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Improvement of Ring Frame Spindle Utilization in Cotton Short Staple Spinning: A Case Study of a Cotton Spinning Mill

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Abstract: *Spinning mills play a very significant role in backward integration of the textile value chain by converting fibres into yarn for fabric production. Ring spinning is the most widely used short staple cotton spinning system to produce yarn from cotton fibers and is used by 7 of the 8 spinning mills. Ring spinning mills have been operating at low spindle utilisation between 67 to 80% which is below the recommended standard norm of 98% resulting to yarn production loss occurring from frequent stoppages of the ring frame and increase in the number of spindles running without producing yarn. This results in low spindle utilisation of the mill which reduces the ring frame spindle hours used for yarn production. The overall objective of this study was to improve ring frame spindle utilisation in terms of spindle hours utilized for yarn production in cotton short staple spinning, by carrying out a case study in cotton spinning mill. The specific objectives were to analyse ring spinning process production parameters, evaluate the factors affecting ring frame spindle utilisation and formulate a productivity improvement method for spinning mills. The Research design adopted by this study was a descriptive and quantitative case study. Pareto analysis was used to classify ring frame production losses based on Overall Equipment Effectiveness (OEE) classification of major losses and Ishikawa diagram used to carry out Root Cause Analysis of main causes of production loss. Failure Mode and Effects Analysis (FMEA) technique was used to map the failures which occurred within the process that contributed to production loss which were ranked using their Risk Priority Numbers (RPN). A questionnaire based on Grunberg (2007) Performance Improvement Method (PIM) was used to analyse and evaluate mill production and management practices. A production improvement method was recommended using 7level evaluation criteria of the PIM technique. Pareto analysis revealed that Idling and minor stoppages accounted for 63% losses while breakdown accounted for 22.8% of losses. Root Cause Analysis (RCA) identified use of manual doffing, lack of time awareness, and delay in replacement of empty bobbins as significant factors that affected ring frame doffing stoppage loss. It was recommended that a standardized procedure based on Single Minute Exchange of a Die (SMED) technique for the doffing procedure would yield the highest results in minimizing ring frame stoppage. A key finding from the study showed that utilisation of equipment for production in manufacturing was not just the overall time the machine was running but about standardization of the entire process of production to maximize utilization of the machine for output. Through this study spinning mills can apply the recommendations to improve ring frame productivity in order to reduce the cost of production and improve their competitiveness.*

Keywords: *Ring spinning, Ring Frame Spindle Utilisation, Performance Improvement, PIM Technique, Idle spindles.*

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I. Introduction

The textile industry is an important component of manufacturing sector with greatest potential to create employment and promote economic development[1]. Developing countries are characterized by increased demand of apparels and textiles which cannot be met by local production. The gap is bridged by importation of low priced products; in addition, imported Second Hand Clothes (SHCs) in some countries further supplements the low market segment resulting to flooding of local markets[2]. Ring spinning which uses the Ring frame is the main spinning system is used by 7 in every 8 mills to produce cotton yarns for fabric production by knitting and weaving factories[3]. The process of fibre to yarn conversion at the ring frame involves drafting, twisting roving of fibres and winding the spun yarn on the bobbin and is the costliest stage in the spinning process flow contributing 60% of the total cost of yarn production[4]. Mills therefore aim at maximizing the utilisation of ring frame to reduce the overall cost of yarn production and improve competiveness of the textile products. The standard operating norm for ring frame spinning mills aims at optimal spindle utilisation (SH) of 98%[5].SH is the ratio between the average spindle hours worked per day and the total number of spindles installed and therefore measures the effectiveness of the ring frame and turns a comparison of actual production per shift against the maximum possible production. SH is related to Overall Equipment Effectiveness (OEE) which is used in manufacturing to quantify how well equipment performs relative to its designed capacity over a period of time when it is scheduled to operate[6,7,8]. Ring frame spindle utilisation is the highest impact Key Performance Indicator (KPI) influencing the efficiency of conversion cost of fiber to yarn in the ring spinning process, high spindle utilisation leads to cost reduction per unit of production of conversion costs drivers such as overheads, depreciation, interest, stores, power and wages and also increases profits due to the higher volume of production and sales turnover. Spindle utilisation (SH) is the ratio between the average spindle hours worked per day and the total number of spindles installed and therefore measures the effectiveness of the ring frame and turns a comparison of actual production per shift against the maximum possible production. Ring frame spindle utilisation is the highest impact Key Performance Indicator (KPI) influencing the conversion cost of fiber to yarn in the ring spinning process, high spindle utilisation leads to cost reduction per unit of production of conversion costs drivers such as overheads, depreciation, interest, stores, power and wages and also increases profits due to the higher volume of production and sales turnover.The process of yarn production using the ring frame are prone to cyclic stoppages due to stoppages for doffing of filled up yarn bobbins, frequent change overs and setting adjustments. Breakages in the individual spindles of the ring frame due to idle spindles and end breakages of the yarn during the production process further results to reduced spindle utilization of the ring frame affecting the production levels and raising the cost of production. Improvement of ring frame spindle utilization influences productivity and overall competiveness of the spinning mill and is necessary in the long term sustainability of the textile industry.

