Development and Evaluation of Overall Equipment Effectiveness of Knitting Machines Using Statistical Tools

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Abstract
In manufacturing industries, well-maintained machines ensure their maximum utilization with good product quality, efficient time, and minimum cost. The objective of this study is to investigate a socks manufacturing line to propose an advanced maintenance plan based on Overall Equipment Effectiveness (OEE) to improve the overall maintenance along with better machine performance and product quality. Firstly, a socks manufacturing unit was selected and its maintenance-related problems were identified. It was observed that, among the six big losses, three losses have the major contribution in reducing the world-class value of OEE. Then a framework was designed based on the OEE model with the amalgamation of problem-solving tools to overcome the identified problems and reduce the contribution of three big losses. After the successful implementation of the proposed model, a significant reduction in the value of three big losses was observed that ultimately improve the value of OEE factors for the socks knitting machines by 2.18%. The statistical analysis is also conducted using three types of statistical tests, the Normality test, Wilcoxon signed-rank test, and Paired samples t-test. Kolmogorov–Smirnov (KS) test by Statistical Analysis Software (SAS). This paper points out a new proposed model of advanced OEE, which can improve machine maintenance, productivity, and quality in a better way as compared to the conventional OEE model.

Keywords
socks knitting industry, overall equipment effectiveness, six losses, problem-solving tools

Introduction
In today’s business world, competitiveness had increased to such a higher rate that maximum output is required with the lowest cost. To strengthen the organization’s competitiveness in the global market productivity and quality effectiveness is required, which ultimately fulfills the dire requirements of the customer. Consequently, excellence in manufacturing is required to achieve good quality and productivity levels (Kang et al., 2018). Effective and efficient maintenance strategy helps the manufacturing organizations in achieving world-class manufacturing performance. Therefore, to achieve good quality and productivity, improvement in the current maintenance practices is required which can be achieved through the critical analysis of the current maintenance systems and processes (Iqbal et al., 2010). In this regard, different types of maintenance techniques and approaches are used according to the nature and type of production method like Reliability-Centered Maintenance (RCM), Total Productive Maintenance (TPM), and business-centered Maintenance (BCM; Mungani & Visser, 2013). The RCM approach optimizes the reliability of the physical assets by identifying the failure modes of the system and ranking the analysis of results for each failure mode. While BCM focuses on the importance of engaging the maintenance method and technique with the company objectives. On the other hand, TPM is a maintenance philosophy that not only improves equipment health but also increases employee morale and job satisfaction. Commitment, trainings, and responsibility at all levels of the organization is the key to ensure cultural change and successful implementation of TPM. The framework of TPM defines that it act as a tool to improve the rate of performance, availability, and quality (Parikh & Mahamuni, 2015).

TPM revolves around two aspects; one belongs to humans and the other belongs to machine. The human aspect revolves...
around the complete ownership of equipment by people working on the machines. Ownership of operators is enhanced by working on five psychological dimensions, which are self-efficacy, self-identity, territoriality, owning a house, and responsibility. While considering the machine aspect, TPM focuses on proper maintenance of the machines that will reduce machine downtime and quality issues. Therefore, plant engineers and technicians must devise an effective maintenance plan to enhance the capability and capacity of the manufacturing companies. Equipment utilization improved by making maintenance techniques an integral part of the business strategy (Seng et al., 2017).

Management, maintenance, and operational staff come together as a team in TPM to reduce losses and wastages thereby improving the quality, productivity, and reducing cost. The methodology of OEE is used to measure the overall performance of the equipment. Incremental improvement in the OEE could only be done by the reduction of six big losses (Badiger & Gadhinathan, 2008; Burhan & Sari, 2019). These losses include setup and adjustment loss, breakdown loss, idle and minor stoppage loss, speed loss, quality defects and rework loss, and start-up loss. Thus, the objective of this study is to propose an advanced form of OEE model such that the contribution of six big losses can be reduced.

To ensure good care and maintenance of equipment, plenty of work has been done in different manufacturing industries. In these studies, various maintenance methodologies have been considered to attain the required productivity and quality. Overall Equipment Effectiveness (OEE) is a tool of TPM which is widely used to overcome machine-related problems in manufacturing industries nowadays. The value of OEE is improved by reducing the share of six major losses. A complete analysis of the pillars of TPM and tools and techniques like Pareto analysis was done to check their impacts on quality and productivity (Okpala et al., 2018). The manufacturing sectors adapted TPM to improve the equipment, human-oriented, and process-oriented strategies. Different management and machine problems were encountered during the implementation of TPM and many difficulties were faced while adopting the basic TPM principles within a manufacturing organization. The methodology using check sheets and one-point lessons resulted in the proper implementation of TPM, which resulted in comprehensive benefits in the shape of improved quality and productivity (Bhalerao et al., 2014). The role of ethical and psychological factors was also judged through data collection of employees in the organization. The methods used for the data collection were structured interviews and questionnaire surveys. The comprehensive implementation of 5S and TPM was carried out based on the results of this study (Kareem & Amin, 2017). The benefits of TPM implementation in the sewing process are also well recognized. Unproductive times and non-value added activities were identified and their countermeasures were made to increase the efficiency of the sewing machines of the footwear industry (Reyes et al., 2018). The improvement in the equipment utilization in the manufacturing of electronic components and boards had studied thoroughly through the implementation of effective maintenance techniques. Global Operator User Interface (GOUI) was used to collect real-time data for the OEE improvement (Fam et al., 2018).

