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ORIGINAL ARTICLE

Improvement of overall equipment efficiency of ring frame through total productive maintenance: a textile case

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Abstract This paper focuses on the application of Kaizen, one of the pillars of total productive maintenance (TPM), for improvement of overall equipment efficiency (OEE) of a ring frame section in a spinning plant. The ring frame is considered as one of the critical sections since rope-like fiber strands become a fine yarn through a high amount of attenuation. Here, Kaizen was applied in the ring frame section to enhance overall performance and increase the productivity. Six major stoppage losses, namely breakdown or equipment failure, setup and adjustment, idling and minor stoppage, reduced speed, defects in the process, and reduced yield in the first place, were examined with the help of Pareto analysis, why why because logical analysis (WWBLA), and cause-and-effect analysis. A well-organized training program was conducted to make the operators educated about these losses and possible ways of improving the condition. Because of Kaizen, losses in the ring frame section were reduced significantly, and the OEE of the equipment was increased from 75.09 to 86.02%, productivity was improved by 23.93%, and production of defective items was reduced by 49.50%. The findings from this work revealed the benefit of application of TPM in real-world manufacturing environments.

Keywords Spinning · Ring frame · Total productive maintenance · Kaizen · Overall equipment efficiency (OEE)

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1 Introduction

Globalization has opened a window of opportunities for enterprises to manufacture textile and clothing product in developing countries due to cheap labor and relaxed environmental policies and regulations for working conditions [10, 30, 53, 59, 60, 75, 80]. Bangladesh is a very prosperous country in the world of textile business and the second biggest exporter of clothing after China [44]. Textiles and ready-made garment industries account for over 82.01% of total export earnings of Bangladesh (Trade Information of BGMEA 2015–2016). Thus, the textile and apparel industries have become the main driving force of economic growth of Bangladesh. To respond to global competition and market vulnerability in the textile and garments supply chain, one of the important key success factors is managing the complex value chain [26, 76]. Efficient backward linkage operation can help manage the complex textile value chain, which in turn could strengthen and help textile and garment industries sustain the globally competitive market [42].

Yarn manufacturing is one of the subsectors of backward linkage of clothing industries. Spinning is the first stage of textile manufacturing, which produces yarn as the final product. The spinning plant consists of several sections, from blow room to winding including ring frame. The compressed mass of cotton bales is converted to yarn by a series of operations including opening, cleaning, blending or mixing, drafting, doubling, twisting, and winding [51].

The ring frame section is considered as a critical section since rope-like fiber strands become a fine yarn through a high amount of attenuation. The two important factors that need to be evaluated to assess a manufacturing plant are the quality of products and the efficiency of machines [31]. Maintenance practices could influence these two factors. Maintenance practices depend on human input in the spinning industry to a greater extent [6]. An average of 28% of total production cost is attributed to maintenance activities that are associated with maintenance personnel and materials [20]. The maintenance department plays a key role to ensure the continuous production of the equipment to its normal functioning state [27, 68].

Total productive maintenance [18, 88] is a stepwise strategy that combines best features of productive and preventive maintenance with total employee engagement to maximize overall equipment efficiency (OEE) [92]. For every manufacturing company, the objective is to produce goods at a profit, and this can only be achieved using an effective maintenance system that helps maximize the availability of equipment by minimizing machine downtime due to unwanted stoppage [27, 71]. The stoppage losses can be divided into six major categories, which affect the overall performance of the equipment. These losses include breakdown losses; setup and adjustment losses; idling and minor stoppage losses; speed losses; rework and quality defect losses; and yield losses [77]. According to Gupta [37], the ring spinning process is the heart of a textile plant and has a direct relation to the production of the plant. It is very difficult to manage ring spinning process, and a lot of problems occur during the process. In this work, we identified stoppage losses and examined overall equipment efficiency to the ring frame of the textile plant under our interest.

The appropriate tools along with their pertinence, establishment, and adoption of operation are a major problem for an organization to improve the performance of equipment [40]. A number of studies examined the application of the total productive maintenance (TPM) approach to a wide range of industries (see Table 1). However, there is a lack of literature that connects textile and clothing industry to the application of TPM. In fact, most of them dealt with weaving [90], printing factory [11], and carding section [78] of the spinning factory.

The main goal of the study is to identify major stoppage losses, to examine and improve the overall equipment efficiency (OEE) of the ring frame of a textile spinning factory in Bangladesh through the application of TPM approach. In particular, we apply one of the pillars of TPM, namely Kaizen

Table 1 An overview of TPM study in different industries

Sl. no.	Authors	Aims	Domain of application	Country
1	Tomar and Bhuneriya [90]	To develop the TPM system to improve the existing maintenance system	Textile weaving industry	India
2	Benjamin et al. [14]	To improve the OEE by reduction of speed loss, i.e., idling and minor stoppage, and to reduce speed losses	Metal barrel manufacturing industry	Malaysia
3	Lalkiya and Kushwaha [61]	Development of a model to predict OEE through the TPM approach	Cement industry	India
4	Ohunakin and Leramo [74]	To increase OEE and reduce stoppage losses by implementing Kaizen	Beverage industry	Nigeria
5	Wudikarn [98]	To implement OEE as a measuring performance and measuring the success of a TPM implementation program	Wire mesh manufacturing company	Thailand
6	Habib and Kang [38]	To improve the productivity by implementing autonomous maintenance, a pillar of TPM	Assembly line of Haldex Brake Products	Sweden
7	Proma et al. [81]	To measure the TPM losses (delays and impedances caused by human inefficiencies) and quantify their effect	Tablet section in a pharmaceutical company	Bangladesh
8	Carannante et al. [19]	A comparative study of the UK and Japanese foundry industries in implementing TPM	Foundry factory	UK and Japan
9	Almeanazel [6]	To measure OEE and improve OEE by applying TPM	Steel company	Jordan
10	Wudhikarn [97]	To develop the present OEE by overall weighting equipment effectiveness (OWEE) based on existing implementation of TPM	Fiber cement roof manufacturing company	Thailand
11	Ahuja and Kumar [4]	To investigate the contributions of successful TPM initiative to competitive manufacturing	Precision tube mills	India
12	Tsarouhas [91]	To increase the productivity of machinery and improve the quality of product by adopting TPM	Food industry especially in bakery products	Greece
13	Eti et al. [23]	To implement TPM as a strategy and improve the performance of machinery and suggestion for self-auditing and benchmarking	Nigerian manufacturing industry	Nigeria
14	Chan et al. [20]	To study the effectiveness and implementation of the TPM program in the industry	Electronics manufacturing company	Hong Kong
15	Ljungberg [65]	To establish a norm based on stoppage of machinery in the TPM framework	Volvo Car Corporation	Sweden

[28, 29, 45], a strategic weapon for continuous improvement [64], to improve the overall equipment efficiency (OEE). To the best our knowledge, there is no literature that focused on the ring frame section of a textile processing factory for TPM study. Thus, this paper contributes to the total productive maintenance and textile literature as follows:

- Firstly, this paper studied the ring frame section of a spinning mill to examine and improve the OEE using one of the TPM pillars, namely Kaizen. To study the OEE, the major stoppage losses to the ring frame were identified in the first place.
- Secondly, we applied Kaizen to improve the overall equipment efficiency of the ring frame. After applying Kaizen, again major stoppage losses were evaluated, and OEE was examined. Finally, a comparison was made between the OEE of the ring frame section of the spinning mill before and after applying the Kaizen.

To achieve the objectives of this research, a systematic procedure was adopted from a review of recent literature. Herein, the Pareto chart was used to diagnose the stoppage losses correctly [48]. A fishbone diagram [99] was employed to find out the general causes of the problem [1]. Why why because logical analysis (WWBLA) work sheet was used to find out the root causes, which aimed to prevent/minimize the future adverse event of problems in question [94].

The rest of the paper is organized as follows. Section 2 illustrates related materials on OEE, TPM, Pareto analysis, fishbone diagram, WWBLA work sheet, and an overview of the yarn manufacturing process. Section 3 gives an overview of the case company. Section 4 gives the methodology undertaken in this research. Section 5 presents results and discussion of findings. Finally, Section 6 concludes the paper.

2 Materials

2.1 Overall equipment efficiency

OEE is used to determine how efficiently a machine is running. It is one of the most effective measures for driving plant improvement. To evaluate the effectiveness of the equipment, [72] developed the concept of OEE as a measure of TPM [87]. It focuses on the plant on the concept of zero stoppage losses and zero wastage [65]. OEE highlights the hidden capacity in an organization. It measures both “doing the thing right” and “doing the right things” [79]. It can be considered to combine the operation, maintenance, and management of manufacturing equipment and resources [83]. The objective of OEE is to identify these losses [47]. These losses are divided into three major areas, namely availability, performance rate, and quality rate of the output [7, 69]. OEE is equal to the multiplication of the three main bases for the six major losses. These losses include breakdowns, setup and adjustment, idling and minor stoppage, reduced speed, a defect in process, and yield loss [85]. Figure 1 illustrates the calculation of OEE from six major stoppage losses.