Several studies have been carried out in the past to investigate the factors affecting production of yarn in textile spinning and their effects on performance of various spinning mills producing yarn for various weaving and knitting industries9. Research developed alternative open end (OE) spinning systems such as Rotor and Air jet which featured higher yarn production rates of 120- 400m/min compared to the ring spinning speeds of 20-30m/min which are 4-6 times less in production[4]. OE also gave advantage of and use drawn sliver as their feed stock eliminating the preparation stages of roving formation and winding processes[9]. However, these spinning systems were only suitable for production of medium and coarse count yarns.

Studies to improve the design feature of the ring–traveller investigated use of traveller made of alloys and ceramics materials and use of surface coating to improve heat dissipation properties of traveller. The traveller ring spindle speed was limited by the friction surface between the ring and the traveller develop high pressure of up to 35N/mm2 during winding generating high temperatures of 400-500 0C which cannot be dissipated by the low mass traveller in the short time limiting the maximum possible operating speeds for the traveller to 40 m/min[10]. Higher traveller spindle speed exceeding the thermal stress limit resulted in drastic change in wear behaviour of the ring and the traveller. Limitation in the size of the bobbin which can be mount on the spindle while operating at the high spindle speed of 8,000 to 25,000 Rpm reduced the ring diameter to 42-48 mm resulting to increase the time and labour required for doffing. Modern ring frame feature also advanced engineering improvements geared towards overcoming these drawbacks, such as automation of the doffing process and integration of a link to winding. Research conducted in India by SITRA, recommend ring spinning spindle utilization standard norm of 98% and indicate that a 1% increase in production per spindle would lead to a saving of US$ 15,000 per annum for a 30,000 spindle mill[5].

From the foregoing literature review no study has been undertaken to determine and analyse the factors affecting the low spindle utilization in ring frame spinning mills and evaluation of production improvement in ring frame spinning.

II. Research Methodology

The case study was carried out in a spinning mill producing cotton yarns using 16 ring frame machines and two rotor spinning machines. The mill operated 24 hours daily on a day and night shift of 11 hours and 13 hours. The operational 15,072 ring frame spindles had an average daily production of 6800 Kgs translating to 0.451kgs per spindle compared to daily rotor production of 6.94 kg per rotor.

A systematic research methodology was designed to study ring spinning process, parameters and identify Ring Frame production losses, losses were categorized and detailed study on the causes of production loss and their impact on productivity of the ring frame undertaken. Moreover, a study of the mill production and management practices was conducted to evaluate performance improvement techniques for the mill. A preliminary study of the ring frame settings and process parameter was carried using basic 7 QC tools. A time-based Pareto analysis of ring frame stoppages was conducted and used to determine production loss based on six major productions on OEE. RCA was used to identify and classify causes responsible for production loss contributing to low spindle utilisation in ring frame spinning. FMEA was carried out to detect the possible failure modes related to the ring spinning process and prioritize them. The failure modes under each sub activity was discussed and given the Risk Priority Number (RPN). Data related to productivity improvement and the operational structure of the mill was collected through for evaluation of performance improvement. Grunberg (2007) PIM technique was applied to come up with improvement method for the mill[10].

III. Resultand Discussion

Table no 1 shows the process parameters for the 16 ring frame operated by the spinning mill.

