking and expanding these efforts to other production lines.

CONCLUSION

The proposed model in this case study is underpinned by two fundamental elements crucial for measuring productivity within a Small and Medium-sized Enterprise (SME). First, it delves into the significance of input data for calculating OEE and explores strategies for leveraging this key performance indicator to enhance overall operational efficiency. Given that OEE is contingent on three primary factors, quality, performance, and availability of production equipment. The model advocates for the introduction of automated measures

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in the context of automated machinery. In instances where the implementation of automatic measures proves unfeasible, the model suggests a pragmatic alternative: the segregation of measures according to the pertinent departments. For instance, the quality factor is recommended to be overseen by the quality management function, and breakdown incidents are advised to be recorded by the production department rather than the maintenance unit. This approach ensures a more targeted and department-specific response to the multifaceted components influencing OEE.

Furthermore, the model embraces a comprehensive process-oriented approach. It emphasizes the integration of streamlined processes to enhance the overall efficiency of the production system. By fostering an automated or departmentally segregated approach to address different facets of OEE, the model envisions a holistic strategy that not only refines the measurement of productivity but also systematically enhances the performance of the SME. This forward-thinking methodology aims to fortify the SME against operational challenges and position it on a trajectory of sustained growth and competitiveness.

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AUTHORSHIP CONTRIBUTION
Conceptualization: Abdelkarim AIT BRIK, Ahmed EN-NHAILI, Anwar MEDDAOUI.
Data curation: Abdelkarim AIT BRIK, Ahmed EN-NHAILI, Anwar MEDDAOUI.
Formal analysis: Abdelkarim AIT BRIK, Ahmed EN-NHAILI, Anwar MEDDAOUI.
Research: Abdelkarim AIT BRIK, Ahmed EN-NHAILI, Anwar MEDDAOUI.
Methodology: Abdelkarim AIT BRIK, Ahmed EN-NHAILI, Anwar MEDDAOUI.
Project management: Abdelkarim AIT BRIK, Ahmed EN-NHAILI, Anwar MEDDAOUI.
Resources: Abdelkarim AIT BRIK, Ahmed EN-NHAILI, Anwar MEDDAOUI.
Supervision: Abdelkarim AIT BRIK, Ahmed EN-NHAILI, Anwar MEDDAOUI.
Display: Abdelkarim AIT BRIK, Ahmed EN-NHAILI, Anwar MEDDAOUI.
Writing - proofreading and editing: Abdelkarim AIT BRIK, Ahmed EN-NHAILI, Anwar MEDDAOUI.