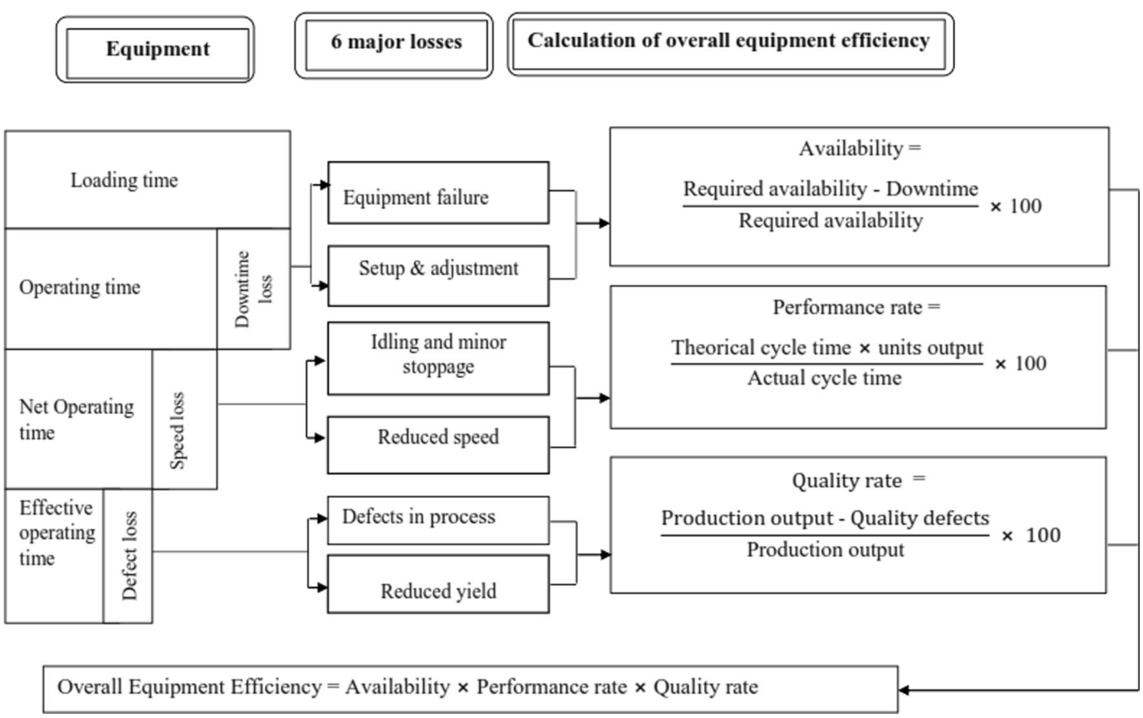


Fig. 1 Calculation of OEE from six major stoppage losses [77]

$$\text{OEE} = \ Availability \times Performance\ rate \times Quality\ rate \quad (1)$$

The availability is a comparison between the amount of time the machine is producing and the amount of time it was scheduled to produce. This can be written as:

$$\begin{aligned} Availability &= \frac{Required\ availability - Downtime}{Required\ availability} \times 100 \\ &= \frac{Actual\ operating\ time}{Planned\ operating\ time} \times 100 \end{aligned} \quad (2)$$

Here, actual operating time = Required availability−downtime = Planned operating time−Unplanned downtime.

The performance rate of the equipment can be defined according to Eq. (3).

$$Performance\ rate = \frac{Units\ produced\ in\ the\ total\ shift\ time}{Number\ of\ expected\ units\ \text{to be}\ produced} \times 100 \quad (3)$$

Expected production can be calculated as follows:

$$Expected\ production = \frac{Actual\ operating\ time}{Theoretical\ cycle\ time} \quad (4)$$

Therefore, we have

$$Performance\ rate = \frac{Theoretical\ cycle\ time \times units\ output}{Actual\ cycle\ time} \times 100 \quad (5)$$

The quality rate can be expressed as the production input into the process or equipment minus the volume or number of quality defects then divided by the production input (Eq. 6).

$$Quality\ rate \ = \frac{Production\ output - Quality\ defects}{Production\ output} \times 100 \quad (6)$$

2.2 Total productive maintenance and Kaizen

TPM is a scientific and company-wide approach in which every employee at all levels in the organization is concerned about the maintenance, quality, and efficiency of their equipment [2, 39]. It is one of the short-term projects of just-in-time (JIT) approach [24]. TPM has a remarkable consequence on the output of a manufacturing organization [36]. As an aggressive maintenance strategy, the TPM approach is used to improve equipment performance by avoiding equipment failure [89]. Communication among operators, maintenance staffs, and engineers is very important [21].

Top management commitment and support are the key factors that promote the morale and motivation of staff [62]. Training programs also enhance the skills and technical capabilities of the production and maintenance staff [63]. Reduction of whole life cost of equipment and six major losses and increase of OEE are the objectives of TPM. Achieving a reliable manufacturing system is the key objective of TPM. It can be executed by maximizing the OEE [58]. It is an innovative approach to maintenance that is used to optimize equipment effectiveness, eliminate breakdowns, and enhance autonomous maintenance [15, 47]. Unscheduled maintenance keeps to a minimum the goal of TPM [79]. The basic practices of TPM are called the pillar of TPM. They are 5S, autonomous maintenance, Kaizen, planned maintenance, quality maintenance, training, office TPM and safety, health and environment.

Kaizen refers to the continual search for improvement, and it is one of the key principles of Japanese manufacturing, developed by Toyoda Motor Company. Kaizen events are also known in other terms as well, e.g., "Kaizen Blitz," "Gemba Kaizen," "rapid improvement events," and "accelerated improvement workshops" in the USA [32]. The principle behind is that "a very large number of small improvements are more effective in an organizational environment than a few improvements of large value." Kaizen programs are organizational improvement mechanism aimed at work area transformation and employee development. A specific short-term (1 week or shorter) dedicated project team does not need to give much attention to exploratory research since they have to study widely in general [25]. It is targeted to achieve and sustain zero loss on minor stops, measurement and adjustments, defects, and unavoidable downtimes. The WWBLA work sheet, Poka-yoke or mistake proofing or error prevention, a summary of losses, Kaizen register, and Kaizen summary sheet are known as Kaizen tools [95].

2.3 An overview of Pareto analysis, WWBLA work sheet, and fishbone diagram

A Pareto analysis is a statistical quality control tool that ranks data arrangements in subsiding order from the highest frequency to the lowest frequency of incidences. The total frequency is equated to 100%. The vital few items occupy around 80% of the cumulative percentage of incidences, and the many trivial items occupy only the remaining 20% of incidences [52]. It is one of the best tools in conjunction with a fishbone diagram [13].

The WWBLA is an analytical and simplest organizing technique to find out the root causes of the problem [14, 16]. In this technique, it is asked "why," many times to identify the root cause of a problem [17, 50]. A work sheet is prepared for each major problem. A cause is identified and called the first factor for a problem. Then, it is verified whether it can be divided into further root causes. Then, the second factor for the problem is identified and verified. In this way, a third factor of the problem is identified. Once it is not possible to identify further, then the verification is marked. Finally, countermeasures are taken to minimize the problem [68].

A fishbone diagram is a useful tool to determine the possible causes for a problem, but it cannot identify root causes. It illustrates the causes of any problem in a more structured approach than other brainstorming tools [1]. It also is known as a cause-and-effect diagram or Ishikawa diagram. It can be used to represent the relationship between problems with their causes as lines illuminating from group branches [41].

2.4 Application of TPM in industry

A growing body of literature examined the benefit and usefulness of the application of TPM for reducing losses and improving productivity in various industries. There is an opportunity for improvement in any organization while anything is less than ideal by applying TPM [8]. TPM has many real life applications in manufacturing industries. Fore and Zuze [27] investigated the present OEE of a general electric company. In their study, interviews, reviewing documentation, historical records, and direct and participatory observation were used as data collection for OEE measurement. After TPM had been implemented, a reduction of major losses and reworks took place in practice. They observed an improvement of OEE at a significant level.

Graisa and Al-Habaibeh [34] investigated the productivity and profitability of four cement factories of a company. They suggested a TPM framework via comprehensive productivity and maintenance system that could be achieved using three main aspects: staff training, staff motivation, and development of the environment.