Table no 1 Ring frame process parameters of the spinning mill

Ring Spinning process parameters	UNITS	Process parameters	
		Low	High
Maximum Spindle Speed	Rpm	16,000	20,000
Operating Spindle Speed	Rpm	10,000	13,000
No. of spindles per ring frame	No.	864	960
Yarn Count	Ne	20	38
Twist per Meter	Tpm	625	925
Break draft	No.	1.21	1.21

Ring Spinning and Doffing Cycles

The spinning cycle was timed from the start of the running of the ring frame when yarn starts building up on the bobbin to the time when ring frame automatically stops due to bobbins get filled up with yarn. The doffing cycle was timed when the ring frame automatically stops up to the time when the machine was restarted for the next spinning cycle. The Ring Frames automatically records the cycle process parameters such as spinning and doffing cycles times automatically recorded were retrieved, recorded and analysed. The spinning and doffing cycles had a mean time of 125.05 and 12.1867 minutes respectively as shown in Figure 1 and 2. The mean weight of ring frame yarn bobbin in grams from 6 different ring frames spinning 20s was of 56.71525 grams representing a loss of 7.5847 grams per bobbin as shown in Figure 3.

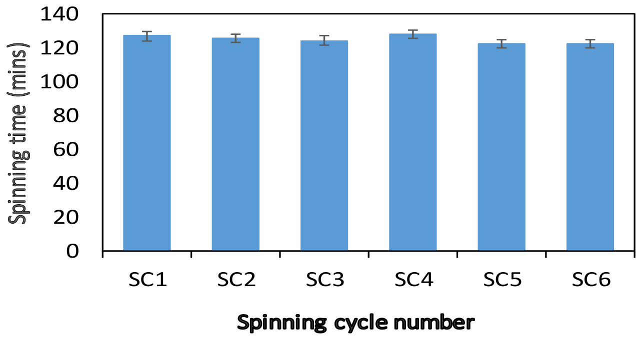

Fig. 1 Ring Frame spinning cycle time

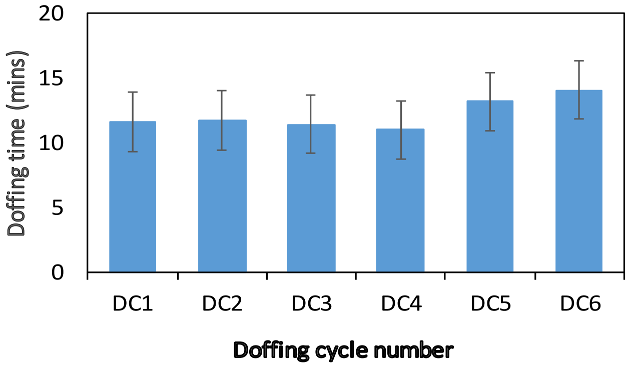

Fig. 2 Ring Frame Doffing Cycle time

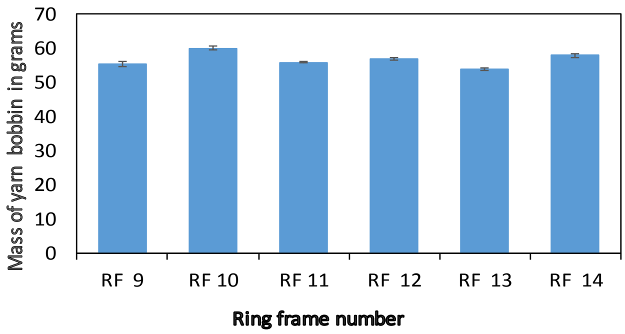

Figure no 3shows average weight of ring frame yarn bobbin in grams from 6 different ring frames spinning 20[s]

Ring Frame Stoppage and Idle Spindle Losses

A Pareto analysis was used to identify significant causes of production loss in ring spinning at the frame and individual spindles. OEE was used to classify frame stoppage and idle spindles into five major classes of production loss as shown in Table 2 and analysed in Figure 4. Idling and minor stoppages losses accounted for 63.2 % and break down loses 22.8 %. The results were in line with the Pareto principle, which states that 20% of the causes are responsible for 80% of the production loss. Distribution of the main causes of Ring Frame Stoppages is shown in figure 5. Investigation of spindle production loss due to idle spindles had end breakage rate of 863.68 spindle minutes of ring frame stoppage in two shifts as shown in Figure 6.

