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Improving Performance of the Confectionery Production Line Through Using Overall Equipment Effectiveness (OEE): A Case Study

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ABSTRACT: *This article examines the application of Overall Equipment Effectiveness (OEE) as a performance measurement tool to improve and enhance the productivity of confectionery production lines in a confectionary and ready-to-eat factory in Egypt. The case study comprises three phases, each involving interventions to enhance the production lines' availability, performance, and quality. The first phase establishes a baseline measurement of the status quo. The second phase focuses on improving the availability of production lines by introducing automation tools for sanitation. In contrast, the third phase involves restructuring the production lines by separating the seven previously produced products into two lines to reduce changeover time and improve availability. The study collects primary data through observations and surveys conducted over three months for each phase. The results demonstrate a significant improvement in the OEE scores for both production lines following the implementation of the interventions. The study also provides insights into the factors that affect the OEE scores, such as downtime, speed loss, and quality defects. The findings can be used to develop strategies to enhance productivity and competitiveness in the food industry.*
KEY WARDS: *Confectionery, Production lines, OEE, Changeover*

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I. INTRODUCTION

Competitiveness in the manufacturing industry is determined by the accessibility and productivity of the production facilities [1]. Because of this, it is crucial to have a valid performance indicator that considers the key components of productivity. One of the essential applied tools for measuring performance in the manufacturing business, overall equipment effectiveness (OEE), is a measure that does this [2]. OEE was first introduced by [3] as part of total productive maintenance (TPM) programs. Academics and practitioners still pay attention to OEE today.

In this study, the case of an Egyptian confectionery company has been examined to develop new procedures based on the lean production approach that will enable the business to decrease the mean time of the changeover process, increase overall equipment effectiveness (OEE), reduce overtime, and increase productivity. Confectionary businesses have recently been affected by product customization, growing complexity, and the need to address legislation specific to the sector. The OEE is an acknowledged measurement of internal efficiency [4], and it is the proper measure of value-added production by equipment [5].

By focusing on the actual levels of OEE using data from a reputable baker's confectionary Egyptian company based on two stock-keeping units (SKU) production lines collected under natural working conditions, this research addresses the gap between theory and practices and reduces the changeover time, thus reducing the direct cost associated with the production line of the confectionary plant, the ideal production scenario in the food sector calls for little to no stopping in the automatic and semi-automatic production lines. This is because any stoppage in a production line caused by the failure of the equipment will lead to a drop in productivity and problems in quality [6]. The study aims to analyze data from the past 12 months and suggest ways to improve OEE. The analysis compares results before and after applying alterations to the setup and changes in the changeover process that affect availability, thus affecting OEE results.

1.1 Background

Businesses should optimize their productivity to prevent unplanned manufacturing losses and eliminate defects. In return, this minimizes manufacturing costs, helps match customers' expectations or standards, and keeps the product competitive. The philosophy of total productive maintenance (TPM), adopted in the 1980s, resulted in a quantitative metric known as Overall Equipment Effectiveness (OEE) that measures many industries' productivity machinery [2]. The OEE is a function of three independent characteristics: availability (A), performance efficiency (PE), and quality rate (Q) [7].

OEE was introduced by [2], but its definition has evolved to become a fundamental performance statistic throughout the years [8]. The classification of losses in [2] into six significant losses in the elimination sequence only considers some variables that reduce capacity utilization, such as planned downtime, shortages of materials and workforce, etc. Planned and unplanned downtime losses as a function of Availability comprise the two most considerable losses necessary to evaluate the actual value of a machine's availability in its industry. Such losses are *failure of equipment* or breakdown losses such as time and quantity losses caused by equipment failure, breakdown, or product faults, and set up *and adjustment* incurred when the production of one item is swapped to another or a variety of items or when equipment is fine-tuned.

According to [1], The aim to stay competitive in any manufacturing business is based on the production facility's availability and efficiency. In contrast, [7] stated that the OEE tool's success as an essential quantitative tool for measuring productivity was limited to personal equipment. According to [9], additional causes of OEE losses, such as preventative maintenance, holidays, and off-shifts, were deemed unsuitable for the capital-intensive firm as initially described by detecting losses, characterized as activities that consume resources and provide no value; these losses were categorized into three categories: Availability, Performance, and Quality losses [10].

Muchiri & Pintelon concluded that OEE is a widely used and well-established metric for measuring and improving manufacturing equipment performance. They highlight the advantages of OEE, such as its ability to provide a comprehensive view of equipment performance, its ease of use, and the availability of OEE data collection software [10]. Some significant losses are discussed in [10]. Speed losses are necessary to calculate a machine's genuine performance value, and idling and minor stoppage occurs when production is briefly paused because of a machine malfunction which may result in serious capacity loss. Reduced speed relates to the gap between the equipment's theoretical and actual working speeds causing losses. Quality losses impact the final product's quality, resulting in significant economic losses for a factory due to the waste of resources and the expense of recycling. Quality losses originate from either defect in process/rework or reduced yield that occur between machine startup and stabilizing. OEE is an integrative measurement tool that encompasses maintenance effectiveness, production efficiency, and quality efficiency, as shown in Fig 1.1.

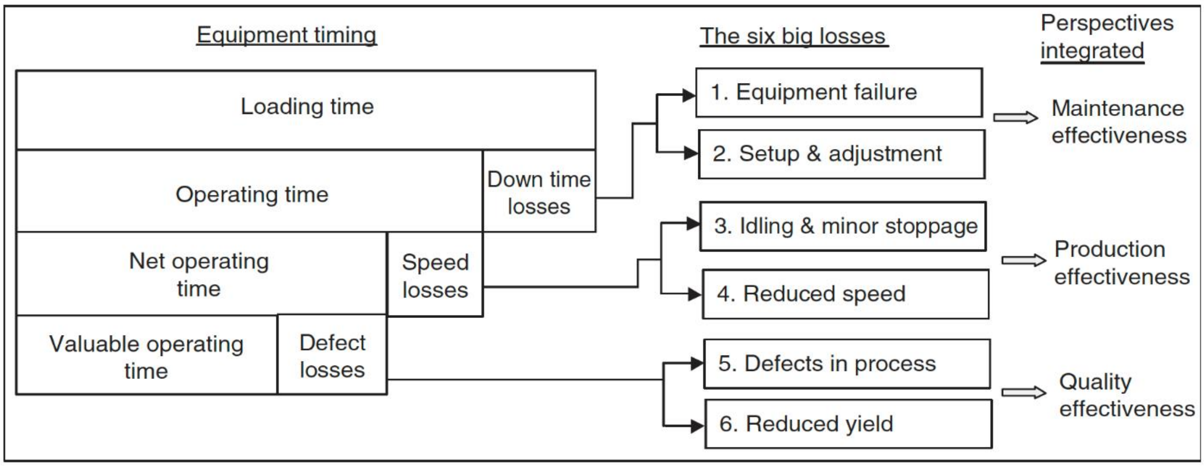

Figure (1.1) OEE measurement tool and the perspectives of performance integrated into the tool [10].

Overall Equipment Effectiveness (OEE) topic papers are an under-researched issue in the Egyptian manufacturing industry. Only [11] discussed and published the implementation of Total Productive Maintenance (TPM) and the measurement of Overall Equipment Effectiveness (OEE) in a manufacturing facility. In Egypt, particularly in the confectionery and patisserie business, there needs to be more case studies and research on implementing OEE, despite its extensive usage in other countries and industries. By implementing OEE in this industry in Egypt, the present study can contribute to the industry's growth and enhance its competitiveness in the worldwide market. In addition, the conclusions of this study might be extended to other sectors in Egypt, resulting in increased productivity and efficiency across the board. Reyes et al. provided the background of OEE and explored its limitation. The paper also shows the conceptual and mathematical development of ORE measurement and formulas for calculation.

Afefy discussed the implementation of Total Productive Maintenance (TPM) and the evaluation of Overall Equipment Effectiveness (OEE) in a manufacturing plant. The author begins by providing an overview of TPM and OEE, explaining their importance in manufacturing operations and highlighting the benefits of implementing them. Then goes on to describe the implementation of TPM and OEE in a case study of a manufacturing plant Salt Company (Emisal) in Egypt [11].