Critical success factors play an important role in the implementation of TPM. A questionnaire survey was conducted to develop a relationship between TPM implementation and improvement in operational excellence (Hernández et al., 2018). Unproductive time loss, availability loss, performance loss, and quality loss were identified by applying TPM. It was also verified that the better value of OEE is obtained in a steel mill using SMED and 5-Y analysis (Rimawan & Irawan, 2017). Huge waste losses occur due to breaking down, operators related issues, process-related issues, and maintenance issues, which in turn affect the overall OEE of the company. Hence, zero tolerance for waste, defects, and breakdown is inevitable for the assembling industry. Workers provided with skills, knowledge, and techniques for timely maintenance of machines in order to improve productivity and OEE of machines (Mahajan et al., 2018). The manufacturing performance of textile and apparel manufacturing firms had a strong positive relationship with the TPM implementation. A questionnaire survey was conducted followed by correlation and regression analysis to identify the impact of TPM. Cost-effectiveness, volume flexibility, product quality, and on-time delivery shows a considerable and significant improvement by applying TPM (Wickramasinghe & Perera, 2016).

All pillars of TPM are implemented in a systematic procedure to reduce the movement of material and cycle time of PCF Gear Box helical assembly, which ultimately improves the assembling procedure. Losses in the production system are identified and eliminated through the effectiveness of the maintenance policy. The cycle time contributing to the movement of material is reduced through the elimination of losses. It involves the participation of all employees that is the proactive maintenance procedure (Chandegra & Deshpande, 2015). The implementation of TPM improved the values of availability, performance, and quality rate of equipment which in turn improved the value of OEE. However, there are some difficulties in the implementation of TPM like lack of understanding in the TPM methodology, lack of top management exposure, and poor follow-up of the initiatives taken. Both human and equipment perspectives are involved in the improvement of productivity and quality in the spinning industry (Katkamwar et al., 2013).

TPM maintains the plant and machinery to its higher productive rate by involving everyone from top to bottom of the organization. The process of data recording to analyze the current state should remain simple and trend line graphs made for every KPI. The critical analysis of the data provides the basis for the long-term plan to improve OEE and other KPI’s of the plant. Improvement in OEE was observed by analyzing the past and current data. Furthermore, the results
show a reduction in the number of accidents and an increment in the motivation level of employees (Rajput & Jayaswal, 2012). Equipment reliability, machine breakdown, process quality, and productivity output are the necessary traits of the performance evaluation of a manufacturing company. In addition, all these traits of performance are achieved through effective and appropriate maintenance strategies. By using “System Dynamics,” effects of the implementation of TPM on workforce efficiency, reach time competence and high-level product quality are analyzed. Improvement in the said performance traits resulted in improved performance of the company (Shahanaghi & Yazdian, 2009). Eliminating six big losses through TPM in a steel company in Jordan resulted in the increment of OEE. SMED, CMMS, and Production Planning tools used to enhance OEE and productivity. The operators on the shop floor know the machine very well in comparison to any other person on the shop floor. Therefore, it is the responsibility of the operator to check each abnormality and maintenance activity of the machines. As a result of the implementation of improved maintenance procedures, 76% availability rate, 72% performance rate, 99% quality rate, and 55% OEE value is achieved (Almeanazel, 2010).

SMED approach works in conjunction with the 5Y analysis to optimize the changeover process time. The losses incurred during the changeover process due to the non-optimized conditions highlighted and all setup-adjustment losses investigated through their root causes in a structured way. Both internal and external activities were highlighted and these activities were streamlined and standardized through the SMED methodology. Ultimately, by minimizing the changeover time an increase in the OEE value is achieved (Braglia et al., 2017). FMEA-TPM integrated approach used to judge the quality systems and the reliability systems. Customer demands qualitatively reliable manufacturing systems so both had their significance in the manufacturing systems. If a system is unreliable then this system will be unpredictable and if a system is not predictable then it cannot produce good quality. FMEA tells about the risk that has a greater impact so that countermeasures are taken against that risk cause so that we can prevent that risk from happening. The quality performance of a firm is critically judged by the reliability of plant equipment and machinery. TPM works by the prevention of equipment frequent breakdowns, by improving the quality of equipment, and by the standardization of machines and equipment through minimum variation which ultimately produces a better quality product (Waghmare et al., 2014).