Table no 2 shows analysis of major production losses in ring spinning

Classification of Loss	Category	Frequency	Percentage	Cumulative Percentage
Idling and minor stoppages	A	97	63.2	63.2
Breakdown	B	35	22.8	86
Set-up and adjustments	E	20	0.6	86.6
Yield loss	C	0.93	0.4	87
Reduce speed	D	0.57	13	100

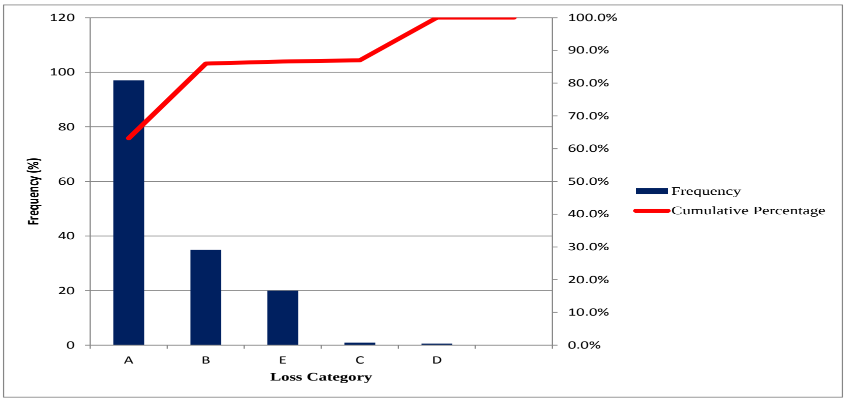

Figure no 4 showsPareto Analysis of major losses in ring spinning

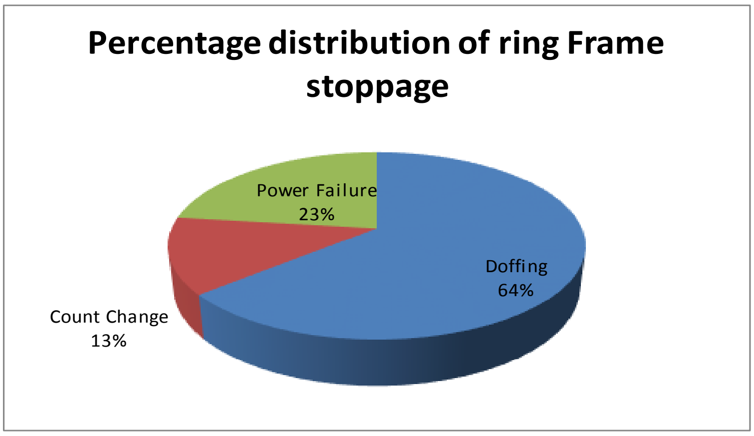

Figure no 5 shows distribution of main causes Ring Frame Stoppages

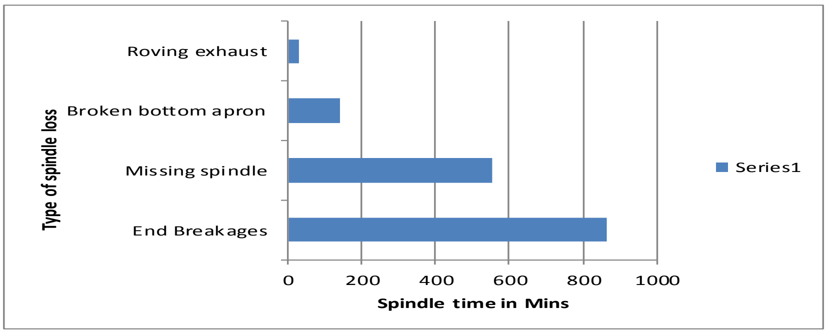

Figure no 6 shows analysis of loss in ring frame spindle hours due to idle spindles in spindle-mins