On the other hand, [12] described the calculation of OEE for an assembly process using a mathematical formula and provided an example of how it can be theoretically applied in a real-world scenario.

The OEE metric is used as a quantitative metric for the performance effectiveness of individual equipment or entire processes [13]; it assists in identifying possible losses and how corrective measures may be taken to lessen them. These measurements could be made on people, machines, and materials, increasing productivity. OEE offers a top-tier world-class status as it boosts productivity while improving labor efficiency as operators are more empowered, leading to operational visibility and improvements. It also results in fewer product reworks and scraps, improving the quality rate. In addition, it improves the equipment's life cycle management by reducing equipment downtime [7].

Empirical and simulation-based investigations and applications of ORE are carried out through two case studies for validation [14].

Braglia et al. have a different approach to discussing the importance of labor productivity measurement in manufacturing, for measuring labor productivity to evaluate the performance of a packaging line in a manufacturing company and the various metrics that have been developed for this purpose, such as Overall Equipment Effectiveness (OEE) and Labor Utilization [15].

Tsarouhas presented a case study of the croissant production line, in which the OEE metric was used to evaluate performance and identify areas for improvement. The author reports detailed data that concludes OEE is a powerful and effective tool for evaluating and improving manufacturing equipment performance and that its application led to an increase in the overall performance of the croissant production line [16].

Although the OEE definition is considered standardized globally**,** different companies still need to interpret the factors constituting this definition. These variations pose a challenge in using OEE as an improvement driver. Previous empirical studies showed variations between planned and unplanned time calculations and the set ideal time, which hurdles site comparisons. Structured and correct implementation and standardized calculations of OEE are essential to act as an effective driver for improvements aiming at achieving process stability [17].

1.2 Problem statements

The current research will investigate the effect of handling one of the six significant losses, which is the setup and adjustments (reducing changeover time), and how this affects the availability. Most manufacturing companies rapidly reside to increasing overtime, extra shifts, or even increasing the number of production lines when they face capacity constraints as the only viable solution to increase productivity. However, the present research shows that using OEE as a diagnostic tool can provide other solutions for enhancing performance using the existing capacity. The study also investigates how OEE could be a valuable tool to release concealed capacity without the cost of overtime, thus saving major capital expenditures and leading to higher profitability and competitiveness. In the selected case study, it has been noted that there is a vast overtime cost as a direct cost, and the production line needed to be appropriately managed to achieve the actual capacity. This is an overall equipment effectiveness problem and has negatively affected the production outcome, therefore, the company’s bottom line.

1.3 Research hypotheses

The primary purpose of this research is to focus on the three main pillars, which are availability, performance, and quality rate, and their effects on the OEE and their inter-relationship. Four hypotheses are proposed as follows:

Hypothesis #1:

Implementation of the OEE methodology to reduce changeover time will significantly increase availability in the confectionery production line.

Hypothesis #2:

Splitting different SKUs with different process flows over other production lines significantly impacts OEE results in the confectionery industry.

Hypothesis #3:

There is a significant interrelationship between the three main pillars of availability, performance, and quality rate, which affects OEE results in the confectionery production line.

Hypothesis #4:
Independent and moderating variables, such as equipment maintenance, operator skills, and environmental factors, significantly influence OEE in the confectionery industry, and leveraging them can improve performance.

The hypotheses will be validated by analyzing descriptive and evaluative data extracted from two assembly production lines. A comparison will be raised between before and after implanting OEE measurements. Finally, a recommendation method will be developed to determine which independent and moderating variable influences the OEE most.

II. MATERIAL AND METHODS

The present research will be carried out at a longitudinal time horizon by implementing OEE, revealing and highlighting the actual "Hidden capacity" by gathering data for nine months divided into three phases. Each phase lasts three months and is applied to the bakery and patisserie confectionary, two production lines. These production lines operate over one shift of 8 hours daily for six days per week. Data has been collected for two products manufactured simultaneously on these production lines: cakes and gateaux, referred to as SKU1 and SKU2, respectively. In both production lines, it starts with producing three types of SKU1(SKU1a, SKU1b, SKU1c), and it follows up with making four types of SKU2(SKU2a, SKU2b, SKU2c, SKU2d) through the same process. Every SKU shall require one hour of production. Based on implementing OEE in the first phase to clarify the status quo of the production line and the actual productivity, modification in downtime loss will be applied. Phase two focused on the measurements after enhancing the sanitation and changeover processes. Finally, phase three shows the measurements after separating SKUs (cake/gateaux) into independent production lines. The present research will rely on numerical data that will be analyzed using quantitative data analysis techniques. In other words, it adopts a quantitative mono-method.

2.1 OEE calculation

Since the present research aims at change and improvement in practice, OEE is calculated pre- and post-changes based on the factors: availability, performance, and quality as follows:

$$\text{OEE} = \text{Availability (A)} \times \text{Performance (P)} \times \text{Quality (Q)} \times \% \tag{1}$$

In order to determine the value of OEE, the losses that may occur during the production must be measured, and OEE constituents can correspondingly be calculated.

2.1.1 Downtime Losses

they include the following

- Organizational holidays t_{org} refer to the scheduled shutdown of the production line.
- Meal break downtime t_m is scheduled at a fixed time during the shift.
- Unplanned breakdown downtime t_{um} refers to unscheduled, unplanned production line interruptions resulting from equipment failures, unexpected breakdowns, or other technical issues resulting in significant losses in terms of time.
- Electrical & utility breakdowns t_{eu} refer to unscheduled interruptions in the production process caused by electrical or utility system issues.
- Raw material & packing material shortage downtime t_{rp} is considered as the disruptions in the manufacturing process caused by a lack of availability of necessary raw materials or packaging materials.
- Planned maintenance downtime t_{pm} refers to scheduled pauses in the production line to perform maintenance activities.
- Changeover and sanitation downtime t_c is transitioning from producing one product to another, requiring adjustments to the production line equipment and the proper raw material to accommodate the new product.
- Setup losses t_s are another type of changeover downtime induced when getting the machine ready to produce the product.

The overall downtime losses can be calculated as follows:

$$\text{Downtime losses} = t_{org} + t_m + t_{um} + t_{eu} + t_{rp} + t_{pm} + t_c + t_s \tag{2}$$

Accordingly, the operation time is:

$$\text{Operation time} = \text{Total available time} - \text{Downtime losses} \quad (3)$$

2.1.2 OEE parameters

Availability (A)
It reflects the time during which the line produces and generates revenue. It can be calculated as:

$$A = \frac{\text{Operation time} - \text{Downtime losses}}{\text{Operation time}} \quad (4)$$

Where Operation time is the total amount of time during which the production line is available and planned to run, including both scheduled and unscheduled downtime losses. At the same time, total Downtime is the (planned/unplanned) time during which the production line is not producing.

Performance (P)
It reflects the speed at which the line produces products. It can be calculated as:

$$P = \frac{\text{Actual pieces}}{\text{Planned pieces}} \times 100 \quad (5)$$

Actual pieces are the number of pieces produced by the production line considering any slowdowns or losses in productivity. In contrast, planned pieces are the number of pieces the production line can produce, assuming ideal conditions.

Quality (Q)
It determines the degree to which the produced units meet customer requirements and standards. It is often expressed as a percentage of suitable units produced and can be calculated by:

$$Q = \frac{\text{Good Units}}{\text{Actual Units}} \times 100 \quad (6)$$

Where Good Units are the number of units that meet customer requirements and standards; at the same time, actual units are the total number of good and defective units.

2.2 Production process

Because it regularly provides similar products (bakery products), the manufacturing process is primarily batch-line and consists of multiple workstations and machines. The plant runs on a semi-automated flow line that the operators monitor, and few interact in some of the processes. Fig. 2.1 shows a process flow diagram that clearly shows the sequence of stages in the manufacturing process. The goal is to estimate current operations management by computing OEE in the proposed bakery and patisserie production lines in Fig. 2.1. Data collection is concerned with the documentation of system reports in each shift.