Aziz et al. [11] investigated the effective implementation of TPM in a textile printing industry. They focused on the TPM pillars Kaizen, autonomous maintenance, planned maintenance, and employee education and training. They found almost 50% reductions in machine breakdown time, mean time between failure (MTBF) and mean time to repair (MTTR).

Kiran et al. [55] studied on the male contraceptive manufacturing industry. They implemented TPM to reduce only the breakdown loss from the six major losses and used the root cause analysis (RCA) method as a problem-solving tool. After taking countermeasures, the breakdown was reduced to a significant level and the profit increased by Rs 210,000 per month.

Paropate and Sambhe [78] studied on the carding section of a spinning plant. They investigated the availability, performance efficiency, quality rate and OEE by breakdown time, productive time and wastage, and recycled cotton wastage. By implementing TPM, they were able to improve OEE from 68.98 to 71.46%.

Benjamin et al. [14] applied TPM on a metal barrel manufacturing company situated in Malaysia. The study focused on speed loss, one of the major stoppage losses of OEE. The root causes of stoppage were identified by Pareto analysis and WWBLA technique. After eliminating speed loss, the company saved $32,811.5 per annum.

In addition to the above literatures on the application of TPM in industry, Table 1 presents some other works. It is revealed that application of TPM is rarely studied in the textile context. Thus, this paper took the opportunity to apply Kaizen, a pillar of TPM, with the hope of analyzing and reducing losses to the ring frame section of a textile processing plant in Bangladesh.

2.5 An overview of the yarn manufacturing process

Spinning is the system by which the filaments or fibers are converted to yarn by drafting and twisting. The process flowchart of carded yarn production is shown in Fig. 2. Ring spinning is the most important step to convert fibers into yarn. The short length natural and synthetic fibers are converted to yarn by spinners [86]. Yarn produced by the ring spinning process constitutes approximately 85% of the total yarn manufactured in the world [66]. It is made to draft the roving into the desired count and impart the desired twist to produce the strength in the yarn [57]. If the twist is increased, yarn strength also increases [66].

The ring frame consists of a large number of spindles (1008 spindles/frame). The productivity of the ring frame depends on some running spindles. One traveler and spindle co-operate with a bobbin, to twist and wind the yarn from a drafting system. Figure 3 shows the schematic diagram of the ring frame. Figures 4 and 5 show the normal and defective ring cops. The production capacity of a ring frame of a spinning factory under question can be determined using Eq. (7).

$$Production\ of\ ring\ frame\ in\ \text{kg per}\ shift = \frac{Spindle\ \text{rpm} \times 60(\text{min to h}) \times 8(\text{h to}\ shift) \times Number\ of\ running\ spindle}{Twist\ \text{per}\ inch\ (\text{TPI}) \times 36(inch\ \text{to}\ yard) \times 840 \times Yarn\ Count\ (\text{Ne}) \times 2.2046(\text{lb to kg})} \quad (7)$$

3 Overview of the case company

This study was conducted in Akij Textile Mills Limited (ATML), a sister concern of Akij Group, in Bangladesh. The company is now producing rotor-spun yarn by installing a rotor frame. At present, the production capacity of the ring and rotor spinning system is 25 and 12 tons per day, respectively. Currently, there are around 1200 people working in the factory. The factory has an installed capacity of 45,000 spindles in the ring spinning system. The industry was designed to produce carded, combed, compact, Siro, cotton-polyester (PC), and chief valued cotton (CVC) yarns. Akij Group has apparel manufacturing facilities with very strong backward integrated industries of spinning, weaving, dyeing,

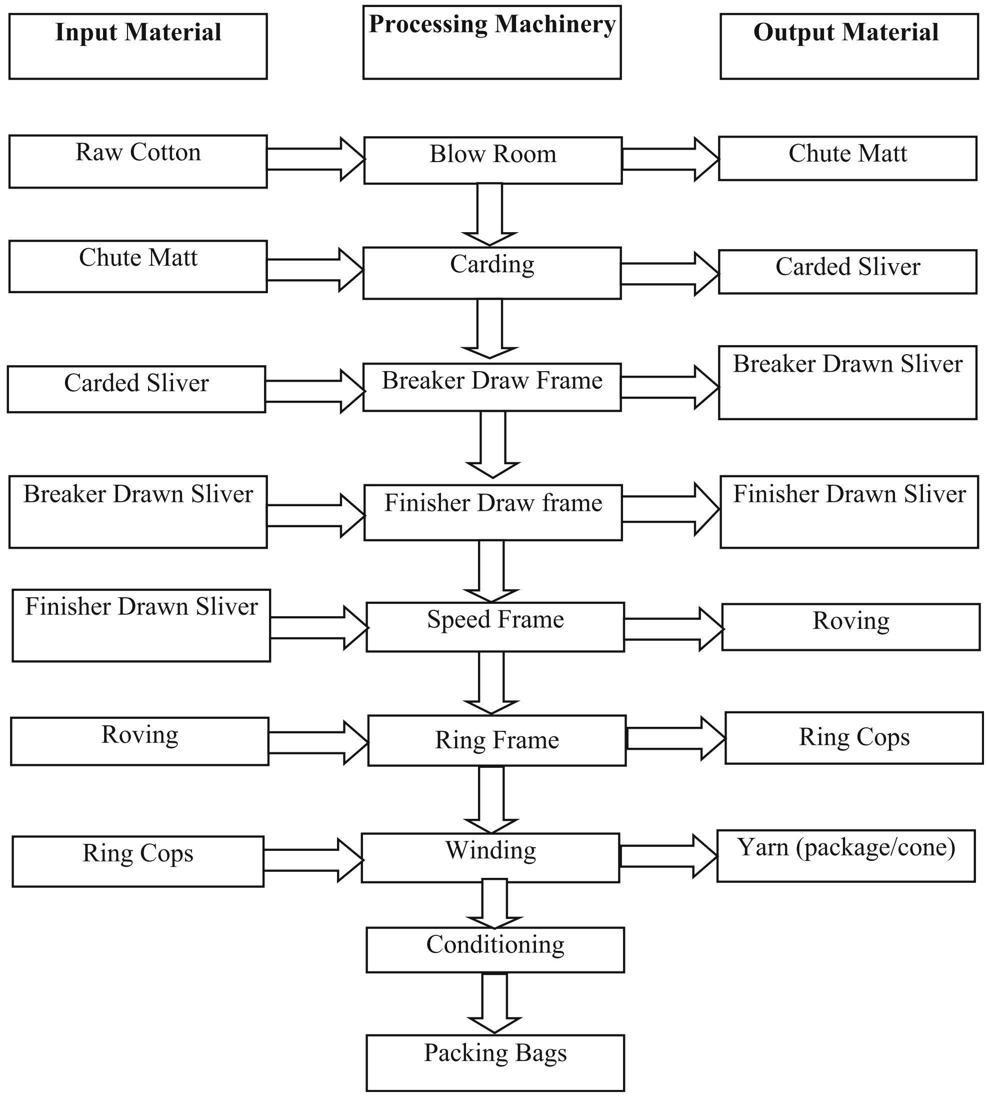


Fig. 2 Flowchart of carded yarn production

finishing, and packaging. They are supplying quality knitted and woven fabric across the world to famous retailers in the fashion industry. Some famous clothing retailers like HnM, Tema, BF Asia, etc. are buying finished fabric from Akij Group. Therefore, this study carried practical significance to Akij Group to benefit all backward linkage operations.

4 Research methodology

The study was carried out in the ring frame section of a yarn manufacturing factory. The main goal of this research was to improve the OEE through TPM. To measure the OEE, six major stoppage losses in the ring frame section were examined. Based on the measured major stoppage losses, the OEE was calculated and the ring frame with the lowest OEE was selected for further study. Three tools, namely Pareto analysis, WWBLA work sheet, and cause-and-effect diagram, were used to analyze data on stoppage losses and OEE of the ring frame. Significant losses were identified using Pareto analysis. The WWBLA work sheets helped to find out the reasons behind those significant losses. Then, the fishbone diagrams were constructed to illustrate the causes of the problem in a structured way. A Kaizen team was formed to train the operators to improve their skills on basic maintenance works such as cleaning of machine parts, oiling, tightening, inspection, and basic routine works. After the training program, OEE of the same ring frame section was calculated in the same ways followed before the training program. Finally, results were compared to assess the improvement in OEE. The study framework can be visualized in Fig. 6.