Cause and Failure Modes in Ring Spinning Production

Root Cause Analysis (RCA) was undertaken to find out factors of the ring frame doffing process that contributed to low spindle utilization in ring spinning. Discussions with the mill management and engineers identified the most significant causes of production loss in the doffing process shown in figure 17 a: (i). The manual doffing procedure of the ring frame which was found to be significantly slow. (ii) Lack of time awareness - the Ring frames automatically stopped when bobbin get filled up with yarn and operators took time to start the process of doffing mainly due to lack of time awareness among the doffers (iii) Poor process of removal of empty bobbins and simultaneously replacing them with empty coded bobbins (iv) Delay in completion of the Preparation of empty codded bobbins for the ring frame delayed the process of starting replacement of the filled up bobbins as the bobbins were not ready due to delay in completion of preparation of bobbins (v)Shortage of bobbins or mix up of bobbins for counts, lots and codes, and (vii) delay Inspection of the ring frame after replacement of empty bobbins and close monitoring of the stoppages of the ring frames were also major contributors of doffing loss. The most significant factors identified to the ring frame doffing were used as the inputs to the Ring Frame Doffing FMEA to find out the possible failure modes and rank them in order of priority. Figure 4.8 shows potential failure causes and effects with highest RPN.

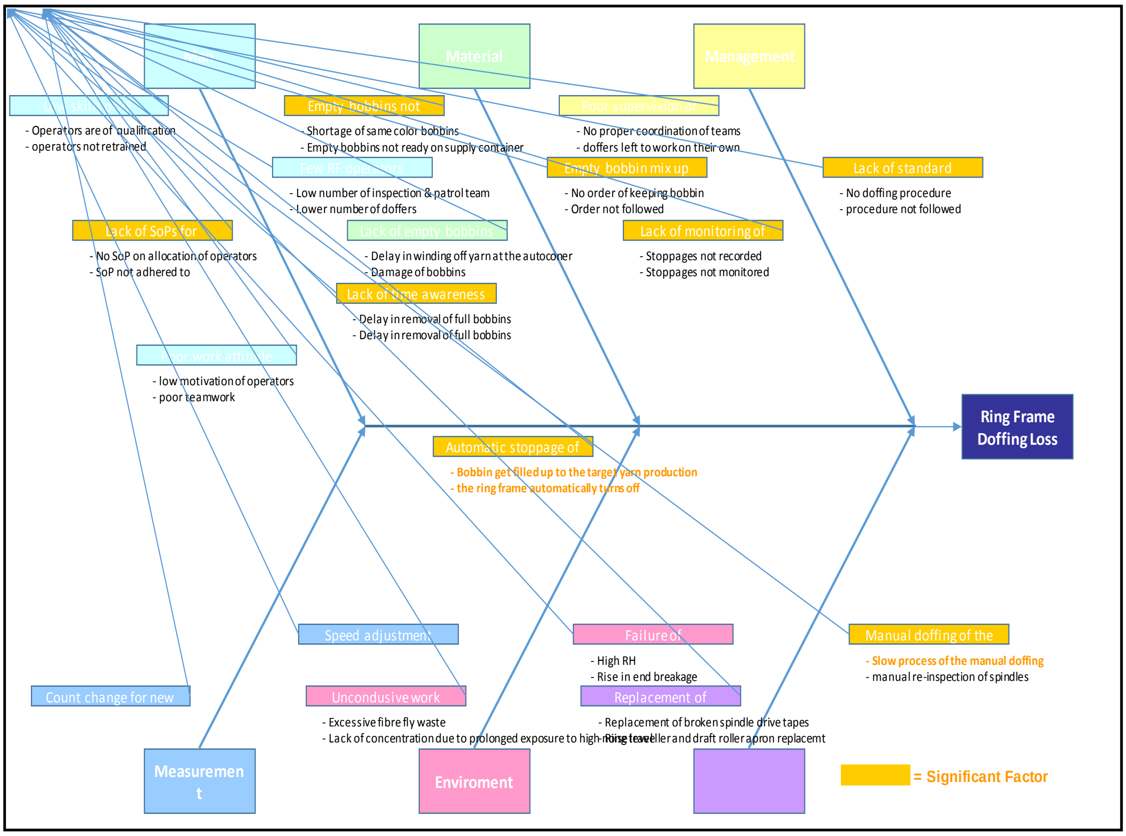

Figure no 7 shows RCA of ring frame doffing process time loss

Table no 3shows potential failure causes and effects with highest RPN from Ring Frame Process FMEA