The methodology's foundational steps are as follows:
(1) data collection that provides information about the design and use of the respective performance measurement systems during the manufacturing process, such as downtime losses, planned downtime, changeover, number of defects, and so on;
(2) calculation of OEE characteristics, including A, P, and Q and the OEE. By inspecting each category of losses related to OEE separately, it should be possible to identify the significant loss using the data.

The cake and gateaux production line under consideration comprises several workstations linked by a shared transfer mechanism and a common control system. Material is moved between stations automatically using mechanical means.

There are workstations for preparing and weighing raw materials, mixing ingredients, baking, cutting into shapes, cream filling, designing and finishing, and packing when making cakes and gateaux. Each workstation is located on a different section of the processing line.

The process flow of the line is as follows:
In Workstation 1: flour, water, and different amounts of ingredients and improvers, such as sugar, are fed into the mixer machine's removable bowl. When the mixing is finished, the bowl is removed from the mixer machine and loaded onto the elevator-tipping device, which lifts and tips it over to the dough extruder of the lamination machine in the next workstation.
In Workstation 2: the dough is laminated and placed on metal trays automatically inserted into carts.
In Workstation 3: the carts are being loaded into the oven. The trays are automatically removed from the carts and placed on a metal conveyor that runs through the oven. The trays bake for a specific time until the cake/gateaux are made. When the trays come out of the oven, they stay on the conveyor for a set amount to cool the cake/gateaux.
In Workstation 4: the cake/gateaux are shaped and formed by cutting into round/square shapes. Again, the trays remain on the conveyor and trace a trajectory for a set amount of time to allow the cake/gateaux to cool.
In Workstation 5: the cake/gateaux are filled with chocolate, cream, or jam via the pump.
In Workstation 6: the cake/gateaux are manually decorated with fruits, chocolates, or cream as required and moved to the next workstation.
In Workstation 7: the cake/gateaux are manually lifted from the trays and placed on the conveyor belt to be flow-packed by the wrapping machine in the next workstation.
In Workstation 8: the production line includes a manual wrapping process where the cake/gateaux are flow-packed. The empty trays are returned to the cake/gateaux-making machine automatically.

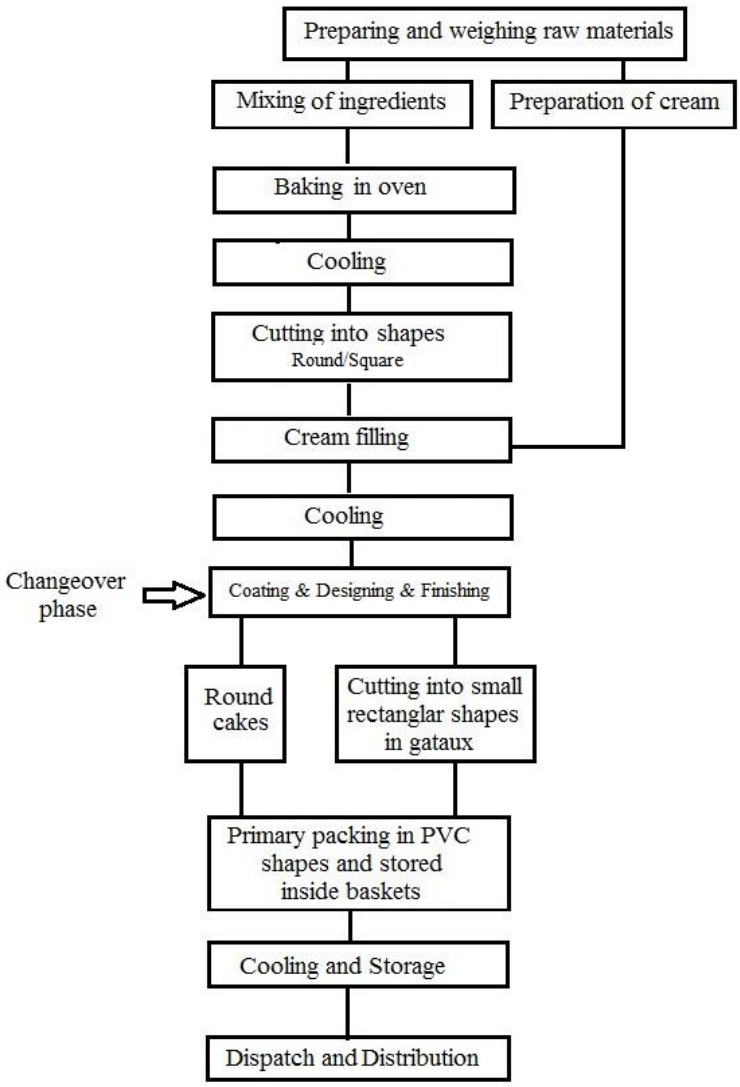

Figure (2.1) Process flow diagram

2.3 Data collection

Data collection can range from manual to automated, as accurate input of parameters obtained from the manufacturing system is required for OEE calculations. Manual data collection is accomplished by documenting the causes and duration of breakdowns, such as minor stoppages and speed losses. Automated data collection is based on equipment sensors and can record stoppages' start time and duration. Operators can use the automatic control to create a list of potential downtime causes, schedule available operating time, and create an automatic OEE calculation for any given period. Then it is simple to retrieve a variety of product performance reports. More information in the system can be a good use of time for operators when searching for each downtime causes.
Furthermore, automatic control is both costly and complex. As a result, it is necessary to use both manual and automatic data collection methods and operator training to qualify the quality of input data as operator competence increases. This increases the operators' involvement in identifying potential performance loss factors and providing accurate information to the system. Quantitative measurements for the OEE calculation were taken for both production lines over nine months.

Tables I and II show data collection for production line one and production line two, respectively. The data collected in this study include Total available time, shift length, Meal break t_m, Organizational holidays t_{org}, Unplanned maintenance downtime $t_{um,}$ Electrical & utility Breakdowns $t_{eu,}$ Raw material & packing material shortage downtime $t_{rp,}$ planned maintenance downtime $t_{pm,}$ Changeover and sanitation downtime $t_{c,}$ Setup losses $t_{s,}$ planned pieces, Actual pieces, and Reject pieces.
Months 1,2,3 represent Phase 1, while months 4,5,6 represent Phase 2, and months 7, 8, and 9 represent Phase 3.

III. RESULTS AND DISCUSSIONS

Results of downtime losses and their stoppage reasons in Cake and gateaux production for the selected items contribute to the values of OEE induced by the factors (Availability, Performance, Quality) and the overall OEE as presented in Tables III, IV for production lines one and two respectively. Months 1,2,3 represent Phase 1, while months 4,5,6 represent Phase 2, and months 7, 8, and 9 represent Phase 3 for both production lines.
The average OEE induced by the availability values is plotted in Fig. (3.1) and (3.2) for production lines one and two, respectively, along nine months during phases 1, 2, and 3.