4.1 Initial status of stoppage losses and OEE

It is essential to get appropriate data on stoppage losses to implement TPM. Often, organizations keep record of repair time in the logbook. However, they do not give the actual scenario of stoppage losses and their causes in most of the

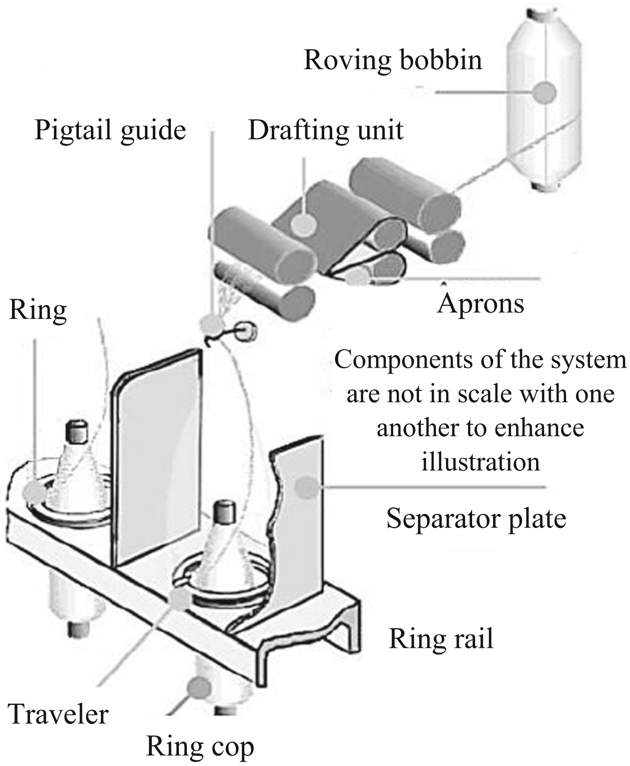


Fig. 3 Schematic diagram of the ring frame [66]

cases. Moreover, it is quite difficult to get accurate data in the process industry. It is obvious that data collection from the factory floor will give the real picture of stoppage losses of the ring frame. In this study, data were collected for 10 days by six major stoppage losses from the selected ring frame that was producing yarn count of 26 Ne KH and twist per inch (TPI) of 18.36. Table 2 shows the stoppage losses of ring frames. It is important to note that those ten working days

Fig. 4 Defective ring cops

Fig. 5 Normal ring cops

were chosen randomly to get the actual scenario of the production process. Here, each working day consists of eight working hours (one shift) as shown in Table 2. Various experiments were performed in this research in order to get a real picture of the ring frame performance. These experiments helped us to better analyze and predict the overall equipment efficiency of the ring frame of the spinning plant.

Availability, performance efficiency, quality rate, and OEE were measured based on collected data. The calculated OEE of the ring frame varies from 72.87 to 76.93%. The average OEE was 75.09%. The OEE in the initial status before implementing TPM is shown in Table 3.

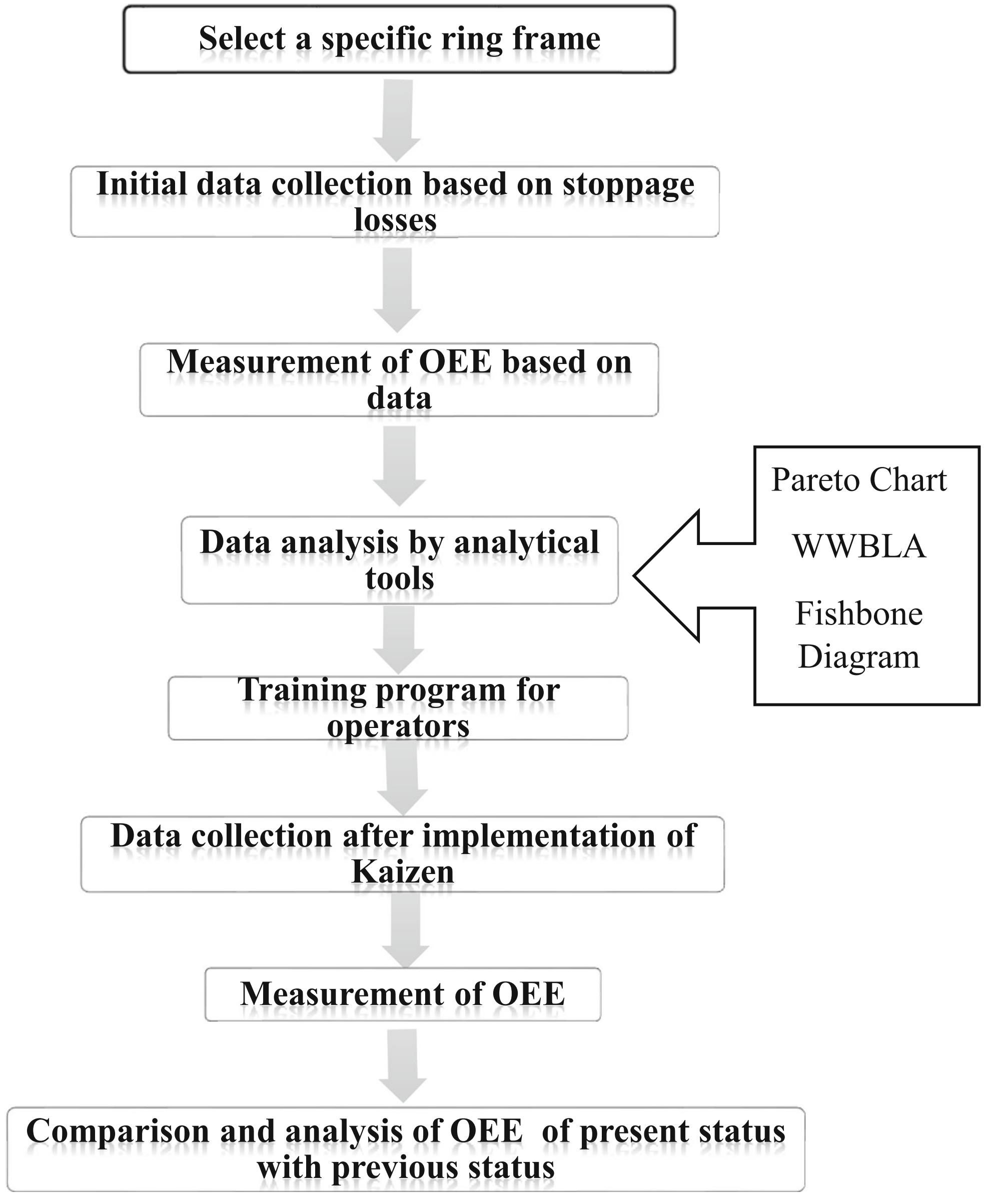
Table 2 shows the significant losses as identified by Pareto analysis. Pareto analysis is a statistical technique in decision-making. Pareto analysis is used for the selection of a limited number of tasks that produce a significant overall effect. Pareto principle represents that by doing 20% of work, 80% of the advantages of doing the entire job can be generated. Figure 7 illustrates the Pareto chart for major stoppage losses.

From Fig. 7, it is revealed that a few vital factors are causing 89.3% of the total stoppage loss. The vital factors are idling and minor stoppage amounting 67.2% and breakdown constituting 22.1%. The other stoppage losses are yield loss with 8.4% and reduced speed with 2.3% of the total stoppage loss.

According to Table 2, the main causes of idling and minor stoppage are higher doffing time and higher traveler change time in the machine. The causes of breakdown stoppage were power failure, front roller and back roller bearing breaking, draft change pinion (DCP), and twist change pinion (TCP) gear breaking into the machine.

To analyze the stoppage losses, the WWBLA technique was used. It was helpful to identify possible causes to a problem. Then, a cause-and-effect diagram was used to associate

Fig. 6 Study framework



multiple causes with a single effect. Figure 8 illustrates the WWBLA work sheet for idling and minor stoppage. The countermeasures taken are also shown in Fig. 8. Based on WWBLA, a fishbone diagram was constructed for idling and minor stoppage.

The fishbone diagram for idling and minor stoppage loss is displayed in Fig. 9. Based on the influence of man, machine, materials, measures, management, and environment, the reasons for idling and minor stoppage were categorized. Operators were not concerned about the time required to release the ring cops from the machine. The front roller was displaced, and bearing was broken due to overloading of the machine. Due to the generation of piles through the front roller, travelers have flown away. To avoid count and lot mix, countwise bobbin color should be fixed. Therefore, a sufficient amount of countwise colored empty bobbins should be stored before changeover of count or lot. DCP and TCP gears were changed due to the new order of higher count, which was a managerial decision. The productivity of machinery, process waste percentage, and the quality of yarn were also dependent on end breakage rate of the ring frame. As noticed, higher RH enhanced the end breakage rate. Thus, proper control of RH was in place to reduce the end breakage rate in the ring frame section.