There are some examples from the textile and clothing industry in which OEE was implemented along with different problem-solving tools. In a readymade garments factory, productivity and OEE increased by working on the six major losses through the implementation of TPM. The OEE level of the factory increases from 59% to 65% by applying TPM (Masud et al., 2007). Similarly, the performance of equipment is maximized by implementing TPM that ultimately improves OEE, quality, productivity, safety, delivery, and cost. The major losses in the Jute mill were identified and the work was done on the reduction of these losses to improve OEE and other KPI. By the implementation of TPM, the OEE of the jute mill increased from 51.93% to 75.35%. Moreover, through this TPM methodology substantial improvement in productivity, quality, job satisfaction, and employee morale was observed (Rahman et al., 2018). Six big losses of ring frames in a spinning factory are examined through Pareto analysis, 5Y analysis, and Cause and Effect analysis. Properly organized training programs guided the operators to reduce these losses. The value of OEE in the ring frame increased from 75.09% to 86.02% by reducing the six major losses through the implementation of Kaizen. Moreover, defective products decreased to 49.50%, and the productivity level improved to 23.93% (Ahmad et al., 2018). Some important studies on TPM and big losses have been summarized in Table 1 to highlight the research gap in this area.

Based on the above literature, it can be concluded that TPM as a general methodology and OEE as a specific tool of lean are widely implemented in different manufacturing industries. It can also be concluded from the literature that real improvement in the value of OEE is obtained by overcoming the factors affecting the six big losses. While no such framework is available that guides the machine operators or managers of manufacturing industries to reduce the share of these big losses. Thus, there is a need to develop a framework that can help the organization overcome the big losses of OEE. Thus, this study will address this gap by proposing a specially designed framework with the combination of the general OEE model and problems solving tools. The proposed model provides complete details about the step-wise implementation plan for the reduction of three big losses for the knitting machines. It can increase the machine availability, overall production, and product quality as well. For this purpose, a socks manufacturing unit from the textile sector is selected and a section of knitting machines is investigated.

**Problem Statement**

All the steps involved in a socks manufacturing process are shown in Figure 1. In the first step, yarn is procured and induted into the knitting section where it is converted into socks using knitting machines. Knitted socks are in the tube form which requires stitching operation for toe closing. Wet processing, such as dyeing, bleaching, or washing, is conducted on stitched socks according to the required shade. The next step is the processing of socks followed by pressing in the boarding section at the optimum temperature for a specified time. While boarded socks are packed and placed in cartons which is the last process of the socks manufacturing process.

In this complete process, the knitting machine is the key area that ensures the quality and productivity of the socks. In this study, this knitting section is specifically focused on. For this purpose, the value of OEE is calculated that is a product
of its three factors: availability, performance, and quality. The value of each factor further depends on two losses that combine to make six big losses. These losses include minor stoppages, startup, quality defects, rework, setup and adjustment, break down, and speed. When the contribution of these losses increases the overall value of OEE is reduced significantly indicating the low maintenance, downgraded quality, poor performance of knitting machines. In such a scenario, the knitting process becomes a problematic area that requires a proper maintenance plan. Therefore, it is desired to define the framework for the reduction of these losses through the effective maintenance plan for the knitting machines.

**Methodology**

To develop and implement the proposed plan, an adopted methodology has been divided into two phases: conceptual model and sampling and procedure.

**Conceptual Model of Research**

The first phase is the development of a conceptual model of advanced maintenance plan keeping in view the above-mentioned research problem. The proposed conceptual model is shown in Figure 2 which is an extension of the basic OEE model and it will ensure improvement in OEE through the reduction of big losses. For this purpose, data of each sub-factors will be collected and different problem-solving tools will be used like preto chart, cause and effect diagram, etc. depending upon the nature of the problem and requirement of the process. Problem-solving tools will further help to propose some corrective action according to the reasons identified and will be implemented through

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**Table 1. Summarized Literature Review.**

| Author               | OEE | Setup/adjustment | Defects/rework | Minor stoppages | Industry | Objectives                                      |
|----------------------|-----|------------------|----------------|----------------|----------|------------------------------------------------|
| Kapuyanyika and Suthar (2018) | ✓   | ✓                | □              | ✓              | Railway  | OEE improvement through TPM                      |
| Reyes et al. (2018)   | □   | □                | □              | ✓              | Footwear | Reduction in unscheduled stoppages through TPM   |
| Wickramasinghe and Perera (2016) | ✓   | □                | □              | □              | Apparel  | Effect of TPM on the manufacturing performance  |
| Fam et al. (2018)     | ✓   | □                | □              | □              | Electronics | Effectiveness of TPM to improve OEE          |
| Mahajan et al. (2018) | ✓   | □                | ✓              | □              | Mechanical | To increase the OEE through TPM                |
| Manjunatha et al.     | ✓   | □                | □              | □              | Hotel    | Cost reduction and energy saving by improving OEE through TPM |
| Ahmad et al. (2018)   | ✓   | □                | □              | ✓              | Spinning | OEE improvement of ring frame through TPM        |
| Prabowo et al.        | ✓   | □                | □              | □              | Food     | Effect of eight TPM pillars on manufacturing performance |
| Rimawan and Irawan (2017) | ✓   | ✓                | □              | ✓              | Steel    | OEE improvement through TPM, SMED and SWH       |
| This research         | ✓   | ✓                | ✓              | ✓              | Textile  | Develop an effective maintenance plan to reduce six big losses |
different types of checklists. Data collection and the required calculations of six big losses, availability, performance, and quality will be performed again after the implementation of checklists. The reduction of each loss improves the rates of availability, performance, quality, and ultimately the OEE value. This tentative model systematically depicts this reduction process through the development and implementation of an advanced maintenance plan. This complete process is shown as an extension on OEE in one of its factor’s losses in Figure 2.