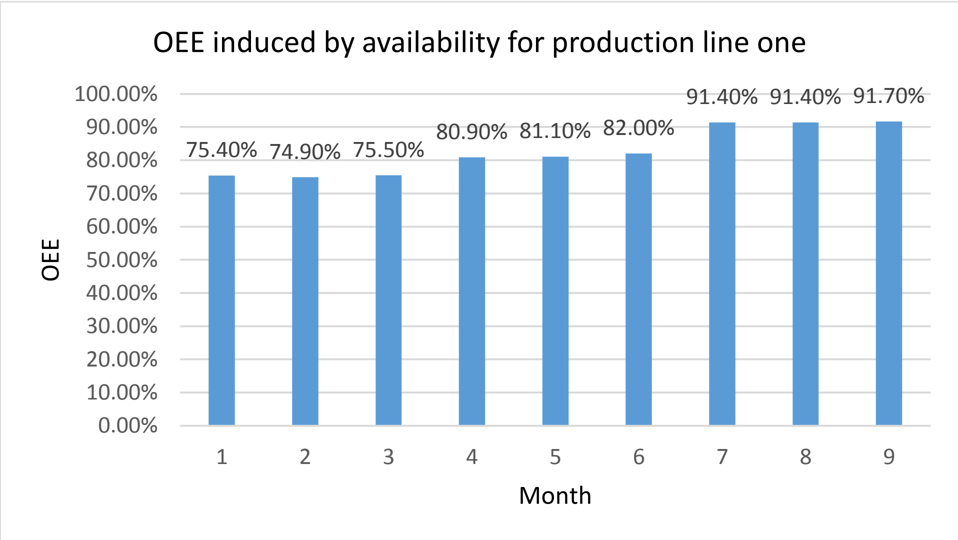

Figure (3.1) Monthly OEE induced by availability for production line one along nine months

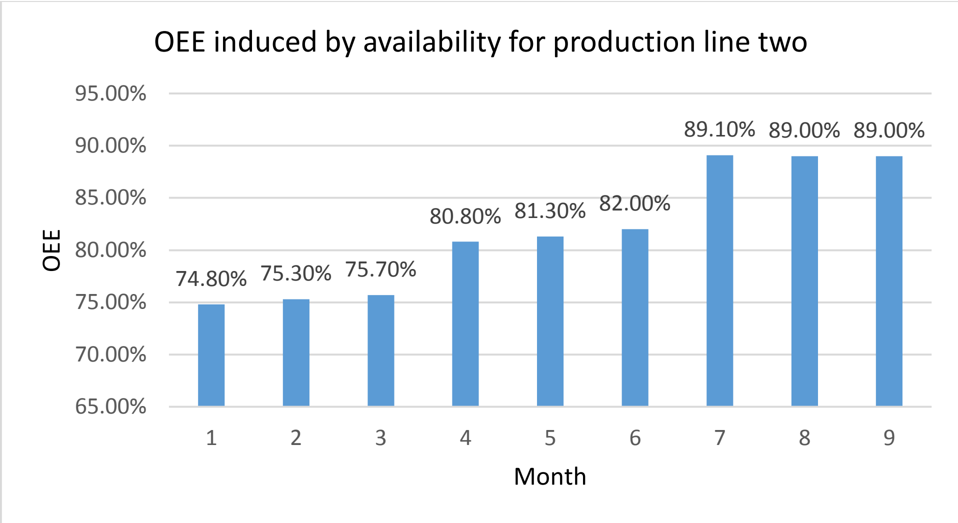

Figure (3.2). Monthly OEE induced by availability for production line two along nine months

From Fig. (3.1), (3.2), it is observed that:

- During phase 1, in which (SKU1a, SKU1b, and SKU1c) are produced, followed by (SKU2a, SKU2b, SKU2c, and SKU2d) in both production lines, the average OEE induced by the availability is at its lowest level (75.26% at lines 1,2) due to the significance of downtime loss which decreases the operating time compared to planned production time.
- During phase 2, in which (SKU1a, SKU1b, and SKU1c) are produced, followed by (SKU2a, SKU2b, SKU2c, and SKU2d) in both production lines with a modification in downtime loss induced by enhancing the sanitation and changeover processes, the average OEE caused by the availability is slightly increased to (81.33% at line 1 and 81.36% at line 2) as the operating time slightly rises than it was in phase 1.
- During phase 3, in which SKU1 is separated from SKU2 into independent production lines, the average OEE induced by the availability is increased to (91.5% at line 1 and 89.03% at line 2)as the operating time slightly rises than it was in phases 1, 2.

The average OEE induced by the performance values is plotted in Figures (3.3) and (3.4) for production lines one and two, respectively, along nine months during phases 1, 2, and 3.

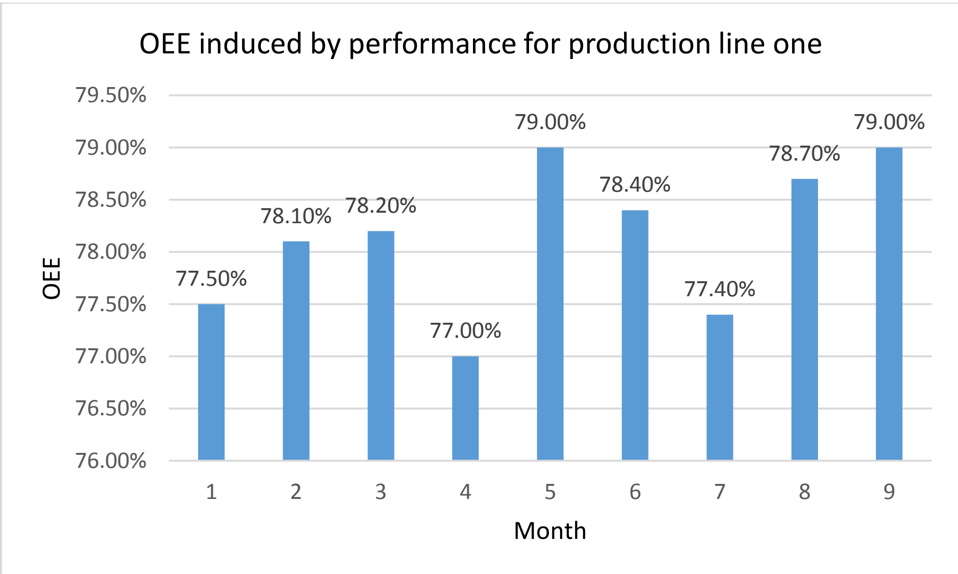

Figure (3.3) Monthly OEE induced by performance for production line one along nine months

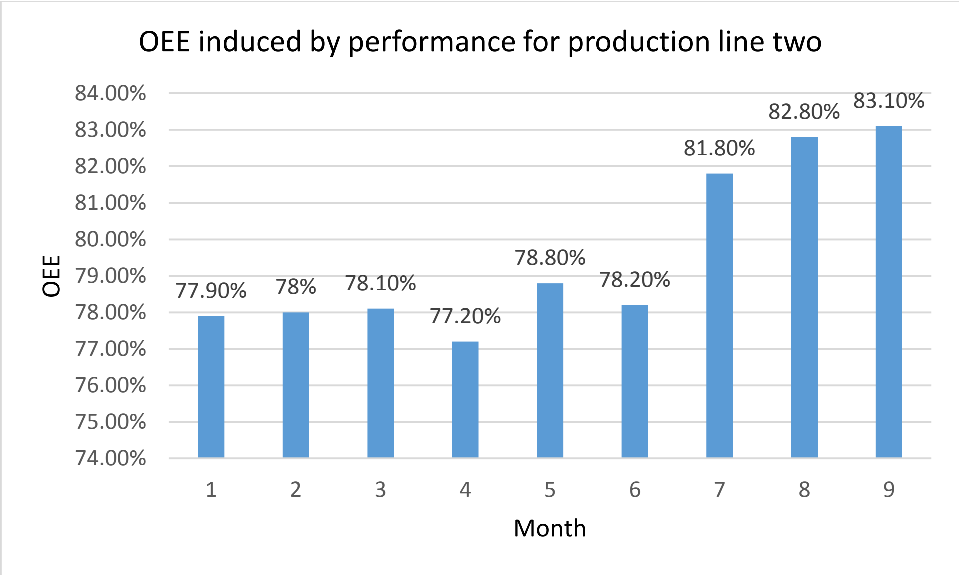

Figure (3.4) Monthly OEE induced by performance for production line two along nine months

From Fig. (3.3) and (3.4), it is observed that:

- During phase 1, in which (SKU1a, SKU1b, and SKU1c) are produced, followed by (SKU2a, SKU2b, SKU2c, and SKU2d) in both production lines, the average OEE induced by the performance is at its lowest level (77.93% at line 1 and 78% at line 2) due to the significance of downtime loss which decreases the number of actual pieces compared to the number of planned pieces.
- During phase 2, in which (SKU1a, SKU1b, and SKU1c) are produced, followed by (SKU2a, SKU2b, SKU2c, and SKU2d) in both production lines with a modification in downtime loss induced by enhancing the sanitation and changeover processes, the average OEE caused by the performance becomes (78.13% at line 1) and nearly still stable (78.06%) at line 2, which indicates that the number of actual pieces slightly rises at line 1 than it was in phase 1.
- During phase 3, in which SKU1 is separated from SKU2 into independent production lines, the average OEE induced by the performance becomes (78.36% at line 1 and 82.56% at line 2) as the number of actual pieces rises than it was in phases 1, 2.