Figure 10 gives the WWBLA work sheet for the breakdown losses. The countermeasures taken have been shown in the WWBLA. The fishbone diagram is presented in Fig. 11 that is constructed based on the WWBLA for breakdown losses.

Figure 11 presents the fishbone diagram for breakdown losses. The reasons are grouped based on the influence of man, machine, materials, and measures. DCP gear is broken

Table 2 Different stoppage losses in the selected ring frame

Day	Activity	Losses	Frequency	Total loss (min)
1	Doffing	Idling and minor stoppage	3	22.5
	Back roller bearing breaks (all ends break)	Breakdown	1	9.5
2	Doffing	Idling and minor stoppage	3	24
	Power failure	Breakdown	1	6
3	Doffing	Idling and minor stoppage	3	22.5
	Traveler change	Idling and minor stoppage	1	8.5
4	Doffing	Idling and minor stoppage	3	22.5
	TCP gear breaks	Breakdown	1	10.5
	Front roller bearing breaks (all ends break)	Breakdown	1	17
5	Doffing	Idling and minor stoppage	3	22.5
	Roving change	Yield loss	1	15.5
6	Doffing	Idling and minor stoppage	3	24
	Power failure	Breakdown	1	12
7	Doffing	Idling and minor stoppage	3	24
	DCP gear breaks	Breakdown	1	11
8	Doffing	Idling and minor stoppage	3	24
	Excess EBR	Yield loss	1	16
9	Doffing	Idling and minor stoppage	3	24
	Traveler change	Idling and minor stoppage	1	10
	Spindle tape breaks (2 positions)	Reduced speed	1	8.5
10	Doffing	Idling and minor stoppage	3	24
	Power failure	Breakdown	1	7
	Front roller bearing breaks (all ends break)	Breakdown	1	10
Total losses (min)				375.5

due to lack of skills of operators. Since the connection between nuts and bolts were loose, the front roller and TCP gear shaft were displaced. Also, V-belts were broken. Also, wastage was increased due to the generation of piles through the front roller. In that case, proper measures were taken to adjust the front roller position and TCP gear shaft.

4.2 Training program for operators

Training and education for all employees are utmost inevitable to gain their pledge and involvement in the activities of quality improvement [49, 93]. In this study, a Kaizen team was built to develop the skills of operators. The team was comprised of operators and supervisory staff. The operators were trained about basic operations of the ring frame, important machine parts, and their functions, improving strategy of the productivity of the ring frame and quality of produced yarn, basic maintenance activities that should be done by an operator and responsibilities of an operator in the ring frame section. After taking all the above steps, data were collected again from the ring frame based on six major stoppage losses to measure and analyze with the previous status. Table 4 shows the summary of the training program for operators. The literature that supports the topics of the training program is also shown in Table 4.

4.3 Status after applying Kaizen

To assess the improvement by training of the operators and application of Kaizen, data from the same ring frame section were collected again. Table 5 shows the stoppage time losses after analysis of data using Kaizen tools and by developing the skills of operators by the training program. Table 6 shows the calculated OEE after reduction of stoppage losses (Fig. 12).

5 Results and discussion

Pareto analysis before and after the application of Kaizen helped us to identify the contribution of different factors to OEE of the ring frame section. Table 5 gives the most significant losses as identified by Pareto analysis. It is clear that the most significant source of loss is also idling and minor

Table 3 OEE at initial stage

		Day									
		1	2	3	4	5	6	7	8	9	10
A	Running time per shift (min)	480	480	480	480	480	480	480	480	480	480
B	Downtime per shift (min)	0	0	0	0	0	0	0	0	0	0
C	Loading time per shift (A − B) (min)	480	480	480	480	480	480	480	480	480	480
D	Stoppage losses per shift (min)	32	30	31	50	38	36	35	40	42.5	41
E	Operating time per shift (C − D) (min)	448	450	449	430	442	444	445	432	437.5	439
	Defective amount (number)	97	106	112	106	106	102	108	124	95	109
F	Output per shift (number)	3416	3317	3393	3483	3443	3487	3314	3393	3493	3363
G	Rate of quality products (%)	97.16	96.80	96.70	96.96	96.92	97.07	96.74	96.35	97.28	96.76
H	Ideal cycle time (min)	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
I	Actual cycle time (min)	0.13	0.13	0.12	0.12	0.12	0.12	0.13	0.13	0.12	0.13
J	Actual processing time (I * F) (min)	430.76	418.27	417.34	424.93	420.05	428.90	420.88	427.86	419.16	424.07
K	Operating speed rate (H/I * 100) (%)	86.52	86.52	88.70	89.43	89.43	88.70	85.91	86.52	90.92	86.52
L	Net operating rate (J/E * 100) (%)	96.15	92.95	92.95	98.82	95.03	97.60	94.58	97.24	95.81	96.60
M	Availability (E/C) * 100 (%)	93.33	93.75	93.54	89.58	92.08	92.50	92.71	91.67	91.15	91.46
N	Performance efficiency (K * L * 100) (%)	83.19	80.42	82.45	88.37	84.99	85.68	81.25	84.13	87.11	83.58
OEE = M * N * G * 100 (%)		75.44	72.98	74.58	76.76	75.85	76.93	72.87	74.31	77.24	73.97
Average OEE (%)		75.09									

stoppage, which is 82% of the total loss. The second significant loss is breakdown stoppage. Here, though the percentage of idling and the minor stoppage was increased from 71.6 to 82%, the overall stoppage losses were reduced by 42.13%.

Figure 13 compares stoppage losses in two scenarios, namely before reducing stoppage losses and after reducing stoppage losses. Before and after applying Kaizen, stoppage losses were 375.5 and 217.5 min, respectively. The losses were reduced to 158 min for 10 days, 15.8 min per shift, and 47.4 min per day.

Figure 14 shows the comparison of OEE, output ring cops, defective ring cops, and production rate before and after implementation of TPM. It is revealed that the OEE is increased from 75.09 to 86.02%. It is due to the reduction of stoppage losses and an increase of output ring cops. After the training program, operators became more concerned about production and small maintenance activities. As a result, the number of idle spindles was reduced, and output ring cops were increased by 11.36%. The defective ring cops were reduced by 49.53% (from 107 pieces to 56 pieces). It was due to countermeasures that were taken to reduce stoppage