Potential failure cause	Potential failure effect	O	S	D	RPN
Lack of enough bobbins for the ring frame	Delay in replacement of full bobbins	8	7	7	392
Breakage of yarn during bobbin change	Increased start end breakage	8	7	6	336
Lack of empty bobbins to start doffing	Time loss due to delay in moving and arranging empty bobbin tray	8	8	5	320
Mix up of speed frame lots and counts during filling activities and piecing in the event	Rejection due to yarn/fabric defect in weaving and dyeing	8	8	5	320
Gaiting done with yarn which is not running	Mix-up of different lots and counts of yarn	6	6	7	252
Deformation of cops	Damaged yarn cops, increase in rejected yarn cops	5	7	7	245
Mix in bobbin size, color and code	Mix up in yarn counts and lots	6	7	3	126

Performance Improvement using Grunberg PIM Technique

Grunberg (2007) developed the PIM Method to Support Performance Improvement in industrial operations, an improvement of Ljungsrom evaluation criteria which was used to evaluate improvement measures for the potential failure causes and rate the most sustainable productivity improvement for application for the mill. The PIM method was designed for the manufacturing sector to assist in formulation and selection of the most suitable improvement technique that supports implementation of improvement where the methods are applicable. The PIM compared 16 methods of Performance Improvement among them Five S, Single Minute Exchanged of a Die (SMED) and Continuous Improvement (CI). PIM also proved to address more criteria than other methods and had an advantage of involvement of the problem owner in selection and supporting the implementation of performance improvement. It also addresses the important criteria of specialist independency.

Mill performance measures were graded on 6 level criteria based on specialist independence, competence supportive, implementation supportive, measurement based, objective supportive and organizational supportive. The supporting scale had 5 levels namely 1, 2, 3, 4 and 5. The total score which indicated the overall support for the improvement measures was used to come up with the strongest improvement measure. Competence, implementation and organizational supportiveness had the highest importance rating score for the spinning mill as shown in Figure 24. Specialist independence had the least score which indicated that a performance improvement for the mill should be usable by non-specialist, must be easy to understand, easy to use and supportive regarding communication of goals and results. According to Grunberg PIM criteria (2007) the methods which partially fulfil this are Process mapping, SMED, Five S, CI and decision support. The second least score was in measurement supportiveness which indicated that it was not easy to measure, tuck and monitor performance which would form a basis for further improvement. To increase support for measurements, the PIM premade forms and instructions were used to promote further understanding when promoting the system. The average scores for overall PIM performance evaluation are shown in Table 4.