The average OEE induced by the quality values is plotted in Fig. (3.5) and (3.6) for production lines one and two, respectively, along nine months during phases 1, 2, and 3.

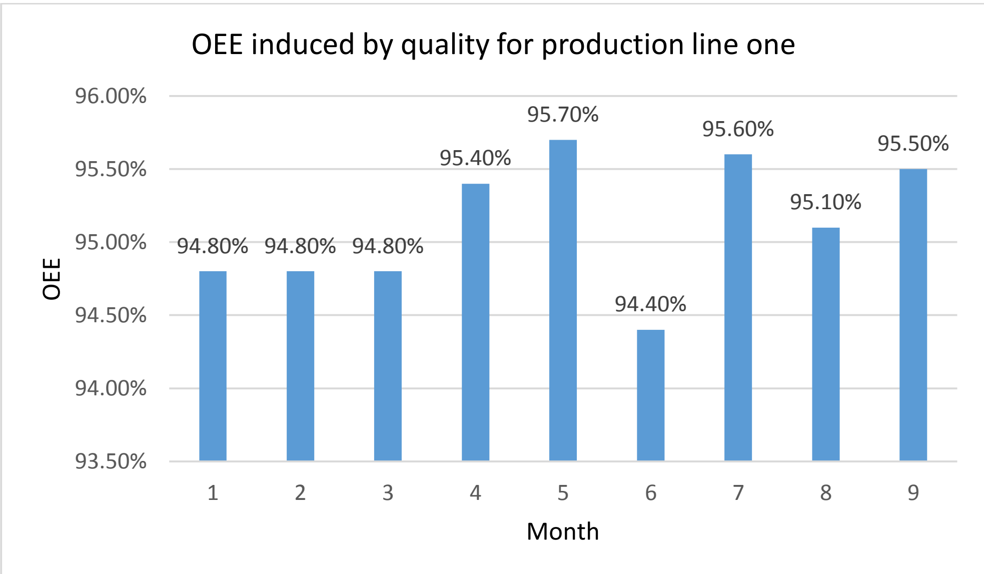

Fig (3.5) Monthly OEE induced by quality for production line one along nine months.

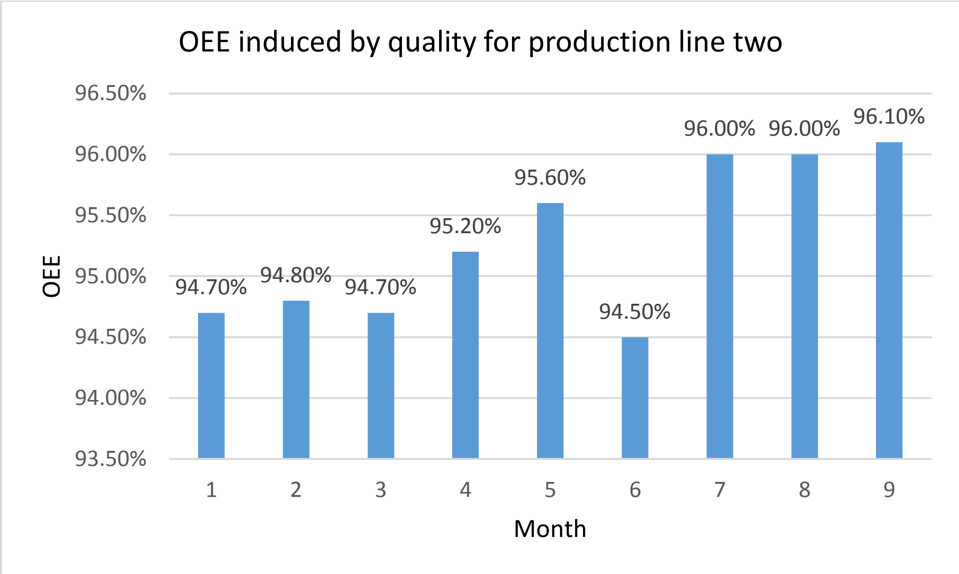

Fig (3.6) Monthly OEE induced by quality for production line two along nine months.

From Figures (3.5) and (3.6) it is observed that:

- During phase 1, in which (SKU1a, SKU1b, and SKU1c) are produced, followed by (SKU2a, SKU2b, SKU2c, and SKU2d) in both production lines, the average OEE induced by the quality is at its lowest level (94.8% at line 1 and 94.73% at line 2) due to the significance of downtime loss which decreases the number of good pieces compared to the number of actual pieces.
- During phase 2, in which (SKU1a, SKU1b, and SKU1c) are produced, followed by (SKU2a, SKU2b, SKU2c, and SKU2d) in both production lines with a modification in downtime loss induced by enhancing the sanitation and changeover processes, the average OEE induced by the quality becomes (95.16% at line 1 and 95.1%at line 2), which indicates that the number of good pieces slightly rises at production lines 1,2 than it was in phase 1.
- During phase 3, in which SKU1 is separated from SKU2 into independent production lines, the average OEE induced by the quality becomes (95.4% at line 1 and 96.03% at line 2) as the number of good pieces rises than it was in phases 1, 2.

Overall OEE values are plotted in Fig. 3.7 and 3.8 for production lines one and two, respectively, along nine months during phases 1, 2, and 3.