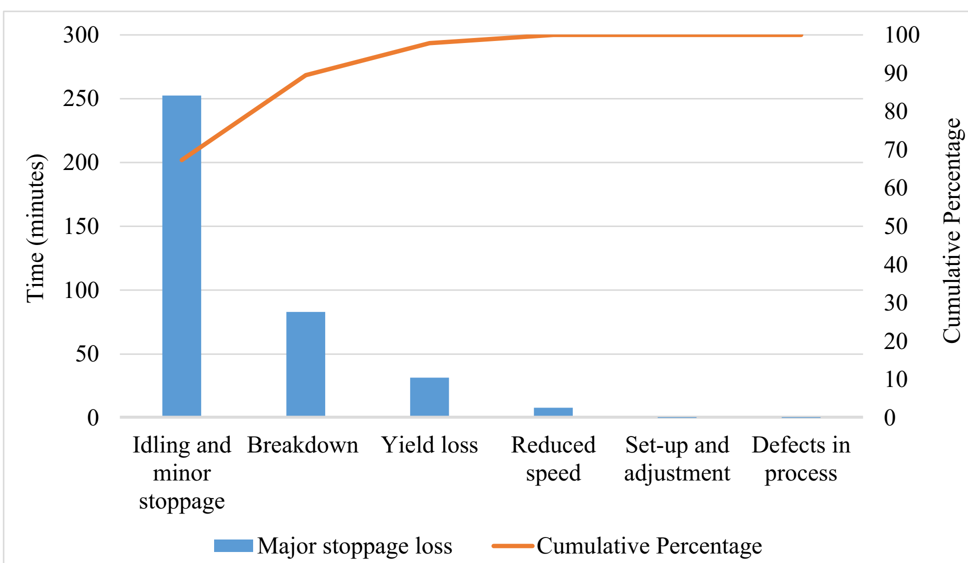


Fig. 7 Pareto chart for major losses before applying Kaizen

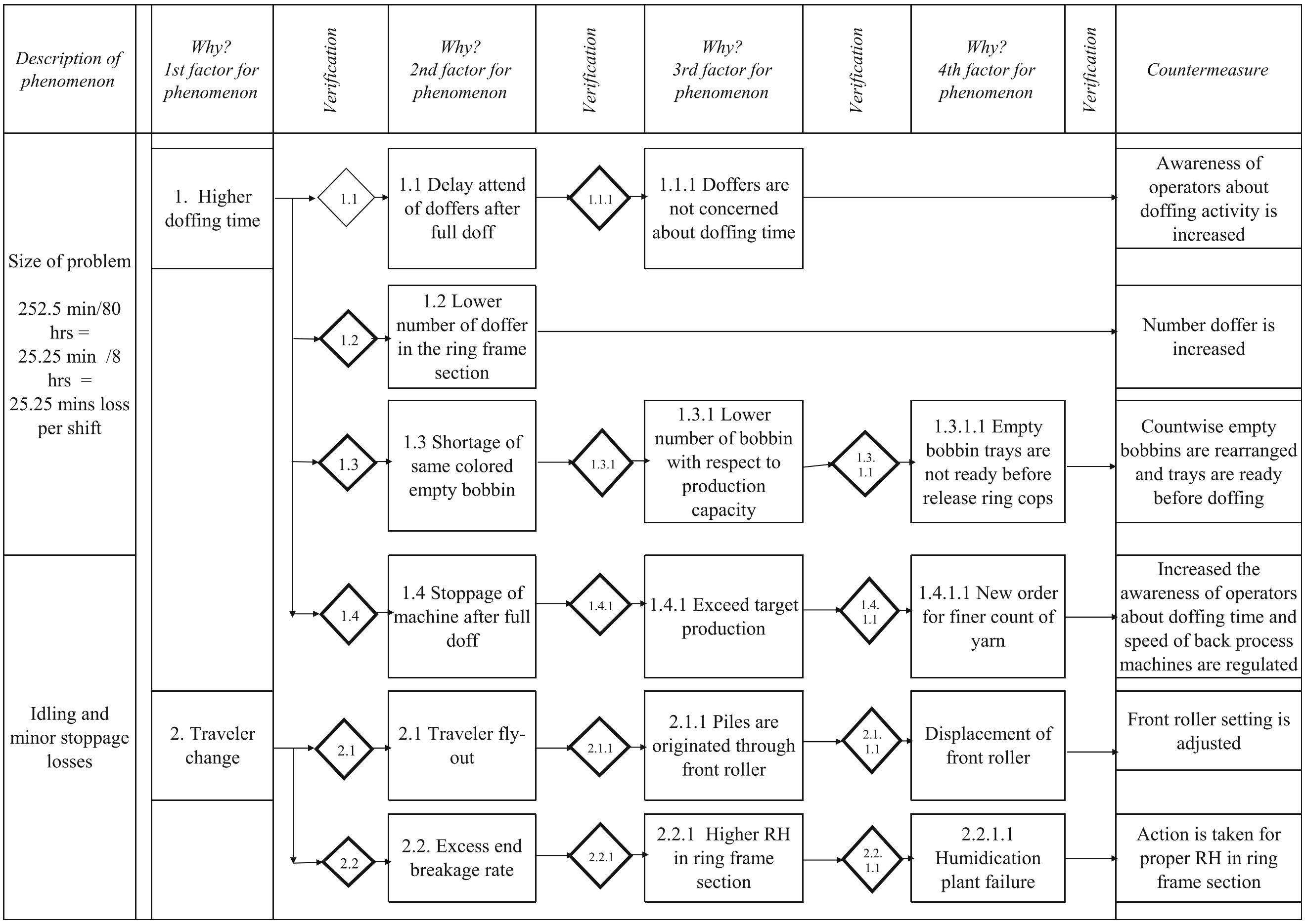


Fig. 8 WWBLA work sheet for idling and minor stoppage

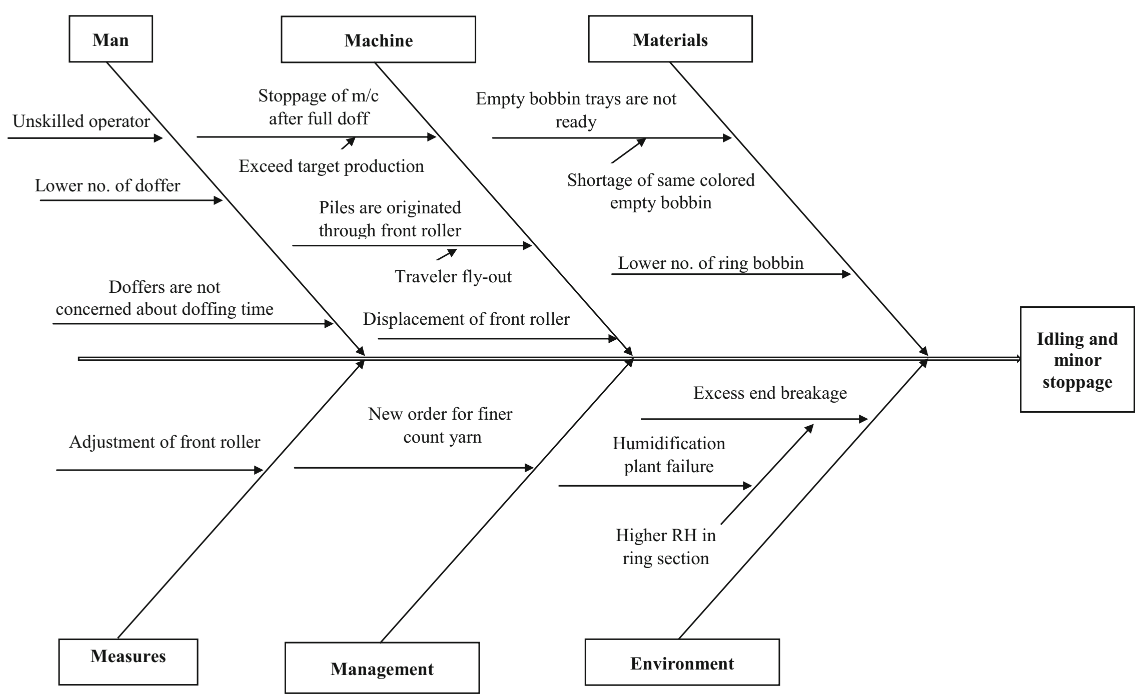


Fig. 9 Fishbone diagram for idling and minor stoppage losses

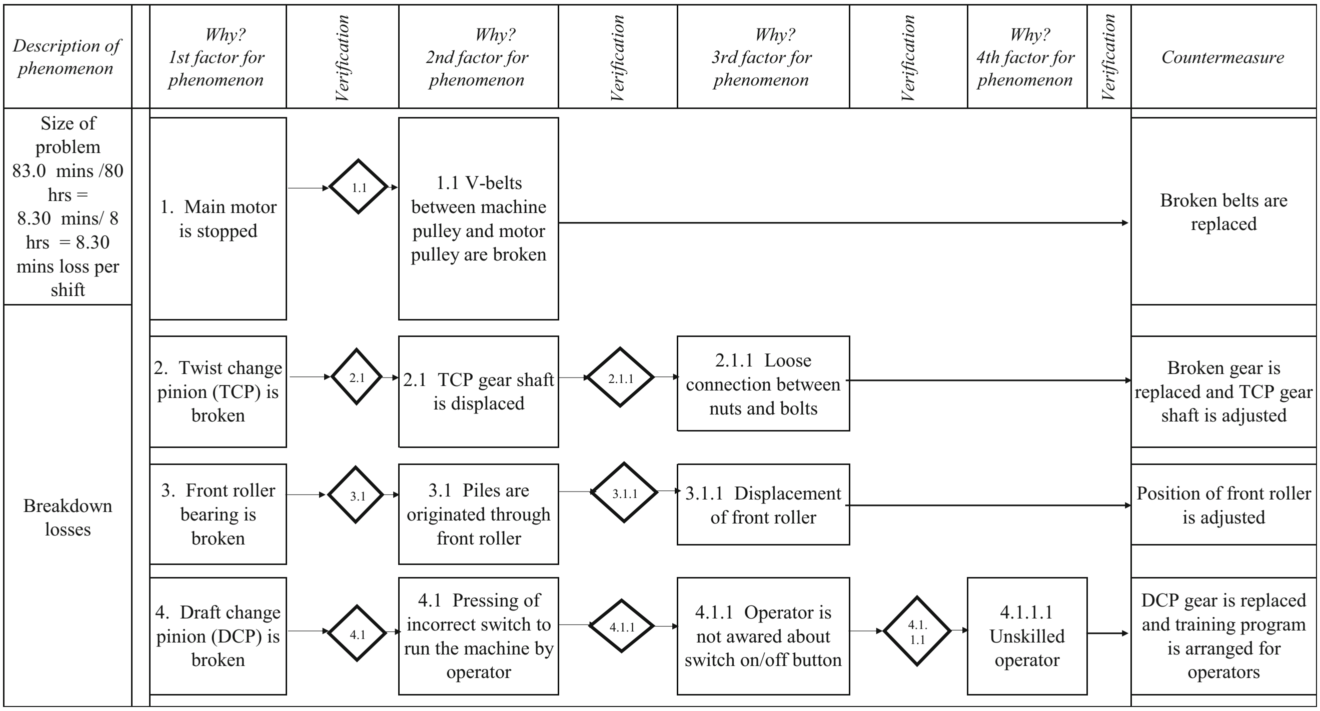


Fig. 10 WWBLA work sheet for breakdown losses

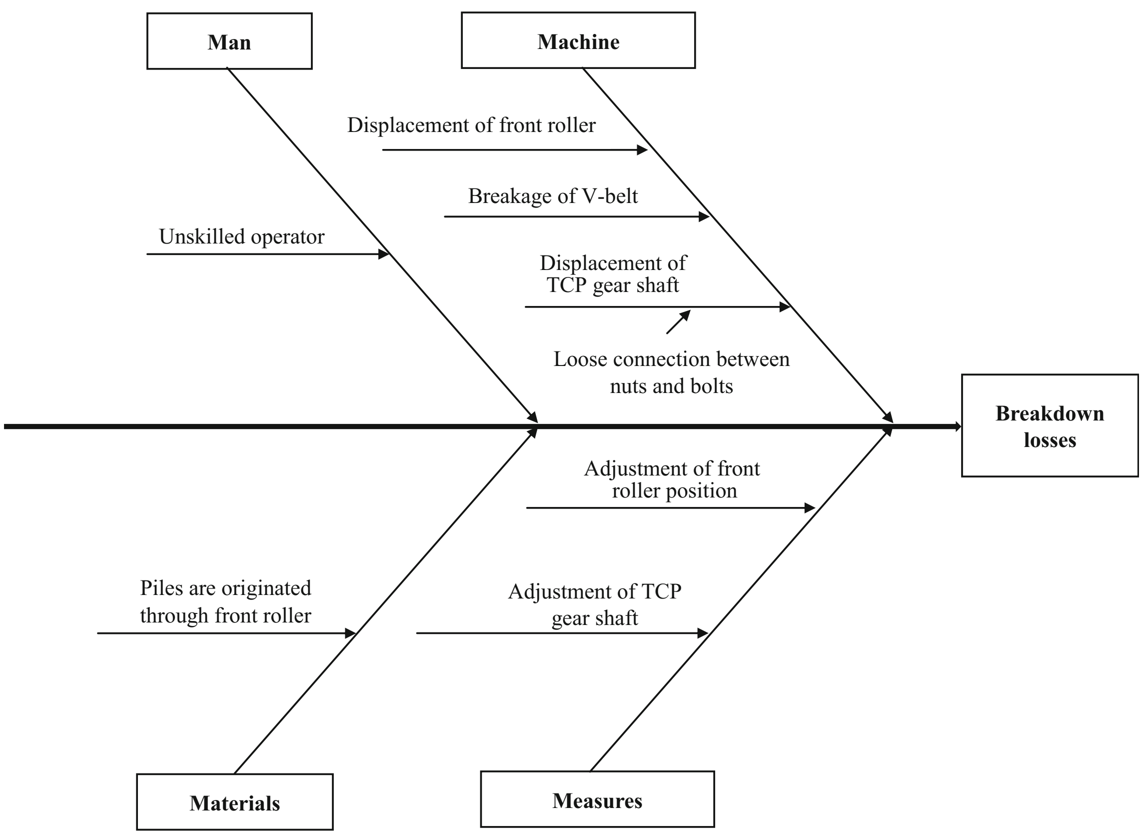


Fig. 11 Fishbone diagram for breakdown losses

Table 4 Topics of training program for operators

Sl. no.	Key focus	Topics included	Supporting literature
1	Ring frame	• Basic operations of the ring frame • Important machine parts and their functions • Improvement of the productivity of the ring frame • Improvement of the quality of yarn	Ahmed et al. [3], Murugan et al. [70], Ishtiaque et al. [43], Khare [54], Klein [56]
2	Fundamentals of maintenance	• Basic maintenance activities that should be done by an operator • Responsibilities of an operator in the ring frame section	Gupta [37], Niijjaawan and Niijjaawan [73], Al-Hassan et al. [5]

losses of the machine. The operators were more concerned about the machine performance. It is noticed that when end breakage occurred in any spindle, the concerned operator pieced together the ends of yarn at the breaking point, and there was less chance to create a defective ring cop.

After taking countermeasure (shown in the WWBLA work sheet, Figs. 8 and 10), the stoppage losses were reduced to 21.75 min, and consequently, defective ring cops were reduced to 54 pieces per shift. The output ring cops were increased to 437 pieces per shift.

As a result of the reduction of stoppage losses as well as for the improvement of OEE and product quality, the production rate was increased by 23.93%. After countermeasures had been taken, the stoppage losses per shift were reduced to 21.75 min, and consequently, defective ring cops were reduced to 54 pieces as well as output ring cops were increased to 3847 pieces. The WWBLA work sheet (Figs. 8 and 10) displays the countermeasures that were taken to reduce stoppage losses to the ring frame of the spinning factory. As a result of taking countermeasures, stoppage time was reduced from 375.5 to 217.5 min.