**Sampling and Procedure**

In order to implement the proposed conceptual model, a complete road map is shown in Figure 3. The flow chart consists of seven steps that include data collection, baseline
study, data analysis, countermeasures development, countermeasure implementation, and comparative analysis. A baseline study is conducted at the start of the process which includes data collection and its calculations. In this regard, a pilot area consisting of 20 knitting machines is selected. Planned production time and ideal cycle time of the machines of a specific order are defined. Downtime data for minor stoppages is collected through recording of each machine data while defects and rework data are collected through the operators’ inspection and by the quality assurance auditors working on that specific knitting machine. The baseline study includes the date-wise data calculations of all six big losses for 2 weeks. A pareto chart is used next to clarify which loss had a major contribution so that relevant efforts can be made to improve the OEE level.

In the next step, Cause and Effect diagrams are made for the selected three losses that have a major contribution in each factor, that is, availability, performance, and quality. These diagrams are further used to develop corrective actions to overcome the share of these losses. Then, the checklists are formulated to confirm the effective implementation of the proposed corrective actions. It will also ensure the recurrence of these losses which is the ultimate goal of this proposed maintenance plan. Lastly, data is collected, OEE calculations are made, and comparative analysis is conducted to find out the improvement in the OEE level.

### Results and Discussion

After implementing the methodology defined earlier, the obtained results have been summarized and explained here. In this regard, this section has been divided into four parts: baseline calculation, development of corrective action, implementation, and comparative analysis.

For baseline calculations, the input data is obtained from the selected pilot area with respect to the requirements of OEE calculations. Then the value of all the OEE factors, that is, availability, performance, and quality is determined that ultimately helped to obtain the baseline value of OEE. The values of OEE and its factors are determined using the following equations (Muchiri & Pintelon, 2008).

- **Availability Rate**
  \[
  \text{Availability Rate} = \frac{\text{Planned Production time (min)} - \text{Downtime (min)}}{\text{Planned Production time (min)}} \times 100
  \]

- **Performance Rate**
  \[
  \text{Performance Rate} = \frac{\text{Total Production (pieces)} \times \text{Cycle Time (sec)}}{\text{Planned Production time (sec)} - \text{Downtime (sec)}} \times 100
  \]

- **Quality Rate**
  \[
  \text{Quality Rate} = \frac{\text{Total Production (kgs)} - \text{Rejected Production (kgs)}}{\text{Total Production (kgs)}} \times 100
  \]

- **O.E.E = Availability Rate x Performance Rate x Quality Rate**

  In the analysis of baseline calculations, the values of OEE and its factors are compared with the world-class values as shown in Table 2 (Muchiri & Pintelon, 2008). The gap of 2.99%, 2.15%, and 4.79% exists in availability, performance, and quality respectively. This comparison reveals that the selected knitting machines require attention to improve the OEE values.

  For this purpose, a micro-level analysis is required to investigate the contributing elements that cause the reduced value of OEE factors. These contributing elements are downtime, rejection rate, and the ideal cycle times while each of

| OEE factors | Availability (%) | Quality (%) | Performance (%) | OEE% |
|-------------|-----------------|------------|-----------------|-----|
| World class value | 90.00 | 99.90 | 95.00 | 85 |
| Baseline value | 87.01 | 97.75 | 90.21 | 77 |
| Difference | 2.99 | 2.15 | 4.79 | 8.69 |

**Table 2. Comparison of OEE Values With World-Class Values.**

Figure 3. Roadmap to implement the proposed model.
these elements has two sub-elements that combine to form six big losses. At the baseline stage, the summary of the contribution of these six losses is given in Figure 4. It is evident that three types of losses have a major contribution that includes minor stoppages, defects and rework loss, setup, and adjustment loss. In quantitative terms, minor stoppages have 37% contribution while other two have 25% and 17%, respectively. Therefore, by working on these three major losses, significant improvement in the availability, performance, quality, and OEE can be obtained.