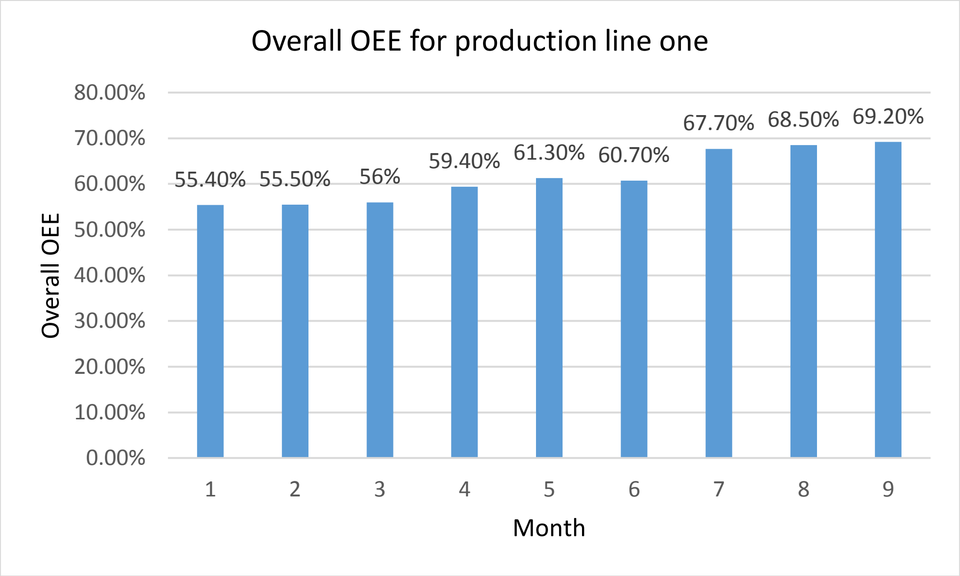

Fig (3.7) Monthly overall OEE for production line one along nine months

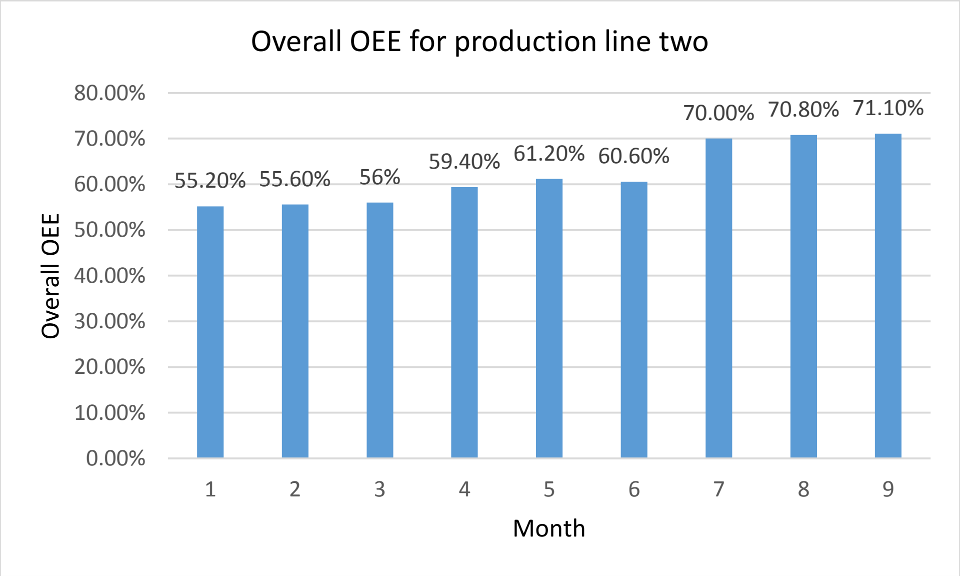

Fig (3.8) Monthly overall OEE for production line two along nine months

From Figures (3.7) and (3.8) it is observed that:

- During phase 1, in which (SKU1a, SKU1b, and SKU1c) are produced, followed by (SKU2a, SKU2b, SKU2c, and SKU2d) in both production lines, the overall OEE is at its lowest level (55.63% at line 1 and 55.6% at line 2) due to the significance of downtime loss which reduces the availability and implies fine effect on the performance and quality factors.
- During phase 2, in which (SKU1a, SKU1b, and SKU1c) are produced, followed by (SKU2a, SKU2b, SKU2c, and SKU2d) in both production lines with a modification in downtime loss induced by enhancing the sanitation and changeover processes, the overall OEE increased to (60.46% at line 1 and 60.4%at line 2), which indicates that the improved availability notably improves the average OEE. Both performance and quality add subtle positive effects to OEE at production lines 1, and 2 than in phase 1.
- During phase 3, in which SKU1 is separated from SKU2 into independents production lines, the overall OEE improved to (68.46% at line 1 and 70.63% at line 2) as the availability significantly enhanced, and both performance and quality added fine positive effect to OEE than in phases 1, 2.

The analysis of Phase 1 and Phase 3 shows a significant increase in overall OEE by 12.83% at Line 1 and 15.03% at Line 2.

Figures (3.9) and (3.10) display the monthly variation in average OEE induced by availability performance and quality and the corresponding overall OEE for production lines one and two, respectively, during phases 1, 2, and 3.

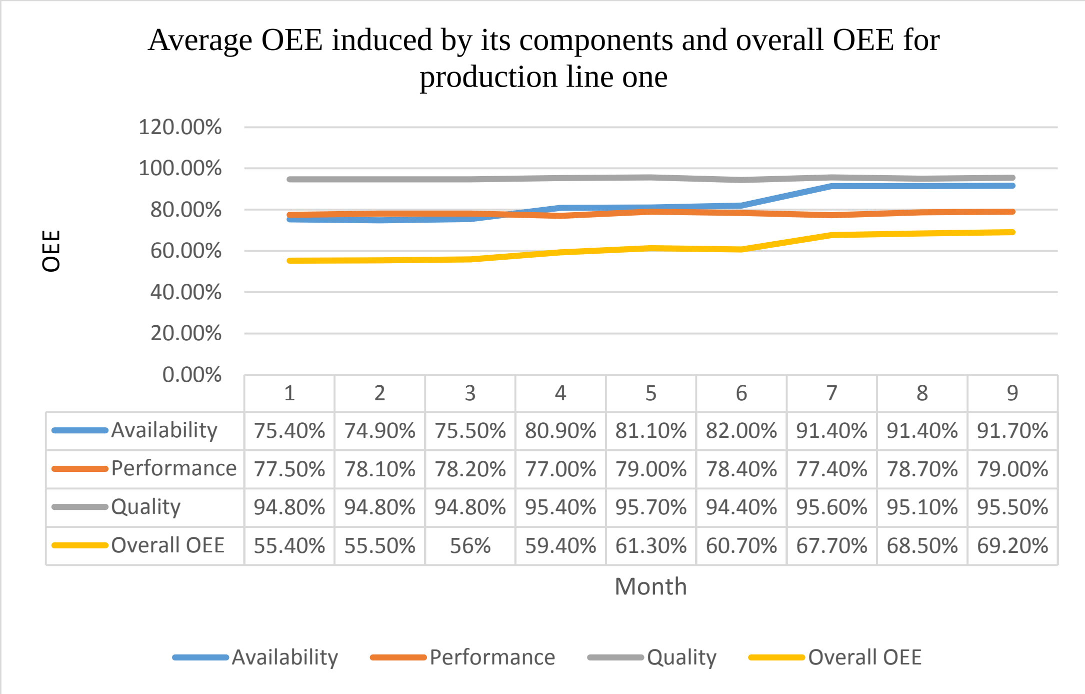

Figure (3.9) Variation in average OEE and corresponding overall OEE along nine months for production line one

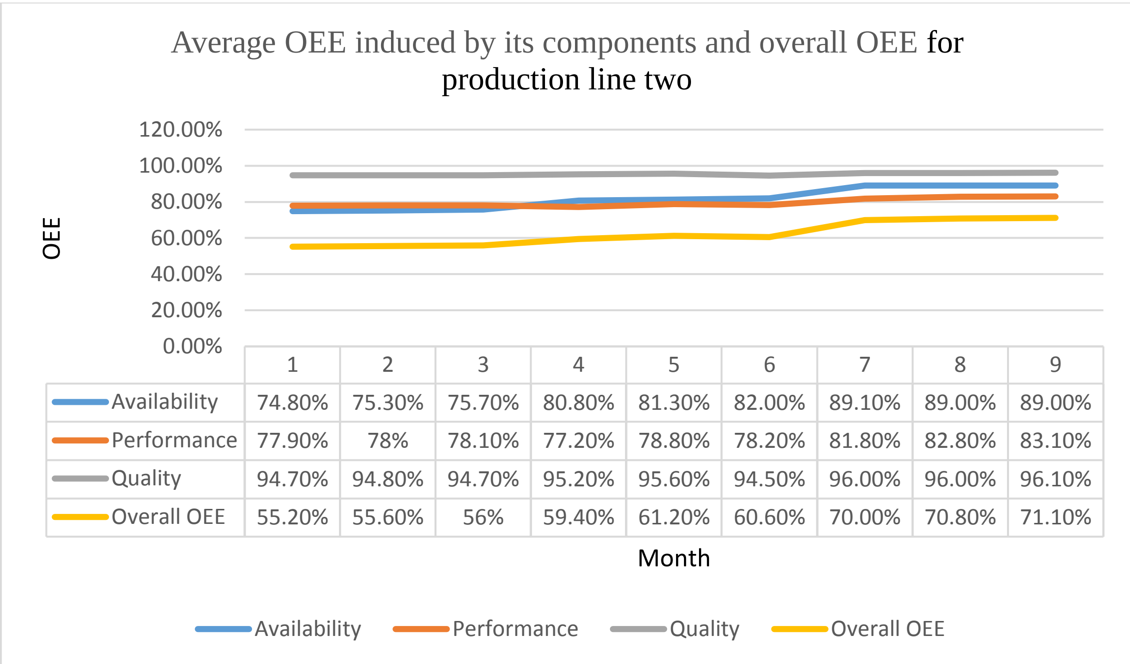

Figure (3.10) Variation in average OEE and overall OEE along nine months for production line two.

From Fig. (3.9) and (3.10), the analysis of Phase 1 and Phase 3 shows:

- A notable improvement in the average OEE was induced by the availability of 6.07% at line 1 and a significant improvement at 13.77% at line 2.
- slight variation in the average OEE induced by a performance of 0.43% at line 1 and little improvement by 4.56% at line 2.