According to Table 6, OEE is increased to 86.02% from 75.09% after countermeasures were taken. At the same time, the number of idle spindles was reduced and the number of output ring cops was increased.

During the research period, the authors involved in this study did not notice any organized company policy for the training of operators. The operators and maintenance staffs of the textile factory lacked the fundamental theoretical knowledge to examine and reduce stoppage losses and to evaluate the OEE. On-the-job and off-the-job training may assist in developing the skill of operators and maintenance staffs [35, 82, 96].

In this study, the off-line training program was arranged to develop the skill of operators. One pillar of TPM, namely Kaizen, was implemented to the ring frame machine in the textile spinning factory. As a result of applying Kaizen, the stoppage time was reduced considerably. Reduction of

Table 5 Data collection after applying Kaizen

Day	Activity	Losses	Frequency	Total loss (min)
1	Doffing	Idling and minor stoppage	3	15.6
	Power failure	Breakdown	1	5.6
2	Doffing	Idling and minor stoppage	3	15.6
3	Doffing	Idling and minor stoppage	3	15
	DCP broken	Breakdown	1	10.5
4	Doffing	Idling and minor stoppage	4	20
5	Doffing	Idling and minor stoppage	3	15
	Front roller bearing was broken	Breakdown	1	10
	All end breaks	Idling and minor stoppage	1	5
6	Doffing	Idling and minor stoppage	3	15.9
	Roving change	Idling and minor stoppage	1	5.5
7	Doffing	Idling and minor stoppage	4	20
	Power failure	Breakdown	1	5
8	Doffing	Idling and minor stoppage	4	20.8
9	Doffing	Idling and minor stoppage	3	15
	Traveler change	Setup and adjustment	1	8
10	Doffing	Idling and minor stoppage	3	15
Total loss (min)				217.5