According to the defined methodology, a problem-solving tool, that is, Cause and Effect Diagram (CED), is used to develop countermeasures to reduce three big losses. Minor stoppage loss is the top contributor among the six losses. Therefore, a slight reduction in this loss can improve the OEE value to a large extent. This loss is mainly due to yarn breakage whether it is platting yarn or main yarn. Fluff in the main yarn path is the top contributor to main yarn breakage. It mainly occurs by the friction of yarn with creel sensors, finger tubes, and BTSR sensors. Moreover, fluff in the heel and toe yarn path of socks is also one of the top causes of minor stoppages. There are some machine parts adjustment issues like cutter adjustment which includes improper settings of the saw blade and knife tip. Platting yarn breakage occurs mostly due to wrong settings of finger tube and take-up spring. This occurs mostly due to low-skill machine operators and technicians. Production balancing on the production tray and cone end issue are also the causes of minor stoppages on the knitting machines. All the causes associated with minor stoppage loss are categorized into four groups as shown in the Figure 5 as a CED.

Five major defects that fall under the category of defects and rework loss are floating yarn, main yarn short, hole at heel and toe, Pattern yarn short, and General Hole. Each defect is analyzed using CED to find out the root causes so that the corrective action for each defect can be proposed. The CEDs for all five defects are shown in Figures 6 to 10 in which the causes have been divided into different categories like material, man, machine, method, etc.

In Figure 6, the CED of Floating yarn is shown which is one of the top faults that contribute to the defects and the rework loss. Yarn tension is the cause that happens due to improper yarn path and wrong tension cap settings. Elastic cutter, elastic binder, elastic roller, and elastic motor are machine-related causes that create the floating yarn problem. Moreover, some measurement issues like vacuum adjustment and suction pressure can also create the defect of floating yarn. Usage of some specialized yarns such as twisted polyester/nylon intermingled polyester/nylon and spun polyester yarn creates this defect. There are some issues related to machine programs like saw blade speed variation, yarn locking in the logo section, and 3D pattern issues that create floating yarn problems. Furthermore, finger improper settings also create this issue, which is the mechanical setting of the socks knitting machine, generating floating yarn issue at the pattern area of socks.

The CED of main yarn short defect is shown Figure 7. Slanted needles caused due to improper needle latch opening and needle butt broken issue create this defect along with dial settings on the knitting machines. Some material related issues like high yarn coefficient of friction and twist per inch are also the major causes of this defect. Suction pressure and vacuum pressure variation from the suction blower and from the machine program creates main yarn short. Finger degree out from the machine program settings from the machine software creates this issue on the knitted product. Improper yarn path and tension cap settings disturbs the yarn tension of the knitting machine create the said problem.

The CED of hole at heel and toe fault is shown in Figure 8 that comes at the third spot in the quality defects and rework loss. Improper yarn selection at the development stage, usage...
Figure 5. CED of minor stoppage loss.

Figure 6. CED of floating yarn defect.
Figure 7. CED of main yarn short defect.

Figure 8. CED of hole at heel and toe defect.
of spun polyester, and improper lycra covering are the main causes of this fault. Take-up tension caps and take-up tension spring settings disturb the standards of take-up assembly settings on the knitting machine causing hole at heel and toe problems. Damage gate ring of sinker cap and the worn-out sinkers of the knitting machines are also the causes of this problem. Hole at heel and toe issue also created by the cut in the terry levers. Machine adjustments of dropper and picker
The initial state of the changeover process is studied to when a knitting machine changed from one article to another. The basic purpose is to improve machine uptime because of the worn-out gaskets and electro valves of general hole. This defect is also created by yarn feeding variation creates the problem of tension on the knitting machine that in turn affects the yarn panel. Improper settings of yarn tension cap disturb the yarn feeding variation of the knitting feeds are the major causes of the pattern yarn short caused by the wrong adjustments on the knitting machines. Moreover, some worn-out flat parts of the knitting machines generate the issue of pattern yarn short. These flat parts include needles, pattern jacks, and dial jacks. The broken needle butt and needle latch opening issue generates this problem at the motif portion of the knitted sock. Yarn tension and adjustments of cone alignment of pattern yarn disturb the adjustments of yarn path on the knitting machines that create pattern yarn short.

The CED of Pattern yarn short defects is shown in Figure 9. This defect is mostly caused due to machine and measurement issues. Electro valves working problems along with the finger screw adjustments of the knitting feeds are the major causes of the pattern yarn short caused by the wrong adjustments on the knitting machines. Moreover, some worn-out flat parts of the knitting machines generate the issue of pattern yarn short. These flat parts include needles, pattern jacks, and dial jacks. The broken needle butt and needle latch opening issue generates this problem at the motif portion of the knitted sock. Yarn tension and adjustments of cone alignment of pattern yarn disturb the adjustments of yarn path on the knitting machines that create pattern yarn short.