- slight variation in the average OEE induced by the quality (0.6%) at line 1 and (1.3%) at line 2.
- significant increase in the overall OEE by 12.83% at line 1 and 15.03% at line 2.

This refers to availability as the most influential contributor to the OEE.

Tables V and VI show the progress in the production of SKU1 and SKU2 at both production lines 1 and 2, respectively.

During phase 1 (Months one, two, three): the production process of (SKU1a, SKU1b, and SKU1c), followed by (SKU2a, SKU2b, SKU2c, and SKU2d) was as follows:

- At production line one:
- The average planned pieces of SKU1 and SKU2 were 20629 and 81233, respectively, leading to total average planned pieces of 101862 (Fig 3.11).
- the average Actual pieces of SKU1 and SKU2 pieces were 15910and 63467 respectively, leading to total average actual pieces of 79377(Fig 3.11).
- At production line two:
- The average planned pieces of SKU1 and SKU2 were 20591 and 81405respectively, leading to total average planned pieces of 101996 (Fig 3.12).
- the average Actual pieces of SKU1 and SKU2 pieces were 15972 and 63505respectively, leading to total average actual pieces of 79477(Fig 3.12).

The low production at both lines was affected by the overall OEE, which was at its lowest level (55.63% at line one and 55.6% at line two) due to the low availability.

During phase 2 (Months 4, 5, 6): the production process of (SKU1a, SKU1b, and SKU1c), followed by (SKU2a, SKU2b, SKU2c, and SKU2d) was improved as follows:

- At production line one:
- the average planned pieces of SKU1 and SKU2 were 22475and 88567 respectively, leading to total average planned pieces of 111042(Fig 3.11).
- the Actual average pieces of SKU1 and SKU2 pieces were 17730 and 69070, respectively, leading to total average actual pieces of 86800(Fig 3.11).
- At production line two:
- the average planned pieces of SKU1 and SKU2 were 22447 and 88468respectively, leading to total average planned pieces of 110915(Fig 3.12).
- the average Actual pieces of SKU1 and SKU2 pieces were 17700 and 68967respectively, leading to total average actual pieces of 86667(Fig 3.12).

The production at both lines was improved as the overall OEE increased to (60.46% at line one and 60.4%at line two) due to the improvement in the availability resulting from the modification in downtime loss induced by enhancing the sanitation and changeover processes. This modification led to an increment in the production of SKU1 and SKU2 to 109% compared to phase 1.

During phase 3 (Months 7, 8, 9): the production process of SKU1 separated from SKU2 into independents production lines (line one and line two) was improved as follows:

- At production line one:
- the average planned pieces of SKU1 was63209(Fig 3.11).
- the average Actual pieces of SKU1 was 47228(Fig 3.11).
- At production line two:
- the average planned pieces ofSKU2 was 169383(Fig 3.12).
- the average Actual pieces of SKU2 was143417(Fig 3.12).

The production at both lines was improved as the overall OEE increased to (68.46% at line one and 70.63% at line two) due to the separation of the two products, which enhanced the availability and decreased the changeover time. This led to an increment in SKU1 and SKU2 production to 148.1% and 112.9%, respectively, compared to phase 1.

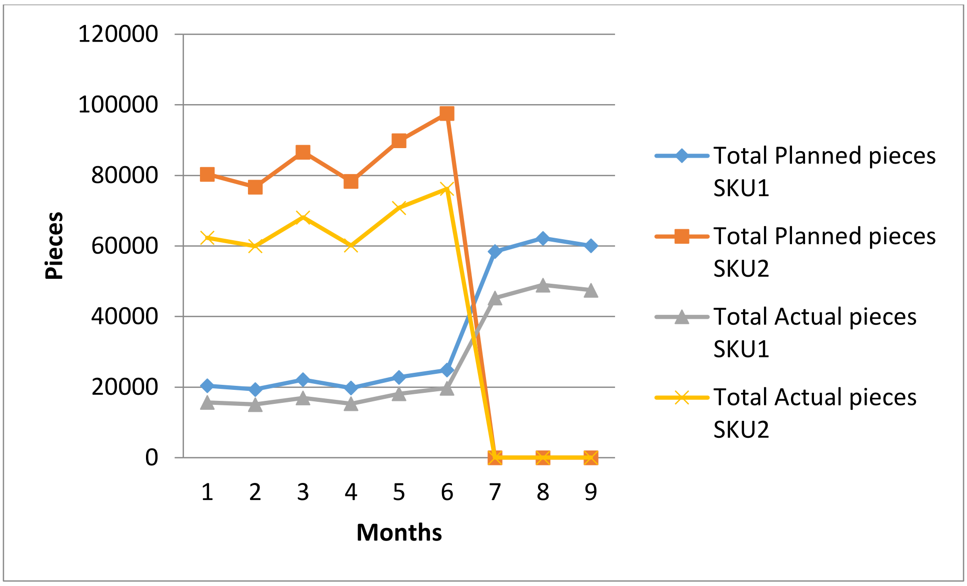

Figure (3.11) Production progress of SKU1 and SKU2 at production line one

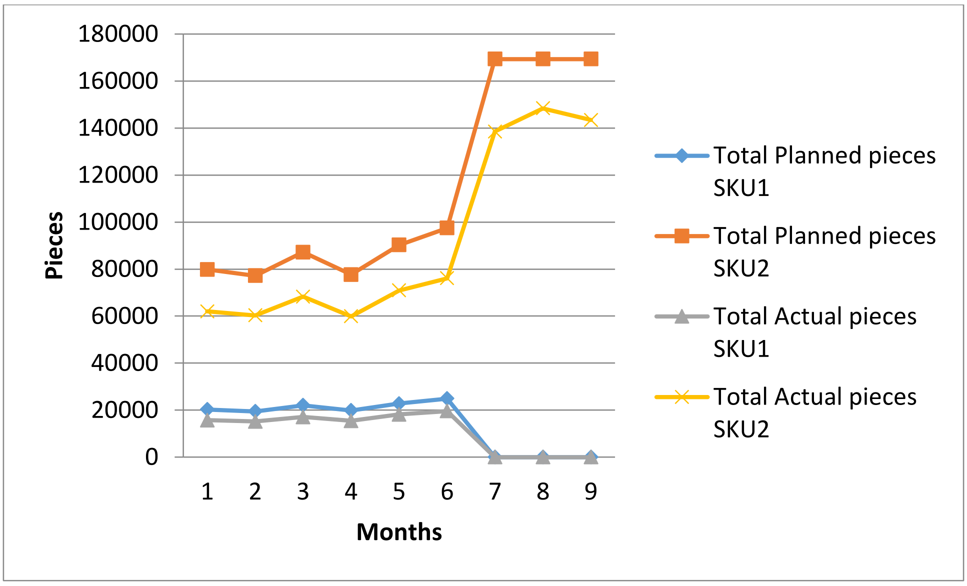

Figure (3.12) Production progress of SKU1 and SKU2 at production line two

Table I Data collection for production line one

	Month one	Month two	Month three	Month four	Month five	Month six	Month seven	Month eight	Month nine
Production data	Time in min in Production Line one								
Total available time	14880	13440	14880	14880	14400	14880	14400	14880	14880
Shift length	480	480	480	480	480	480	480	480	480
Meal break t_m	1500	1440	1620	1320	1560	1680	1500	1620	1560
Organizational holidays t_{org}	2880	1920	1920	4320	1920	1440	2400	1920	2400
Unplanned maintenance downtime t_{um}	17	13	17	9	30	15	28	24	22
Electrical & utility Breakdowns t_{eu}	46	49	38	59	57	24	32	30	32
Raw material & packing material shortage downtime t_{rp}	23	33	33	28	33	16	42	29	18
Planned maintenance downtime t_{pm}	16	9	17	23	38	19	19	12	17
Changeover and sanitation downtime t_c	2126	2075	2282	1407	1652	1765	530	589	554
Setup losses t_s	357	348	388	236	253	283	256	287	265
Planned pieces	100694	96100	108715	98082	112644	122402	58435	62187	60059
Actual pieces	78012	75086	85035	75482	88955	95965	45250	48960	47475
Reject pieces	4039	3907	4443	3475	3826	5330	1971	2401	2156
Planned production time	10500	13440	11340	9240	10920	11760	10500	11340	10920
Operation time	7915	7553	8565	7478	8857	9638	9593	10369	10016
Good pieces	73973	71179	80592	72007	85129	90635	43279	46559	45319