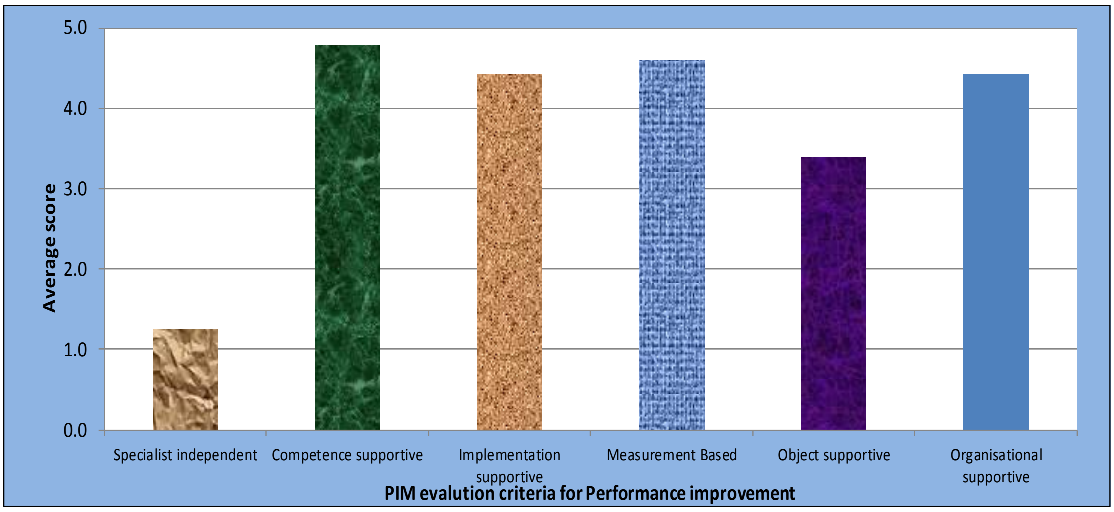

Fig. 8 Overall PIM Performance Evaluation of the mill based on PIM

Table no 4 showsoverall PIM Performance Improvement Evaluation

Overall PIM Performance Improvement Evaluation	**Average Score**
Specialist independent	1.3
Competence supportive	4.8
Implementation supportive	4.4
Measurement Based	4.6
Object supportive	3.4
Organizational supportive	4.4
Overall mean	**3.8**

The PIM's Method to Scoring Criteria to support performance improvement in industries was used to evaluate the applicable performance improvement methods and techniques for the mill. The scoring criteria allocated applicable numeric values to the method on the basis of; 1= weak or low support, 2= partly supportive, strong support and Not applicable (N/A) and as shown in Appendix III: The results of the evaluation shown in Table 5 recommended five performance improvement techniques/ method for the mill. Decision Support was not competence supportive to the unique object supportiveness of the ring spinning process and was not supported by organizational set-up of the mill. Process Mapping was not applicable to implementation supportiveness, it is important that a proposed performance improvement technique has support amongst the management and employees of the mill as much of the improvement work would be performed by employees of the mill. SMED had the strongest support with an overall score of 13, the score was highest in implementation and object supportiveness and had a score of 2 for specialist independent, measurement base and organizational supportiveness. SMED and Fives S and Continuous improvement (CI) ranked highest with scores of 13, 10 and 12 respectively as shown in Table 6 and were most suitable improvement methods applicable for production improvement for the mill.

Table no 5 shows evaluation of Performance Improvement methods based on PIM

	Process mapping	**SMED**	**Five S**	**CI**	**Decision Support**
Specialist Independent	2	2	2	2	2
Competency supportive	1	1	1	1	1
Implementation supportive	N/A	3	3	1	N/A
Measurement based	2	2	1	2	2
Object supportive	1	3	1	1	N/A
organizational supportive	2	2	2	2	N/A

Table no 6 showsthe score of performance improvement methods for the mill

Method	***Process Mapping***	***SMED***	***Five S***	***CI***	***Decision Support***
PIM Score	8	13	10	9	5

IV. Conclusions and Recommendations

Significant improvement of Ring Frame spindle utilisation would be achieved by minimizing machine stoppage and improving utilization of the spindles during the running cycle of the machine. Minimizing of ring frame stoppage time for doffing would yield the highest result. SMED was recommended as a performance improvement technique for the mill to improve the process of frequent change-over and set-up adjustments which occurred in ring spinning process. SMED was an easy to use tool for large improvement attempts and was supported by the mill practices and procedures for improvement of spindle utilisation of the ring frame.

A doffing based set-up and change-over SMED procedure would yield the highest performance improvement ring frames spindle utilisation at the mill. Important aspect of SMED involved separating external activities; ring frame doffing process was modified to include 3 separation activities involving the pre-set up external, internal and post external activities. The ring frame doffing pre-set up external activities whereto completed before the stoppage of the machine without any loss in the ring frame operating time and included identification, preparation, coding and packaging of bobbins in trolleys. The trolleys were to be kept near the ring frame ready for doffing. The external process was to be enhanced to include identification idle and defective spindle numbers and the cause. Secondly improvement in the internal resetting process of ring frame which could only be done when the machine had stopped were achieved by recommendation of use of doffing trolleys with separation for empty bobbins and ejected filled up bobbins. Two doffers to be assigned to doff the frame from left to right at the same time. Doffers were to detach full cops from the spindle while simultaneously replacing it with empty bobbin cop from the tray. The maintenance team was to be incorporated in the internal set-up team to carry out spindle repairs such as drafting system replacement, spindle drive tape replacement to minimize running idle spindles and production of defective bobbin in the next spinning cycle. Post external activities where to be undertaken when the machine had been restarted. Internal activities of replacement of exhaust roving, handling transportation and storage of full bobbins were converted into external activities. Improvement in spindle utilisation would be achieved by doffing internal set-uptime into external set-up time.

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