Lastly, the setup and adjustment loss associated with the factor availability were analyzed. The process of knitting machines can be optimized by reducing the setup and adjustment loss. The basic purpose is to improve machine uptime when a knitting machine changed from one article to another. The initial state of the changeover process is studied to identify the gaps. Afterward, an improved state of the changeover process was made through process optimization. In this way, the downtime of changeover process is reduced on the knitting machines. Major downtime loss was observed during the sinker changing of the socks knitting machine. The sinker’s untying process along with the sinker insertion process optimization which decreases our downtime of the changeover process to 7 minutes. Before the process optimization, the removal and tying of sinkers were done by the technician only but now these sinkers removal along with their tying by the operators. During the removal and insertion of sinkers by operators, the technician changes the needles and finger adjustments on the machines, saving 6 minutes. Therefore, 38% reduction in the changeover process time is done as the overall changeover process time reduces from 33 to 20 minutes. The process optimization of setup and adjustment loss is shown below in Table 3.

After analyzing the baseline data and developing the CEDs of three losses, the next step is the implementation of an action plan to decrease the impact of these losses. A well-organized training program was conducted to educate the operators about these losses and possible ways of improving the condition. This action plan is implemented using checklists. Two types of checklists are developed. The first one is a cleaning checklist that was developed with a complete description of machine number and area cleaning required. Before this, the existing mechanism of cleaning was not affected because that mechanism was not systematic. The proposed checklist focused on all those areas that require cleaning daily while others require cleaning on weekly basis. The frequency, responsibility, and remarks column were also added. The checklist shown in Table 4 gives a detailed description.

| Sr. # | Before | After |
|-------|--------|-------|
| 1.    | Sinkers untying is done when the machine stops for changeover process | Sinkers untying done before the machine stops for changeover process |
| 2.    | Sinkers insertion and machine handle rotation is done by the Technician | Sinker insertion is done by the technician while handle rotation is done by the cone boy |
| 3.    | The removed sinkers tied by the technician | The removed sinkers tied by the operator |
| 4.    | Sinkers removal, finger changing, and needles insertion done by the technician only | Sinkers removal done by the operator while finger changing and needles insertion done by the technician |

| Changeover time | Before | After | Impact |
|-----------------|--------|-------|--------|
| 33 minutes      | 20 minutes | Changeover process downtime is reduced by 38% |

Table 3. Process Optimization of Setup and Adjustment Loss.
tasks and shift technicians while some complicated tasks are checked by line technician, electronics technician, and technical in charge. Every knitting machine had its inspection checklist and it is to be filled on daily basis by the concerned people. The inspection checklist is the preventive approach for the reduction of six losses ultimately improving the OEE level. The proposed inspection checklist is shown below in Table 5.

To reduce the process downtime, a changeover checklist is proposed in which the workforce is assigned different tasks and responsibilities. According to this checklist, operator does the untying of sinkers before machine stoppage for changeover. Sinkers insertion is done by the technician while machine handle rotation is done by the cone boy and both operations proceeded at the same time. Sinkers tying is the responsibility of operator whenever the machine stops for

Table 4. Checklist for Machine Cleaning.

| Area                              | Frequency | Machine no. | Date         | Responsibility |
|-----------------------------------|-----------|-------------|--------------|----------------|
| Yarn creel sensors                | Daily     |             |              | Operator       |
| Cone hangers                      | Daily     |             |              | Operator       |
| Yarn tension caps                 | Daily     |             |              | Operator       |
| BTSR panel                        | Daily     |             |              | Operator       |
| Suction Hood                      | Daily     |             |              | Operator       |
| Elastic binder                    | Weekly    |             |              | Shift Technician |
| Elastic roller                    | Weekly    |             |              | Shift Technician |
| Feed plate                        | Daily     |             |              | Operator       |
| Cam plate                         | Daily     |             |              | Operator       |
| Drum plate                        | Weekly    |             |              | Shift Technician |
| Yarn cone stand                   | Daily     |             |              | Operator       |
| Yarn cone plates                  | Daily     |             |              | Operator       |

| Checked By: ___________________ | Verified By: ______________ |

Table 5. Checklist for Machine Inspection.

| Inspective area                  | Frequency | Machine no. | Date         | Inspected By | Remarks |
|-----------------------------------|-----------|-------------|--------------|--------------|---------|
| Cone hanger adjustment            | Daily     |             |              | Operator     |         |
| Cone alignment                    | Daily     |             |              | Operator     |         |
| Yarn tension adjustment           | Daily     |             |              | Operator     |         |
| Saw blade speed standardization   | Fortnightly|             |              | Technical in-charge |        |
| Knife tip adjustment              | Fortnightly|             |              | Shift technician |       |
| Saw blade cutter adjustments      | Fortnightly|             |              | Shift technician |       |
| Take up wire and spring adjustments| Weekly   |             |              | Shift technician |       |
| Sinker cap pressure and movement adjustments | Fortnightly|             |              | Technical in-charge |        |
| Terry lever adjustments           | Fortnightly|             |              | Line technician |        |
| Finger settings                   | Weekly    |             |              | Shift technician |       |
| Dial position adjustments         | Weekly    |             |              | Line technician |        |
| Elastic motor inspection          | Fortnightly|             |              | Electronics technician |     |
| Elastic binder adjustment         | Weekly    |             |              | Line technician |        |
| Elastic roller adjustment         | Weekly    |             |              | Line technician |        |
| Drappers adjustments              | Fortnightly|             |              | Line technician |        |
| Picksers adjustments              | Fortnightly|             |              | Line technician |        |
| Pattern drum adjustments          | Weekly    |             |              | Shift technician |       |
| Drum nails adjustments            | Weekly    |             |              | Shift technician |       |
| Graduation motor inspection       | Fortnightly|             |              | Electronics Technician |     |
| Vacuum motor pressure adjustments | Weekly    |             |              | Technical in-charge |       |
| Suction pressure adjustments      | Weekly    |             |              | Technical in-charge |       |