Table II Data collection for production line two

	Month one	Month two	Month three	Month four	Month five	Month six	Month seven	Month eight	Month nine
Production data	Time in min in Production line two								
Total available time	14880	13440	14880	14880	14400	14880	14400	14880	14880
Shift length	480	480	480	480	480	480	480	480	480
Meal break t_m	1500	1440	1620	1320	1560	1680	1500	1620	1560
Organizational holidays t_{org}	2880	1920	1920	4320	1920	1440	2400	1920	2400
Unplanned maintenance downtime t_{um}	21	22	24	26	23	6	25	19	38
Electrical & utility Breakdowns t_{eu}	46	50	38	59	57	25	30	33	31
Raw material & packing material shortage downtime t_{rp}	24	19	40	27	29	6	29	24	35
Planned maintenance downtime t_{pm}	17	17	8	27	39	16	16	15	20
Changeover and sanitation downtime t_c	2156	2030	2252	1386	1619	1781	793	877	804
Setup losses t_s	377	355	395	249	272	286	248	278	268
Planned pieces	100009	96658	109226	97507	113054	122385	169381	179140	172576
Actual pieces	77666	75410	85358	75292	89034	75676	138491	148366	143394
Reject pieces	4098	3957	4542	3635	3941	5262	5473	5885	5568
Planned production time	10500	10080	11340	9240	10920	11760	10500	11340	10920
Operation time	7859	7588	8583	7466	8881	9640	9359	10094	9724
Good pieces	73568	71453	80816	71657	85093	90414	133018	142481	137826

Table III Calculation of Average OEE for production line one

	Month one	Month two	Month three	Month four	Month five	Month six	Month seven	Month eight	Month nine
OEE factor	Average OEE for Production Line one								
Availability	75.4%	74.9%	75.5%	80.9%	81.8%	82.0%	91.4%	91.4%	91.7%
Performance	77.5%	78.1%	78.2%	77.0%	79.0%	78.4%	77.4%	78.7%	79.0%
Quality	94.8%	94.8%	94.8%	95.4%	95.7%	94.4%	95.6%	95.1%	95.5%
Overall OEE	55.4%	55.5%	56.0%	59.4%	61.3%	60.7%	67.7%	68.5%	69.2%

Table IV Calculation of Average OEE for production line two

	Month one	Month two	Month three	Month four	Month five	Month six	Month seven	Month eight	Month nine
OEE factor	Average OEE for Production line two								
Availability	74.8%	75.3%	75.7%	80.8%	81.3%	82.0%	89.1%	89.0%	89.0%
Performance	77.9%	78.0%	78.1%	77.2%	78.8%	78.2%	81.8%	82.8%	83.1%
Quality	94.7%	94.8%	94.7%	95.2%	95.6%	94.5%	96.0%	96.0%	96.1%
Overall OEE	55.2%	55.6%	56.0%	59.4%	61.2%	60.6%	70.0%	70.8%	71.1%

Table V Production progress of SKU1 and SKU2 on production line one

	Month one	Month two	Month three	Month four	Month five	Month six	Month seven	Month eight	Month nine
Production data	Production line one								
Planned pieces SKU1a	5715	5415	6140	5730	6315	6890	58435	62187	60059
Planned pieces SKU1b	6756	6450	7332	6582	7584	8286			
Planned pieces SKU1c	7945	7497	8638	7455	8911	9674			
Planned pieces SKU2a	18096	17376	19632	17616	20048	21936			
Planned pieces SKU2b	19142	18156	20893	18581	21250	23494			
Planned pieces SKU2c	20520	19746	21780	20178	22896	24822			
Planned pieces SKU2d	22600	21460	24300	21940	25640	27300			
Total Planned pieces SKU1	20416	19362	22110	19767	22810	24850	58435	62187	60059
Total Planned pieces SKU2	80358	76738	86605	78315	89834	97552	0	0	0
Total Planned pieces	100774	96100	108715	98082	112644	122402	58435	62187	60059
Actual pieces SKU1a	4178	4040	4544	3906	4652	4991	45250	48960	47475
Actual pieces SKU1b	5217	5067	5641	5281	6308	6923			
Actual pieces SKU1c	6285	5998	6760	6138	7182	7810			
Actual pieces SKU2a	13685	13098	14826	13795	15968	17232			
Actual pieces SKU2b	14714	14160	15982	14067	16646	17896			
Actual pieces SKU2c	15772	15153	17052	14433	17052	18399			
Actual pieces SKU2d	18161	17570	20230	17862	21147	22714			
Total Actual pieces SKU1	15680	15105	16945	15325	18142	19724	45250	48960	47475
Total Actual pieces SKU2	62332	59981	68090	60157	70813	76241	0	0	0
Total Actual pieces	78012	75086	85035	75482	88955	95965	45250	48960	47475

Table VI Production progress of SKU1 and SKU2 on production line two

	Month one	Month two	Month three	Month four	Month five	Month six	Month seven	Month eight	Month nine
Production data	Production line two								
Planned pieces SKU1a	5615	5375	6100	5720	6230	6900			
Planned pieces SKU1b	6774	6432	7320	6570	7680	8304			
Planned pieces SKU1c	7882	7672	8603	7567	8890	9681			
Planned pieces SKU2a	18080	17296	19792	17344	20560	21872	169381	179140	172576
Planned pieces SKU2b	18989	18343	20825	18632	21284	23392			
Planned pieces SKU2c	20304	19440	22086	19854	22950	24876			
Planned pieces SKU2d	22460	22100	24500	21820	25460	27360			
Total Planned pieces SKU1	20271	19479	22023	19857	22800	24885	0	0	0
Total Planned pieces SKU2	79833	77179	87203	77650	90254	97500	169381	169383	169385
Total Planned pieces	100009	96658	109226	97507	113054	122385	169381	179140	172576
Actual pieces SKU1a	4231	4037	4510	3877	4593	4938			
Actual pieces SKU1b	5249	5005	5714	5424	6314	6807			
Actual pieces SKU1c	6221	6103	6847	6115	7217	7815			
Actual pieces SKU2a	13562	13277	15221	13528	16208	17205	138491	148366	143394
Actual pieces SKU2b	14681	14204	16023	14004	16520	17839			
Actual pieces SKU2c	15613	15039	17015	14453	17002	18339			
Actual pieces SKU2d	18109	17745	20028	17891	21180	22733			
Total Actual pieces SKU1	15701	15145	17071	15416	18124	19560	0	0	0
Total Actual pieces SKU2	61965	60265	68287	59876	70910	76116	138491	148366	143394
Total Actual pieces	77666	75410	85358	75292	89034	95676	138491	148366	143394

IV. CONCLUSIONS AND RECOMMENDATIONS

The research focused on the production line of an Egyptian bakery for cakes and gateaux production to develop new procedures based on the lean production approach that can enable the business to decrease the mean time of the changeover process, increase overall equipment effectiveness (OEE), reduce overtime, and increase productivity. The numerical calculations and statistical presentation of the data showed that the availability was the most influential contributor to the OEE values, in such a manner that the OEE induced by the availability was improved by 6.07% at production line 1 and 13.77% at production line 2 from phase 1 to phase 3. At the same time, the improvement induced by both performance and quality is minimal. This leads us to conclude that eliminating downtime losses relevant to the availability could improve the performance of cake and gateaux production lines.

The presented study has been limited, focusing only on specific aspects of equipment performance in terms of one variable (Availability). This can make it difficult to draw general conclusions about equipment efficiency and performance or compare different equipment types. The study also was limited in scope as it only considered one type of production line, so it is recommended that future studies should consider a broader range of equipment types in different industries.

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