Table 6 OEE calculation based on collected data

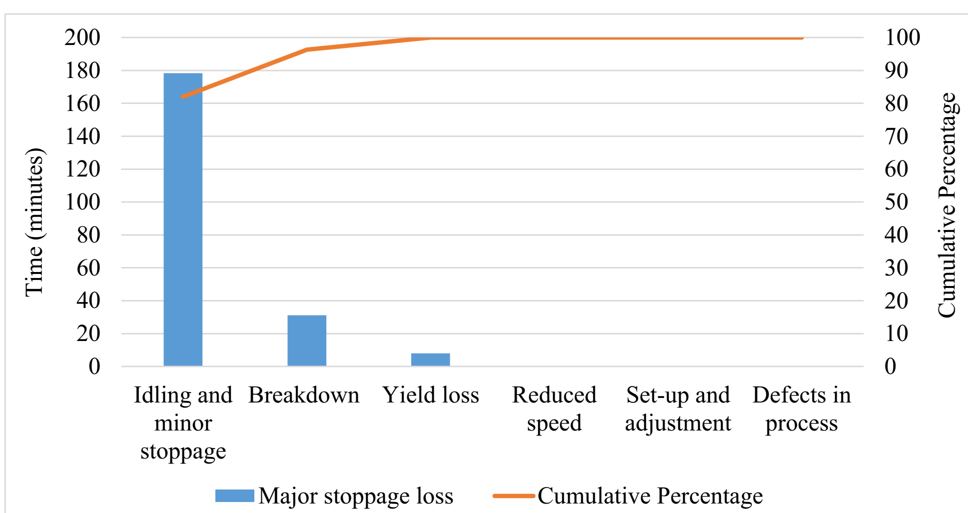
		Day									
		1	2	3	4	5	6	7	8	9	10
A	Running time per shift (min)	480	480	480	480	480	480	480	480	480	480
B	Downtime per shift (min)	0	0	0	0	0	0	0	0	0	0
C	Loading time per shift (A − B) (min)	480	480	480	480	480	480	480	480	480	480
D	Stoppage losses per shift (min)	21.2	15.6	25.5	20	30	21.4	25	20.8	23	15
E	Operating time per shift (C − D) (min)	458.8	464.4	454.5	460	450	458.6	455	459.2	457	465
	Defective amount (number)	64	65	52	61	51	48	53	50	45	49
F	Output per shift (number)	3978	3775	3912	3865	3727	3685	3920	3798	3889	3919
G	Rate of quality products (%)	98.39	98.28	98.67	98.42	98.63	98.70	98.68	98.68	98.84	98.75
H	Ideal cycle time (min)	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11
I	Actual cycle time (min)	0.11	0.12	0.12	0.117	0.12	0.12	0.12	0.12	0.12	0.12
J	Actual processing time (I * F) (min)	453.49	441.68	449.88	452.21	436.06	438.52	450.8	448.16	447.24	454.60
K	Operating speed rate (H/I * 100) (%)	95.70	93.25	94.87	93.25	93.25	91.68	94.87	92.46	94.87	94.05
L	Net operating rate (J/E * 100) (%)	98.84	95.11	98.98	98.31	96.90	95.62	99.08	97.60	97.86	97.76
M	Availability (E/C) * 100 (%)	95.58	96.75	94.69	95.83	93.75	95.54	94.79	95.67	95.21	96.88
N	Performance efficiency (K * L * 100) (%)	94.59	88.69	93.90	91.67	90.36	87.66	93.99	90.24	92.84	91.94
OEE = M * N * G * 100 (%)		88.90	84.33	87.73	86.46	83.55	82.66	87.89	85.19	87.37	87.96
Average OEE (%)		86.20									

stoppage time, in turn, decreased throughput time and increased machine performance. It is mentioned here that implementation of the TPM strategy did not interfere with scheduled maintenance, rather it helped reduce the stoppage time losses and increased the productivity. It also gave the operators the opportunity to raise their skills on fundamental background on maintenance operations relevant to the application of total productive maintenance.

The stoppage time loss in the initial stage was 37.5 min per shift, whereas after implementation of TPM, it was reduced to 21.75 min per shift. After analyzing the causes of the stoppage by the WWBLA (Figs. 8 and 10) work sheet, the root causes were identified, and corrective actions were taken. The reduction of stoppage losses helped in decreasing the idle number of spindles, in the reduction of the defective bobbin, and in the increase of production. The key results of the application of Kaizen were as follows:

- The reduction of defective ring cops was 49.50%.
- The increase of output ring cops was 11.36%.
- The production was increased by 23.93%.
- OEE was increased from 75.09 to 86.20%.

Fig. 12 Pareto chart for major stoppage losses after applying Kaizen



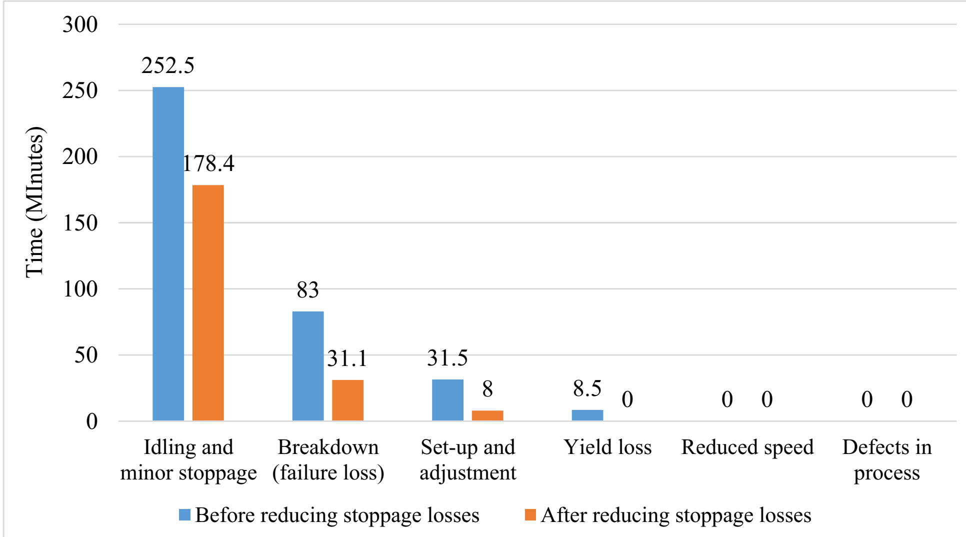


Fig. 13 Six major losses status before and after applying Kaizen

6 Conclusions and recommendations for future research

Continuous improvement is essential for sustaining and gaining a competitive advantage for manufacturing industries. As the textile spinning plant is a continuous processing unit, the OEE depends on process stability as well as equipment performance. The objective of this study was to examine the OEE of the ring frame section by identifying the related losses. Kaizen, one of the pillars of TPM, was applied to improve the OEE of the ring frame. The six major stoppage losses identified in the manufacturing plant are breakdown or equipment failure, setup and adjustment, idling and minor stoppage, reduced speed, defects in the process, and reduced yield. The study revealed that Kaizen improved the productivity and enhanced the quality of ring cops. By applying Kaizen, the OEE of the ring frame section increased from 75.09 to 86.02%. The study can further be extended in the following direction to shed more light on TPM from the viewpoint of the textile and clothing industry:

- *Section-wise Kaizen extension*: We only focused on the ring frame section of the spinning factory. Kaizen could also be implemented in the winding, speed frame, draw frame, and carding section to improve the OEE of these sections.
- *Possible implementation of rest of the TPM pillars*: Apart from implementing Kaizen, other TPM pillars such as autonomous maintenance [12]; planned maintenance [46]; and safety, health, and environment [22] could be implemented in the factory in question.

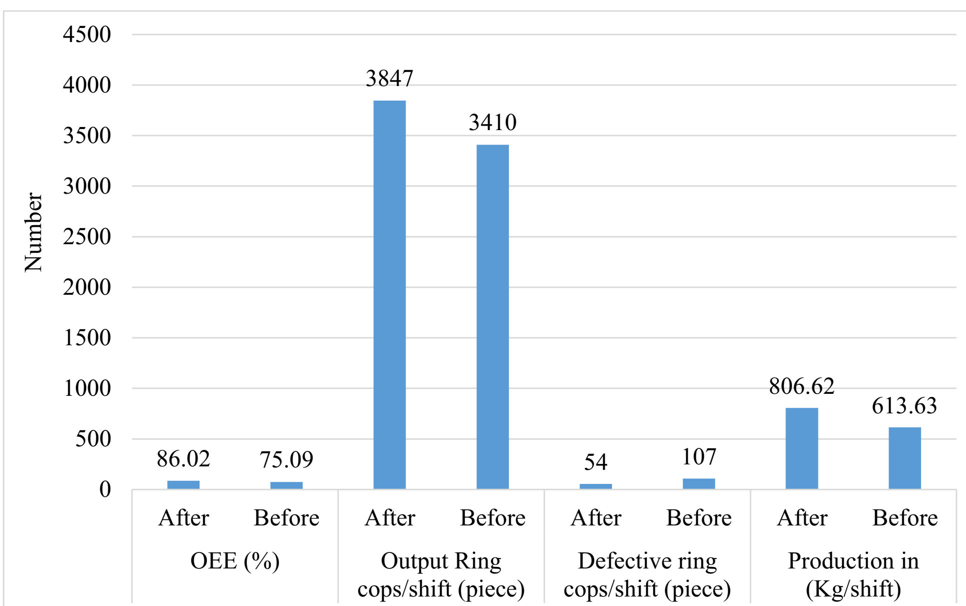


Fig. 14 Comparison of OEE, output ring cops, defective ring cops, and production rate

- *Possible implementation of green maintenance strategy*: At present, implementing green practices across all operations of an organization is gaining increased attention among academics and practitioners [67, 84]. In this connection, greening the maintenance practices [9] could benefit the enterprise to gain stakeholder's confidence and to sustain the competitive edge.
- *Realization of Risk-sensitive total productive maintenance*: An interesting extension may be to include a risk-sensitive approach to total productive maintenance as proposed by Gosavi [33].

The research undertaken in this study could be applied to a variety of textile industries. Moreover, apart from the textile context, we hope that the study would provide other categories of manufacturing industries with background foundations and ideas, as well as practical and managerial insights for applying the TPM approach to improve productivity in a real-world manufacturing setting.

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