| Checked by: ___________________ | Verified By: ______________ |
changeover process. Removal and insertion of needles along with the sinkers is the job of the technician. The changeover checklist is shown in Table 6.

**Data After Implementation of the Action Plan**

After implementing the corrective actions for all selected losses, the value of OEE and its factors are determined again using the same equations and procedure that already described. A significant reduction in the three big losses was observed which confirms the effectiveness of the corrective action plan. It has reduced the contribution of all six big losses which ultimately improve the value of OEE. There is a significant reduction of 1.32% in the minor stoppages loss, 0.54% in setup and adjustment loss, and 0.65% in the defects and rework loss observed. The baseline values of six big losses are compared with the new values in Figure 11.

Similarly, the baseline values of OEE and its factors are compared. The implemented corrective plan improved the availability rate, performance rate, and quality rate that ultimately increasing the OEE value. It is because the contribution of three big losses, minor stoppages, setup and adjustment loss, and quality defects and rework loss, have been reduced. The availability rate increases from 87.01% to 87.57%, which shows that 0.56% increment in the value of availability rate was observed. Moreover, the quality rate increase from 97.75% to 98.38% increasing the value to 0.63% while 1.38% increase in the performance rate is observed which had increased the value of performance rate from 90.21% to 91.59%. Ultimately, the OEE value increases from 76.72% to 78.90% eventually increasing the value of OEE to 2.18%.

| Table 6. Checklist for Machine Changeover. |
|--------------------------------------------|
| **Shift :- _______** | **Machine no :- _______** | **Date :- _____________** |
| Description | Ok | Not Ok | Responsibility | Remarks |
| Sinkers untying | Operator |
| Sinkers insertion | Technician |
| Machine handle rotation | Cone boy |
| Sinkers tying | Operator |
| Needles removal | Technician |
| Needles insertion | Technician |
| Fingers removal | Technician |
| Fingers insertion | Technician |
| Checked by: ____________ | Verified by: ____________ |

**Figure 11.** Six big losses comparative analysis after action plan implementation with baseline.
The comparative analysis of OEE% and its sub-factors data with the baseline data is shown in Figure 12.

**Statistical Analysis**

Lastly, the statistical analysis is applied using different tools to verify that the improvements in the values of OEE and its factors are statistically significant. For this purpose, Statistical Analysis Software (SAS) is used to identify the significance of variables of the baseline data with respect to the data obtained after the implementation of an action plan. The statistical analysis is conducted using three types of statistical tests, the Normality test, Wilcoxon signed-rank test, and Paired samples t-test. Kolmogorov–Smirnov (KS) test is used to check the normality of data. The KS test is a nonparametric test of the equality of continuous or discontinuous, one-dimensional probability distributions that can be used to compare a sample with a reference probability distribution or to compare two samples. If the \( p \)-value of a variable is less than .05 than the data of that variable is normal. The results of the normality test are shown in Table 7.

Secondly, the Wilcoxon signed-rank test is used what is a non-parametric statistical test used to compare two related samples, matched samples, or repeated measurements on a single sample to check the difference in the population mean ranks. This test is conducted on the baseline data in comparison to the data obtained after the implementation of an action plan and it is performed on the variables having KS Normality test \( p \)-values more than .05. The result of the Wilcoxon signed-rank test shows that the total production (kg) is non-significant as its \( p \)-value is more than .05 while downtime, quality rate, and performance rate are significant as their \( p \)-values are less than .05 as shown in Table 8.

Lastly, the paired sample \( t \)-test is a statistical procedure used to check whether the mean difference between two sets of samples is zero. This test is also conducted on the baseline data in comparison to the data obtained after the implementation of the action plan and it is performed on the variables having \( p \)-values less than .05 in the Normality test. The results of Paired sample \( t \)-test show that the variables named as the planned production time and availability rate are non-significant as its \( p \)-value is more than .05 while rejection rate, total production in pieces, cycle time, and OEE are significant as their

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**Figure 12.** OEE% and its sub-factors comparative analysis with baseline.

**Table 7.** Kolmogorov–Smirnov Normality Test.

| Description            | Statistic | df | \( p \)-Value |
|------------------------|-----------|----|----------------|
| Down time              | 0.127     | 26 | .200           |
| Planned production time| 0.508     | 26 | <.0001         |
| Availability rate      | 0.186     | 26 | .021           |
| Total production (kg)  | 0.103     | 26 | .200           |
| Rejection rate         | 0.204     | 26 | .007           |
| Quality rate           | 0.144     | 26 | .179           |
| Cycle time             | 0.233     | 26 | .001           |
| Total production (pieces)| 0.196   | 26 | .011           |
| Performance rate       | 0.127     | 26 | .200           |
| OEE                    | 0.204     | 26 | .007           |
p-values are less than .05. Paired sample t-test results are shown below in Table 9.

**Advance OEE Model**

The general form of OEE model along with its sub-factors is already defined and implemented in various manufacturing industries. However, this study aimed to propose an advanced form of OEE such that a complete framework should be provided to decrease the contribution of all six big losses. Based on this study, the proposed OEE model defines the process and methodology required to give the comprehensive maintenance plan for the reduction of minor stoppages, quality defects and rework, setup, and adjustment loss. The complete process consists of a set of tools or techniques for each OEE loss that includes baseline study, data analysis by Pareto chart and cause and effect diagrams, implementation of the corrective action using checklists, data collection after the implementation of the action plan, and finally the comparative analysis of the data as shown in Figure 13. These steps are followed for the reduction of two big losses which include minor stoppages, quality defects, and rework, setup, and adjustment loss. For the setup and adjustment loss, a process optimization technique is applied instead of cause and effect diagrams. Process optimization reduces the downtime of changeover process which ultimately reduces the setup and adjustment loss. It is observed that to improve the overall performance of knitting machines, the proposed model of OEE gave much better results. It is because of the fact that this model provides proper guidance to reduce the share of each big loss associated with OEE factors. Once the share is reduced, the rate of factors will improve that ultimately improve the OEE values. Thus, it can be concluded that the proposed model of advanced OEE improves machine maintenance, productivity, and quality in a better way as compared to the conventional OEE model.

**Conclusions**

The objective of this study was to implement Overall Equipment Effectiveness (OEE) in the knitting textile industry. An advanced model of OEE was developed that provides the complete guide to decrease the share of big losses to improve the value of OEE. The proposed model is equipped with problems solving tools and a conventional OEE model to make a complete framework. The successful implementation of this advanced model ensures the following:

1. Availability rate increases to 0.56% due to reduction in the Setup and Adjustment loss.
2. Performance rate increases to 1.38% due to a reduction in the Minor Stoppage loss.
3. Quality rate increases to 0.63% due to a reduction in the Quality Defects and Rework loss.
4. OEE rate increases to 2.18% due to increment in the availability, performance, and quality rates.

Lastly, the statistical analysis is conducted to show that the achieved results are statistically significant. Seven variables are significant which are downtime, quality rate, performance rate, rejection rate, cycle time, total production in pieces, and OEE rate. Thus, it can be concluded that the proposed model will be fruitful for the manufacturing industry that wants to improve their quality, productivity, and machine maintenance. In the future, similar work can be conducted by considering the rest of the three big losses. There are some limitations of this work like this study is conducted on the socks knitting machines for the textile industry. A similar study can also be planned for other knitwear products.

**Table 8. Wilcoxon Signed-Rank Test.**

| Description                                      | Downtime baseline—downtime after action plan | Total production (kg) baseline—total production (kg) after action plan | Quality rate baseline—quality rate after action plan | Performance rate baseline—performance rate after action plan |
|--------------------------------------------------|-----------------------------------------------|------------------------------------------------------------------------|-----------------------------------------------------|----------------------------------------------------------|
| z                                                | −2.411                                        | −0.245                                                                 | −2.201                                              | −2.691                                                   |
| p-Value                                          | .016                                          | .806                                                                   | .028                                                | .007                                                     |

**Table 9. Paired Sample t-Test.**

| Paired differences                                      | t       | df   | p-Value |
|---------------------------------------------------------|---------|------|---------|
| Pair 1 Planned production time baseline—planned production time after action plan | 0       | 12   | 1       |
| Pair 2 Availability rate baseline—availability rate after action plan | −1.883  | 12   | .084    |
| Pair 3 Rejection rate baseline—rejection rate after action plan | 2.208   | 12   | .047    |
| Pair 4 Cycle time baseline—cycle time after action plan | 4.678   | 12   | .001    |
| Pair 5 Total production (pieces) baseline—total production (pieces) after action plan | −7.584  | 12   | <.0001  |
| Pair 6 OEE baseline—OEE after action plan              | −4.977  | 12   | <.0001  |
Figure 13. Advance OEE model.
The proposed model should also be implemented in other manufacturing industries after making it more generalized. In this study, three problems solving tools are used: Pareto analysis, Cause and Effect diagrams, and Checklists. Other tools can also be used.

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